

CHAPTER 6

6.1 INTRODUCTION TO BIOMECHANICAL ASPECTS

“How do you steal the ball away from opponents who are dead set on making sure you don’t? One is speed with which you do it...The other... is the art... of changing the angle of attack on the player’s grip of the ball...The same methods apply when you have the ball. Some guys are far superior to me in strength, so I try to keep changing the balls position or angle so they can’t get a good grip on it... It’s all about getting the right angle of purchase. You need to know a bit about how levers and fulcrums work, a bit about torque.”

(Kronfeld & Turner, 1999)

When William Webb Ellis first picked up the ball and ran with it in 1823, he probably didn’t think too much about the physics behind the movements he was making at the time. However, all the movements involved in rugby rely heavily on the laws of physics, and by understanding them you can learn how to perform them more effectively (McKenzie *et al.*, 2000).

Almost every aspect that takes place in rugby from how fast a wing runs down a field to score a try to how far a flyhalf can kick a ball downfield is bound by the laws of physics. In this study the author will look in detail at the isolated aspect of ball carrying collisions and identify this bond in order to maximise a team’s ability to dominate the aspect of collisions in a rugby context.

6.2 KINEMATICS

Kinematics is the science of describing the motion of objects using words, diagrams, numbers, graphs, and equations (Kreighbaum & Barthels, 1996). The goal of any study of kinematics is to develop sophisticated mental models which serve to describe (and ultimately, explain) the motion of real-world objects (Adrian & Cooper, 1995; Hamill & Knutzen, 1995; Kreighbaum & Barthels, 1996; Bartlett, 1999).

6.3 SCALARS AND VECTORS

Physics is a mathematical science – that is, the underlying concepts and principles have a mathematical basis. The motion of objects can be described by words – words such as distance, displacement, speed, velocity, and acceleration (Beer & Johnston, 1990; Young, 1992; Van Staden *et al.*, 1992; Adrian & Cooper, 1995; Hamill & Knutzen, 1995; Kreighbaum & Barthels, 1996; Elliot, 1999).

These mathematical quantities which are used to describe the motion of objects can be divided into two categories. The quantity is either a vector or a scalar. These two categories can be distinguished from one another by their distinct definitions:

1. Scalars are quantities which are fully described by a magnitude alone.
2. Vectors are quantities which are fully described by both a magnitude and a direction (Beer & Johnston, 1990; Young, 1992; Van Staden *et al.*, 1992; Hamill & Knutzen, 1995; Kreighbaum & Barthels, 1996).

Anytime a player is moving up the field, whether carrying the ball or not, factors such as the magnitude and direction of the moving player come into play. For this reason the measurement of player's actions is possible by means of applying scientific laws of movement.

6.4 DISTANCE AND DISPLACEMENT

Distance and displacement are two quantities which may seem to mean the same thing, yet they have distinctly different meanings and definitions.

1. Distance is a scalar quantity which refers to “how much ground an object has covered” during its motion.
2. Displacement is a vector quantity which refers to “how far out of place an object is”; it is the object's change in position (Hamill & Knutzen, 1995; Kreighbaum & Barthels, 1996).

For example, if a player in possession of a rugby ball runs 5m from position A to position B, the distance the player has moved would be 5m. During the course of the player’s motion, the player “covered a distance of 5m of ground”.

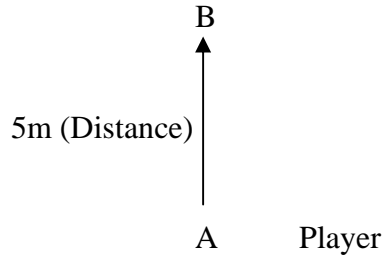


Figure 6.1: Diagram indicating the distance covered by a player moving from A to B

However, if the ball carrying player ran 5m forwards from position A to position B and was then tackled backwards by an oncoming defender and landed on the ground in the same position he started (position A). The player would thus not be “out of place” – i.e., there would be no displacement of his motion (displacement = 0m).

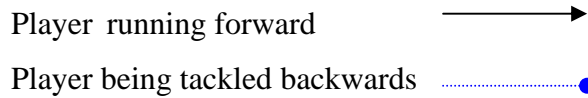
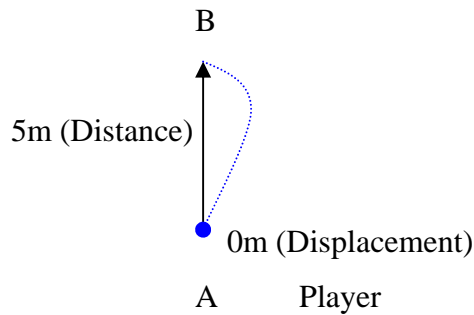


Figure 6.2: Diagram indicating a player moving forwards from position A towards position B, then being tackled backwards to the initial starting position

Thus displacement, being a vector, must give attention to direction. The 5m forward is cancelled by the 5m backwards after the tackle resulting in the 0m displacement.

6.5 NEWTON'S LAWS OF UNIFORM MOTION IN A RUGBY CONTEXT

Most everyday movements, including those in rugby, are based on three basic laws that are known as Newton's Laws of Uniform Motion (McKenzie *et al.*, 2000).

6.5.1 NEWTON'S FIRST LAW

“Any object that is either moving or stationary will tend to stay that way unless a force acts upon it.” (Beer & Johnston, 1990; Young, 1992; Van Staden *et al.*, 1992; Adrian & Cooper, 1995; Hamill & Knutzen, 1995; Kreighbaum & Barthels, 1996; McAleer, 1998; Brister, 2000; McKenzie *et al.*, 2000; Quarrie & Wilson, 2000; Tripi, 2001; Unknown author, 2003; Gay, 2004).

This law says simply that mass wants to continue doing what it is doing, whether it's at rest or in motion. While this law seems pretty straightforward, the First Law is actually counterintuitive. When considered, it becomes obvious our everyday experiences suggest that objects want to come to a stop. If one is driving along on a level street and the foot is taken off the accelerator and put the car in neutral, the driver will slowly coast to a halt. This everyday physics experiment seems to tell us that the natural state of matter is to be at rest. However, this naïve analysis fails to factor in the braking effects of frictional forces. The slowing and stopping of the moving objects can be attributed to a natural tendency on their part, but in fact the friction generated by the car's tyres making contact with the road causes this action. Newton however saw through the apparent reality to the underlying truth: Unless acted on by an external force, the natural state of matter is to continue on its initial, straight-line path indefinitely. The First Law also says that the more massive an object is, the more it wants to continue doing what its doing and the less likely it is to be deflected, slowed down, or sped up by an outside force. This law can also be applied to rugby by looking at a kick or pass (East, 1994). In the absence of air resistance and gravity, once the ball has left the players foot or hands it would tend to move in the same direction forever. But with air resistance and gravity, both of which are forces acting on the ball the ball will come to rest after a few seconds (Beer &

Johnston, 1990; Young, 1992; Van Staden *et al.*, 1992; Hamill & Knutzen, 1995; Kreighbaum & Barthels, 1996; McAleer, 1998; Brister, 2000; McKenzie *et al.*, 2000; Tripi, 2001; Unknown author, 2003; Gay, 2004).

6.5.2 NEWTON'S SECOND LAW

“The force applied to an object is equal to the acceleration of the objects involved multiplied by their mass.” (Beer & Johnston, 1990; Young, 1992; Van Staden *et al.*, 1992; Adrian & Cooper, 1995; Hamill & Knutzen, 1995; Kreighbaum & Barthels, 1996; McAleer, 1998; Brister, 2000; McKenzie *et al.*, 2000; Quarrie & Wilson, 2000; Tripi, 2001; Unknown author, 2003; Gay, 2004).

This law can be explained in the following equation: $F = ma$, where F is force, m is mass and a is acceleration. One can also use this formula to appreciate just how much force is expended when one player hits another, and how much force exerted over a given time would have been needed to stop a huge bollocking forward hurtling toward a defender. The mass (m) of an object is basically the amount of matter – the number of atoms it has in it. Mass and weight are connected, but they are not the same thing. While mass is a measure of how much matter an object has, weight is a measure of how strongly this mass is attracted by gravity. This equation can be applied to a player starting off running from stationary and accelerating up to speed of 4 metres per second in about 1 second. For the purpose of this example the player weighs 100 kg. Based on this information it becomes evident that the acceleration (or change in velocity) is 4 metres per second, and the mass is 100 kg. If these values are placed into the equation it becomes possible to establish the force the player needs to generate with his or her legs in order to attain that kind of acceleration. In this case the player needs to apply +/- 40 kg of force in the direction he or she wants to run in order to attain the required acceleration (Beer & Johnston, 1990; Young, 1992; Van Staden *et al.*, 1992; Adrian & Cooper, 1995; Hamill & Knutzen, 1995; Kreighbaum & Barthels, 1996; McAleer, 1998; Brister, 2000; McKenzie *et al.*, 2000; Quarrie & Wilson, 2000; Tripi, 2001; Unknown author, 2003; Gay, 2004).

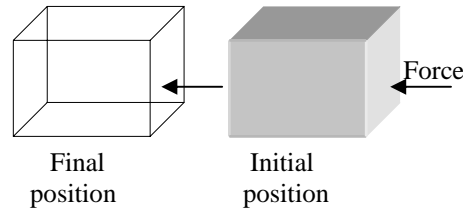
6.5.2.1 Acceleration, Speed, and Position: Kinematics

After mass (m), the next variable in the equation $F = ma$ is acceleration (a). Acceleration should not be confused with speed. Speed indicates how rapidly an object is changing its position, while acceleration indicates how rapidly this speed is changing in time. In rugby, speed is used to measure the time a player needs to travel a certain distance: i.e., the player can run 40 yards in 4.7 seconds from a standing start. The player's average speed is thus 40 yards divided by 4.7 seconds, or 8.5 yards per second. (This is equivalent to 25.5 feet per second.) The reason that one talks about a player's "average" speed" is because over the course of a run he is likely to speed up or slow down. The next term related to speed is velocity. Velocity is a speed specified in connection with a direction. The units of both speed and velocity are meters per second or yards per second, abbreviated "m/s or yards/s". The units of acceleration are meters per second per second or yards per second per second (Gay, 2004).

6.5.2.2 Figuring out the force of a "Big Hit"

What is force? Simply put, according to Newton's Second Law, force is the thing that speeds mass up or slows it down – in other words, gives it an acceleration or deceleration. This is strictly true only for one-dimensional motion, see Figure 6.3. In two-dimensional motion, it is possible for forces to change an object's direction but not its speed. For example, when a ball carrier is given a sharp, impulsive blow from the side by a defensive tackle, the hit doesn't necessarily slow him down, but it will deflect his path. For example, the force that a ball carrier "hits" a defender is proportional to the ball carrier's mass times his acceleration: $F = (1/32)ma$. If two players face each other with similar weight 245 pounds (lbm). The ball carrier hits a gap opened up by the attacking backline and he is running hard, so the ball carrier's initial speed is about 10 yards per second, or 30 feet per second. The defender enters the collision area, and "hits" the ball carrier and the play comes to a screeching halt. The ball carrier's final speed, immediately after the hit is thus zero. The duration of the hit, from the first contact of bodies to the point when the ball carrier's forward motion stops, is about two-tenths of a second. Dividing the speed change by the time interval over which it occurred gives the acceleration of the ball carrier – or, rather, the deceleration, as his forward motion is stopped cold: $a = (0 \text{ ft/s} - 30 \text{ ft/s})/0.2 = -$

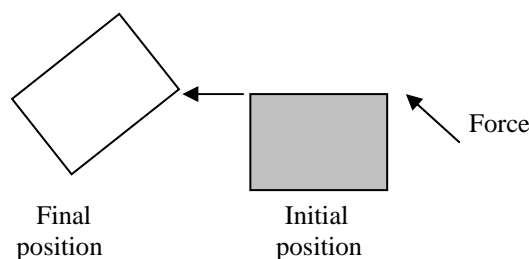
150 feet per second squared. (The minus sign indicates that a is actually a deceleration.) Following, the next step is to multiply by the ball carrier’s mass (lbm) to find the force acting on him: $(1/32) \times (-150 \text{ ft/s}^2) \times (245 \text{ lbm}) = -1,150$ pounds of force in a backward (negative) direction (Gay, 2004).



(Adapted from McKenzie *et al.*, 2000)

Figure 6.3: The effect of a force

Torque is similar to force with the exception that it tries to cause motion about an axis of rotation instead of motion in a straight line as in force, see Figure 6.4. One can think of rotation as the axle of a wheel, and a hand that spins the wheel around the axle as generating torque. While a force acts through the centre of mass of an object, a torque is created any time the line of action of a force doesn’t pass through the centre of mass of an object (straight on collision where the ball carrier uses footwork/hit & spin, in order to “slide out” of the collision) (Beer & Johnston, 1990; Young, 1992; Van Staden *et al.*, 1992; Adrian & Cooper, 1995; Hamill & Knutzen, 1995; Kreighbaum & Barthels, 1996; McAleer, 1998; Brister, 2000; McKenzie *et al.*, 2000; Tripi, 2001; McClymont & Cron, 2002; Unknown author, 2003).



(Adapted from McKenzie *et al.*, 2000)

Figure 6.4: The effect of a torque

6.5.2.3 A Force to be reckoned with

In order to create a perspective, it's important to consider how big a deceleration of -150 feet per second squared is by comparing it with the acceleration that an object of the same mass would experience falling out of a fifth-story window. In this case, the object is acted on by the force of gravity alone and accelerates under its influence. The interesting thing about the force of gravity is that it is proportional to an object's mass: $F_{\text{gravity}} = (1/32) mg$. This is a direct result of Newton's Universal Law of Gravitation, developed to describe the motion of planets. If a 245-pound object were to fall out of a fifth-floor window, it would accelerate downward with a value of $a = g = 32$ feet per second squared. This is true for any object with any mass – *all* falling bodies experience the same acceleration under the pull of a gravitational field (Gay, 2004).

In the collision between the ball carrier and the defender, the unfortunate ball carrier experience a force causing his body to have more than *five times* this acceleration – a force greater than 5 g's. Still, such collisions don't leave the defender unscathed. In the quick burst forward the ball carrier has built up quite a head of steam and exerts some force of his own onto the defender. The defenders speed, also about 10 yards per second, is reduced to zero at the point of contact. Here, though, the defender's initial speed will be assigned a minus sign because he is moving in a direction opposite that of the ball carrier of his initial velocity, his acceleration actually turns out to be a positive: $a = (0\text{ft/s} - [-30\text{ft/s}])/0.2\text{s} = 150$ feet per second squared. The defender has a mass of about 245 pounds (lbm), so the Second Law states that the force on him is 1,150 pounds (Lbf). It becomes evident that the collision in question is relatively symmetric, meaning that the ball carrier and defender have roughly the same initial magnitude of speed, albeit in different directions. They also have the same final speed: zero. The opposite signs on the forces correspond to the differences in their respective accelerations – minus 1,150 pounds of force for the ball carrier, plus 1,150 pounds for the defender – and so the magnitude of the force each one feels from the collision is the same (Gay, 2004).

6.5.3 NEWTON'S THIRD LAW

“For every action there is an equal and opposite reaction” (Beer & Johnston, 1990; Young, 1992; Van Staden *et al.*, 1992; Adrian & Cooper, 1995; Hamill & Knutzen, 1995; Kreighbaum & Barthels, 1996; McAleer, 1998; Brister, 2000; McKenzie *et al.*, 2000; Quarrie & Wilson, 2000; Tripi, 2001; Unknown author, 2003; Gay, 2004).

Newton's Third Law says that whenever two objects collide, no matter what their individual masses, no matter how fast they're going, they always exert the same amount of force on each other, but in opposite directions. Mathematically, this can be written as $F_{12} = -F_{21}$, where F_{12} is read as “the force that the body 1 exerts on body 2.” The minus sign means, again, that the forces have opposite directions (Beer & Johnston, 1990; Young, 1992; Van Staden *et al.*, 1992; McNitt Gray *et al.*, 1993; Adrian & Cooper, 1995; Hamill & Knutzen, 1995; Zatsiorski, 1995; Kreighbaum & Barthels, 1996; McAleer, 1998; Brister, 2000; Kent, 2000; McKenzie *et al.*, 2000; Tripi, 2001; Unknown author, 2003; Gay, 2004).

6.5.3.1 Momentum and Impulse

The word momentum is often used, and usually imprecisely. In physics, momentum is defined to be the mass times the velocity (or speed): $p = mv$. (Momentum is designated with the letter p to conform to tradition and to avoid confusing it with mass.) Momentum is what Newton called “the quantity of motion”. In any collision on the rugby field, momentum is always conserved – a principle that is extremely useful in analysing collisions. In addition to momentum, one also needs to consider impulse, which is really just the change in an object's momentum. If one object strikes another, it is said to have delivered an impulse to that body that is equal to the change in the second body's momentum as a result of the collision. The impulse is equal to the product of the time over which the collision occurs multiplied by the average force exerted on the body. Therefore, since both objects (players) exert the same force on each other but in opposite directions ($F_{12} = -F_{21}$) during the collision, and they do so over the same interval, they must deliver equal but oppositely directed impulses to each other. This means that one player gains exactly the same momentum

that the other loses, so the net change in the momentum of the two players is zero (Beer & Johnston, 1990; Young, 1992; Van Staden *et al.*, 1992; McNitt Gray *et al.*, 1993; Adrian & Cooper, 1995; Hamill & Knutzen, 1995; Zatsiorski, 1995; Kreighbaum & Barthels, 1996; McAleer, 1998; Brister, 2000; McKenzie *et al.*, 2000; Tripi, 2001; McCllymont & Cron, 2002; Unknown author, 2003; Gay, 2004).

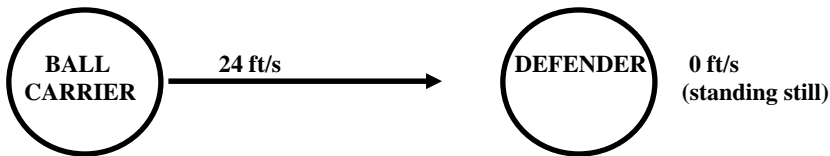
This is referred to as the principle of Conservation of Momentum, and it is one of the most important rules in physics. Alternately it says that when any two objects interact with each other (and forces due to other external objects, such as a third player or friction from the ground, are negligible), the sum of their momenta will not change over the course of the interaction. In determining the change in momentum of an object, one must be careful to remember the directions of the motion involved. This is done by plus and minus signs (Beer & Johnston, 1990; Young, 1992; Van Staden *et al.*, 1992; McNitt Gray *et al.*, 1993; Adrian & Cooper, 1995; Hamill & Knutzen, 1995; Zatsiorski, 1995; Kreighbaum & Barthels, 1996; McAleer, 1998; Brister, 2000; Kent, 2000; McKenzie *et al.*, 2000; Tripi, 2001; Unknown author, 2003; Gay, 2004).

A practical example could look as follows, see Figure 6.5. If a ball carrier and defender were to meet in a collision, and the ball carrier runs directly towards a defender with a speed of 24 feet per second. The defender prepares for the tackle in a stationary position. The defender's velocity is zero and he has a mass of 180 pounds (lbs). The ball carrier, weighing in at 310 lbs, is storming towards the defender. The ball carrier hurtles into the defender so hard that the defender falls to the ground after contact has been made, rolling on the ground at perhaps 3 feet per second. The ball carrier is knocked in the same direction as the defender was moving before the collision. How quickly is he moving?

The initial momentum of the two players is due entirely to the ball carrier and equals his mass times his velocity: 7,440 lbm*ft/s (in math nomenclature, an asterisk means "times"). It is important to note that momentum is never lost, it's conserved, so the momentum of the ball carrier and that of the defender combined after the collision must also be 7,440 lbm*ft/s. Knowing the ball carrier's final velocity, the defenders final speed can be calculated: 31 feet per second. The defender really does go flying! (Beer & Johnston, 1990; Young, 1992; Van Staden *et al.*, 1992; McNitt Gray *et al.*,

1993; Adrian & Cooper, 1995; Hamill & Knutzen, 1995; Zatsiorski, 1995; Kreighbaum & Barthels, 1996; McAleer, 1998; Brister, 2000; McKenzie *et al.*, 2000; Tripi, 2001; McCllymont & Cron, 2002; Unknown author, 2003; Gay, 2004).

BEFORE COLLISION



AFTER COLLISION



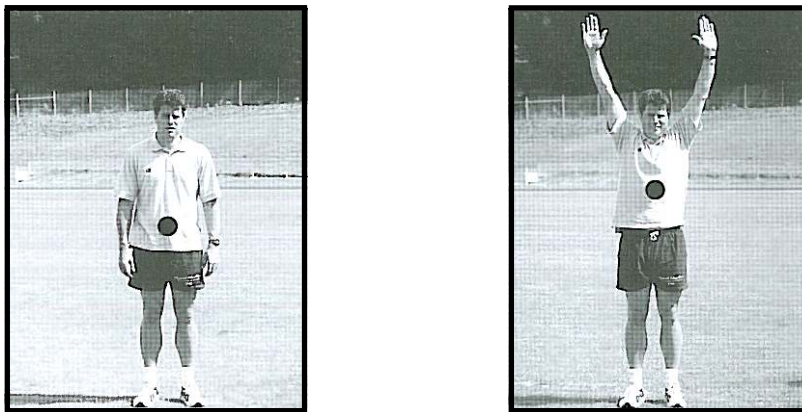
(Adapted from Gay, 2004)

Figure 6.5: The velocities of both players are indicated for before and after the collision. Momentum is conserved in the collision.

6.6 BASIC TERMS ASSOCIATED WITH BIOMECHANICAL ANALYSIS OF RUGBY SITUATIONS

Before actual specific rugby movements are analysed further, some additional basic terms need to be defined. In conjunction with mass there is also the term **centre of mass**. Centre of mass is also known as centre of gravity, and is a single point that can be used to represent an entire object (See Figure 6.6). This is very handy when one is dealing with an unusually shaped object like the human body. When a person is standing upright their centre of mass lies just around the area of the navel.

Because the centre of mass represents all different parts of the body at once it moves according to the movement of various parts of the body. For example, if a person who is standing up straight with their hands at their sides (centre of mass around the navel) lifts both arms over their head, the centre of mass will rise slightly because part of the body's mass (the arms) has risen, see Figure 6.5 (Beer & Johnston, 1990; Young, 1992; Van Staden *et al.*, 1992; Adrian & Cooper, 1995; Hamill & Knutzen, 1995; Kreighbaum & Barthels, 1996; McAleer, 1998; Brister, 2000; McKenzie *et al.*, 2000; Tripi, 2001; Unknown author, 2003).



(Adapted from McKenzie et al., 2000)

Figure 6.6: Indication of centre of mass in various positions

Another characteristic that is vital to all movements, whether a player is running, kicking, passing tackling or scrumming, is **stability**. If a player is not in a stable position while executing a skill, the success of that skill is usually compromised. Some of the characteristics of a stable position are described in the following principles.

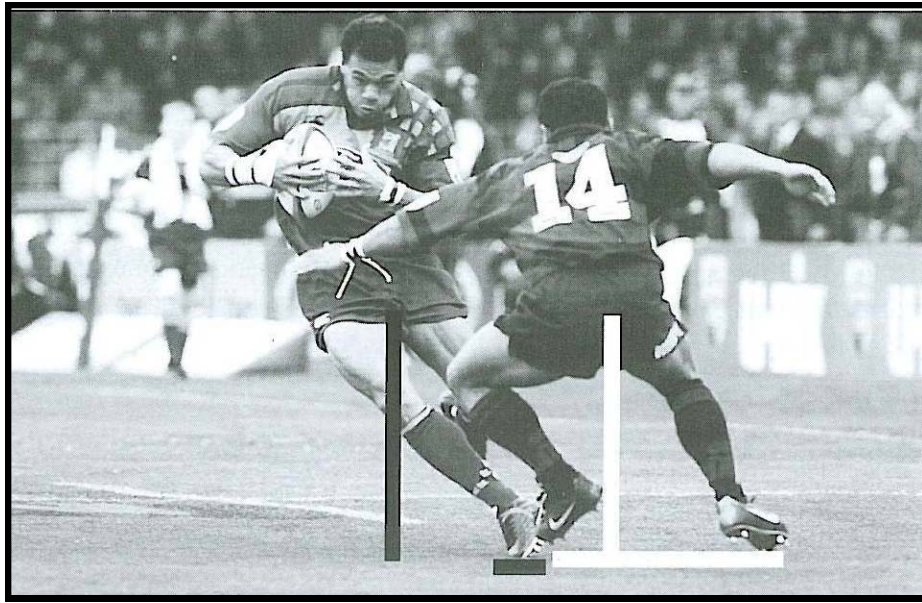
6.6.1 PRINCIPLE 1 - STABILITY

“In order to maintain stability, establish a wide base of support when possible, maintain the centre of mass over the base of support, lower the centre of mass towards the base of support, and shift the centre of mass towards any expected force which may cause instability.”

(Bauman, 1991; Grabiner *et al.*, 1993; MacKinnon & Winter, 1993; McKenzie *et al.*, 2000)

The most important of these factors is to keep the centre of mass over the base of support (Kronfeld & Turner, 1999). If one looks at Figure 6.7 below one can see that if a vertical line is drawn from the defenders centre of mass to the ground, the line falls within his base of support, indicated by the horizontal line. For the moment assume that the ball carrier is not moving but is in a stationary position. If one looks at the ball carrier and do the same thing as with the tackler, you see that the vertical line is well away from his base of support, shown by the short horizontal line.

This means that the defender is very stable in his position while the ball carrier, if he were not running, would fall over, making him ineffective at dominating a collision if he were to meet the force from the defender. Therefore, one can see that aligning the centre of mass over the base of support will keep a player on his or her feet and better be able to perform the skill of dominating a collision as indicated in Figure 6.6 (Bauman, 1991; Grabiner *et al.*, 1993; MacKinnon & Winter, 1993; McKenzie *et al.*, 2000).



(Adapted from McKenzie *et al.*, 2000)

Figure 6.7: Stable and unstable positions when the ball carrier and defender meet

6.6.2 PRINCIPLE 2 – GROUND REACTION FORCES

“The amount of momentum a player generates depends on the size of the force applied and the amount of time for which that force is applied.”

(Bauman, 1991; Elliot, 1999;
McKenzie *et al.*, 2000)

In terms of running, the force referred to is the **ground reaction force** described above with regard to Newton’s third law. This ground reaction force is responsible for generating almost all human motion and will be discussed throughout this chapter.

6.6.3 PRINCIPLE 3 – DIRECTION OF THE GROUND REACTION FORCES

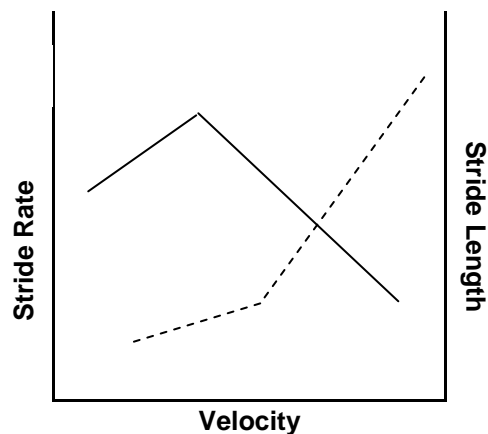
“Forces (i.e. ground reaction forces) must be applied in the direction of the desired change of motion (forward, sideways, up, down etc.”

(Bauman, 1991; Elliot, 1999;
McKenzie *et al.*, 2000)

In order to maximise straight-line running speed and give a player maximum amount of momentum, the player needs to generate large ground reaction forces for a relatively long time.

This is achieved by determining the optimal combination of stride rate (how fast the player’s legs are turning over) and stride length (how far the player travels for every complete stride). This relationship looks something like that indicated in figure 6.8 (McKenzie *et al.*, 2000).

Relationship of stride rate, stride length and running velocity.



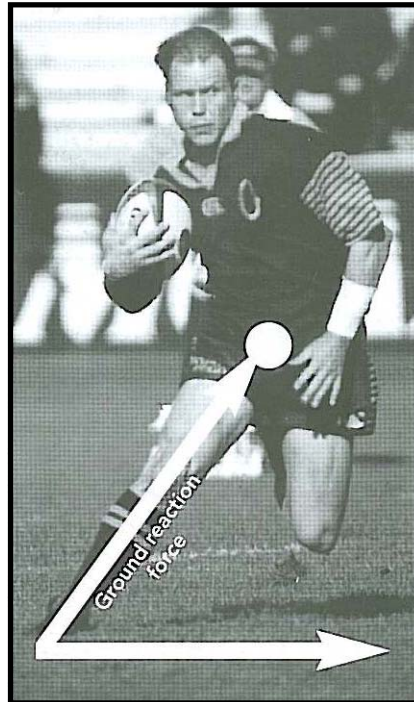
(Adapted from McKenzie *et al.*, 2000)

Figure 6.8: Relationship of stride rate, stride length and running velocity

It is evident that as velocity increases the player is able to increase both stride rate (dashed line) and stride length (solid line) to a point, but then stride length begins to fall off and stride rate begins to climb rapidly. Most players will use a stride rate that is rapid but not so rapid that there is a significant drop off in stride length. If one observes track sprinters one will notice that during the middle part of a race they travel a fairly large distance during every stride they take, while still having quite a rapid stride rate (Unknown Author, 2005d).

They have learned through practice what stride rate they need to use in order to maximise their performance. The problem when applying this to rugby is that with a long stride length, and therefore a relatively low stride rate (or turnover), the player is not able to reposition their foot back on the ground in order to change direction as quickly as if the player had a quicker stride and shorter stride length. If a player is not trying to change direction, but simply trying to get from one side of the field to the other as quickly as possible, then a longer stride is appropriate. However, when players like Christian Cullen or Jeff Wilson are watched running a weaving pattern through defenders they tend to shorten their stride (Bauman, 1991; Elliot, 1999; McKenzie *et al.*, 2000; Unknown Author, 2005d).

By quickening their stride they can get their feet back on the ground faster, and into positions that will generate sideways ground reaction forces which causes them to move sideways. It is this lateral force that provides the cutting motion characteristic of much of the running involved in rugby. In figure 6.9 one can observe how the ground reaction force acting on the players body passes right through his centre of mass, indicated by the white dot. The horizontal white line indicates the proportion of the ground reaction force that is moving him sideways and allowing him to change direction (Bauman, 1991; McKenzie *et al.*, 2000; Unknown Author, 2005d).



(Adapted from McKenzie *et al.*, 2000)

Figure 6.9: Use of ground reaction force to cause lateral motion

Another aspect of this type of movement involves the stability of the player, or their balance. It is important for the player who is about to execute a change in direction that they position themselves so that the ground reaction forces are moving them sideways rather than tipping them over (Grabiner *et al.*, 1993; MacKinnon & Winter, 1993; Elliot, 1999).

When observing Figure 6.9 above, one can imagine that if the line of the ground reaction force did not pass through the player's centre of mass, a torque would be created. As previously mentioned, objects tend to rotate about their centre of mass, a torque is applied – the player would start to rotate, which could cause him to fall over. Therefore the best position when changing direction is to lower your body slightly or to lean it in the direction the player wants to go, so that the ground reaction force will push the player sideways rather than tip him or her over (Bauman, 1991; Grabiner *et al.*, 1993; MacKinnon & Winter, 1993; McKenzie *et al.*, 2000).

6.6.4 PRINCIPLE 4 – EFFICIENT USE OF GROUND REACTION FORCES

“Players should position their body in such a way as to use ground reaction forces efficiently”

(Bauman, 1991; Grabiner *et al.*, 1993; McKenzie *et al.*, 2000)

Another important characteristic of high-speed running which is often overlooked is the role of the upper body. When the concept of torque was discussed it became evident that running is a prime example of torque generation in that the legs generate a large torque about the vertical axis of the player’s body (i.e., think of this as a line travelling from the player’s head to their feet) when they are driving their knees during the running stride. Therefore, since a torque tends to cause rotation, one would expect that the body would turn in the direction in which the player’s legs were driving (i.e., left leg driving forward causing the player to turn to the right) because of the torque the leg was generating. However, running players continue to move in a straight line rather than turning from side to side. This is due to the contribution of the upper body (Bauman, 1991; Grabiner *et al.*, 1993; MacKinnon & Winter, 1993; McKenzie *et al.*, 2000).

When observing track sprinters it becomes evident that they have extremely big arms and shoulders rather than just the legs. They need to have strong muscles in the upper body in order to generate a torque in the opposite direction to the legs, in order to create a balance between the two halves of the body to keep it moving straight. With all the different situations involved in a rugby game, it’s important to understand how to modify a player’s running technique to maximise his or her performance in any given situation, whether it calls for a high-speed sprint or a dramatic change of direction (Bauman, 1991; Grabiner *et al.*, 1993; MacKinnon & Winter, 1993; McKenzie *et al.*, 2000).

6.7 THE ANALYSIS AND INTERPRETATION OF THE OBSERVED COLLISIONS

6.7.1 THE SCIENCE OF BALL CARRYING COLLISIONS

A collision in rugby is highly variable in nature due to the wide variety of situations in which a collision can occur. In order for a ball carrier to be most effective the player needs to be able to generate sufficient momentum in his or her own body to counteract the momentum of the defender when a tackle situation arises. Probably the most important principle applicable to a collision is as follows and which has been previously dealt with:

6.7.2 PRINCIPLE 5 – COLLISION STABILITY

“In order to maintain stability, establish a wide base of support when possible, maintain the centre of mass over the base of support, lower the centre of mass towards the base of support, and shift the centre of mass towards any expected force which may cause instability.”

(Bauman, 1991; Grabiner *et al.*, 1993; MacKinnon & Winter, 1993; McKenzie *et al.*, 2000)

This principle can influence a collision in the following two ways:

1. If the tackler is starting from a stable position, the tackler is thus able to adjust to any changes in direction by the ball carrier. If the tackler is not in a stable position, such as when the ball carrier has used footwork or has come in on an effective running line, the tackler will not be able to change direction and the ball carrier can more easily avoid the tackle or dominate the collision when it takes place (Bauman, 1991; McKenzie *et al.*, 2000; Unknown Author, 2005d).
2. If a player is not in a relatively stable position when going into the collision, the player will not be able to utilise the ground reaction forces effectively in order to

be able to generate sufficient momentum into the collision. In order for the ball carrier to achieve this stability it is important for the player to keep his or her centre of gravity low to the ground and to lean towards the oncoming defender (Bauman, 1991; Elliot, 2000; McKenzie *et al.*, 2000).

6.7.3 THE EFFECTIVE BODY POSITIONING REQUIRED FOR ENTERING THE COLLISION SITE

The reason for leaning into the collision is that it gives more time for the ball carrier to apply force from a stable position because, even if they are driven back by the defender, the ball carriers centre of gravity is still over their base of support. This allows for a decrease in the force required at any given instant in time. If the ball carrier doesn't lean into the collision then in order to get the same result, they will need to apply a much greater force over a shorter period of time, which can result in a high velocity jarring impact at the collision site (Elliot, 2000; McKenzie *et al.*, 2000; Unknown Author, 2004a).

This situation is primarily explained by the following principle which has been previously dealt with:

6.7.4 PRINCIPLE 6 – EFFECTIVE MOMENTUM GENERATION

“The amount of momentum you generate depends on the size of the force applied and the amount of time for which that force is applied.”

(McKenzie *et al.*, 2000)

The generation of these very high forces is not only harder to achieve but it also greatly increases the impact forces for both the ball carrier as well as the defender. The player who is able to absorb and apply these collision forces well will dominate this area of play (Millburn, 1995; Unknown Author, 2004a; Unknown Author, 2004b).

6.7.5 PRINCIPLE 7 – EFFECTIVE BODY TECHNIQUE USAGE

“When involved in an impact situation, use proper techniques and equipment in order to absorb, minimise and be able to apply the forces involved”

(McKenzie *et al.*, 2000)

This principle implies the following: there must be a middle ground, where the impact forces experienced by the body are lower but are still at a level where the ball carrier is able to dominate the defender (Hay, 1993; Unknown Author, 2004a; Unknown Author, 2004b).

The same principles in terms of collisions apply with the ball carrier’s goal being to get the defender into an unstable position where they are less effective (Millburn, 1990). The ball carrier also wants to have as little force acting on his or her body as possible. This is where a side-step or swerve away from the defender can be used.

By moving away from the defender the ball carrier is able to draw them into an unstable position. It is also imperative that the ball carrier maintains a stable position by keeping his or her centre of gravity low and over their base of support (Millburn, 1987; Gerrard, 1998; McKenzie *et al.*, 2000; Unknown Author, 2004a; Unknown Author, 2004b).

When a ball carrier runs into a tackle situation it becomes noticeable that the ball carrier has the tendency to lean towards the defender just before impact. This enables the ball carrier to remain in a relatively stable position for longer; this will give the ball carrier more control when he or she enters the collision site (Alexander, 1992; McKenzie *et al.*, 2000; Unknown Author, 2004a; Unknown Author, 2004b).

CHAPTER 7

METHODS, THE EXPERIMENTAL DESIGN AND THE RELEVANT PROCEDURES

7.1 METHOD

At this stage of the discussion the purpose of this section is to identify and explain the concepts that are to be incorporated into the experimental design of this study. The study will take the form of a quasi-time series experiment. The following key components that are to be extracted from the analysis sheets will be used in order to evaluate whether the concept of collisions in rugby can be used as a determining factor in success in rugby.

1. The average number of collisions for the try to be scored. The collisions mentioned here, includes the number of rucks / phases, off-loads in the tackle and a forced missed tackle;
2. The ratio of dominant collisions versus the number of passes executed for the try to be scored. (number of collisions / number of passes);
3. The average number of forced missed tackles for the try to be scored;
4. The average velocity change of the dominant collisions for the try to be scored. (momentum of the ball carrier – momentum of the defender)

The following factors will be used as a further possible indication of the effectiveness of determining factors for success in rugby (see APPENDICES 4 – 9).

5. The comparison of whether a try is scored from a clean line break, or from extra players in support, versus the percentage of tries scored where a dominant collision took place by the try scorer before the try was in fact scored;
6. The ratio of forced missed tackles per phase for the try to be scored. (forced missed tackles / number of phases); and

Once an increase or decrease in the various forms of collisions as well as these specific observations as mentioned above has been established, an in-depth study of the reasons why the collisions were successful or not will be evaluated. The concepts explained in this section will be evaluated in relation to footage obtained from the following rugby competitions;

1. The Super 12 of 2003,
2. The Super 12 of 2004, and
3. The Super 12 of 2005.

Video Analysis will be done according to prescribed Notational Analysis sheets that have been developed in order to identify and isolate the pertinent factors which will be used in the appropriate discussion regarding the concept of “Dominant Collisions”. During the course of these competitions these identified aspects regarding the execution and implementation of the concepts that form the integral part of collisions will be focussed on with the objective of attempting to identify for what reasons there was an increase in the success rate of dominant collisions during match situations. By means of statistical information gathered during the 2003 Super 12, 2004 Super 12 and the 2005 Super 12 rugby competitions a comparison is to be made in order to evaluate whether there was a significant change in success when compared to the results of the other competitions. The concepts identified as imperative to achieving successful dominant collisions and to be concentrated on during the rugby situations are as follows:

7.2 PRE - CONTACT SITUATIONS BEFORE THE COLLISION TOOK PLACE – BALL CARRIER/S

1. The initial attacking base from which the try was scored.

Once it can be established which of the following starter facets resulted in the most try's being scored, coaches will inevitably adjust their focus areas in training in order to emphasise training in that specific area of play.

1.1 Restarts

This will include phases of play including the following;

- 1.1.1 Kick off receives,
- 1.1.2 Kick off on the team's own ball,
- 1.1.3 22m Kick in receives, and
- 1.1.4 22m kick in on the team's own ball.

1.2 Scrums

The position on the field of play will be notated in order to identify from which position teams can most effectively attacked from in order to be most effective in an attacking play. The field area will be divided into the following sections;

- 1.2.1 The left hand side of the field (20 meters in from the touchline);
- 1.2.2 The middle of the field ; and
- 1.2.3 The right hand side of the field (20 meters in from the touchline).

1.3 Lineouts

The greater space forced onto teams due to the laws of the game has often be used as the reason why teams are possibly more effective in attacking play from this facet of play. The study will aim to show that this is in fact so and possibly identify reason why it is or is not so.

The side of the field will also be notated in order to identify if there is a significant difference in terms of from which side of the field the lineout takes place from.

- 1.3.1 The left hand side of the field; or
- 1.3.2 The right hand side of the field.

1.4 Turnovers

The emphasis of teams being able to recycle and maintain possession has been conditioned into teams with the belief that attacking teams are the most

vulnerable when they have applied all their attacking players in an attack and while in the execution of the play turn the ball over to the opposition. The defending team are thus able to use the turnover possession and run at a team that has no defensive organisation which is the most vulnerable defence to run at. The study will measure if there is in fact a significant indication of the level of success of attack from turnover possession.

2. The predominant type of running line used into the collision

The type of possible running lines used in attacking plays has been confined into two basic angles of entrance into the collision. These lines are categorised into either a running line that comes in back towards where the ball has been received, i.e., “against the grain”, or a running line that moves away from where the ball has been received, i.e., “working with the grain”. The lines have been categorised as follows;

2.1 An under’s running line; or

2.2 An over’s running line

3. Was the collision a mismatch?

The term “mismatch” is used to describe the situation when a forward runner carries the ball into a collision with a backline player having to defend against the ball carrier. This type of collision will invariably result in a more dramatic collision as a forward will tend to try to run “over” the backline player. The opposite is also true. A backline player will tend to back his or her ability to beat the forward with footwork and try to evade the collision and attempt to break the line with as little contact as possible. The coach will thus try to manipulate attacking play to possibly be able to take advantage of these types of situation so to be most effective when in possession of the ball. As previously mentioned the mismatches or lack thereof will be evaluated as follows;

3.1 A forward ball carrier running at a back (defender);

3.2 A situation where no mismatch occurred, i.e., a forward running at a forward or a back running at a back; or

3.3 A back ball carrier running at a forward (defender).

4. Was there footwork involved before the collision took place?

In all collisions or attacking plays, there has to be a certain amount of footwork applied by the ball carrier in order to manipulate the defender so as to attempt to try and minimise the level of impact at the collision site. The opposite is also true if in fact the ball carrier wishes to use the footwork in order try and maximise the impact at the collision site. This aspect of the collision will be evaluated according to the following factors;

4.1 The use of a pre-step before the collision takes place;

4.2 The use of a side-step before the collision takes place;

4.3 The use of a deceleration step before the collision takes place;

4.4 The use of an acceleration step before the collision takes place; or

4.5 A situation where the ball carrier makes use of no step before the collision takes place.

5. The yardage the ball was carried before the collision took place

This figure is imperative in that it is required to work out the velocity that the ball carrier is able to “build up” into the collision. It also becomes an indication of how much time the defender has to position his or herself to be able to get into a strong defensive situation.

6. The amount of time that the ball carrier/s was in possession of the ball before the collision took place

This figure also forms part of the equation to work out the velocity of the ball carrier into the collision.

7. The velocity of the striker/s into the collision

This is a vital figure that plays a marked role in regards to the amount of momentum that the ball carrier/s can take into the collision. This will influence with what kind of “force” the ball carrier/s can impart onto the defender when they meet at the collision area.

8. The mass of the striker/s into the collision

This figure will also be used in the equation to establish the amount of momentum of the ball carrier/s into the collision.

9. The amount of momentum the striker/s takes into the collision

This value will be used in the discussion in order determine the velocity change when comparing the ball carrier s momentum to the defenders momentum. It represents the amount of velocity either the ball carrier or the defender takes into collisions.

7.3 PRE - CONTACT SITUATIONS BEFORE THE COLLISION TOOK PLACE – THE DEFENDER/S

This section will focus on the defenders who are involved in the collision. It will take a detailed look at the following factors:

1. Was there a defensive error that may have influenced the defenders ability to dominate the defensive situation?

If it is possible to identify situations where the defence can be beaten or forced into weaker defensive situations, and a team can manipulate the opposition into these situations, then collisions could be made easier to dominate.

The following defensive errors have been identified;

1.1 Slow reload

This is described as the ability of a defender/s to get into an organised and well positioned defensive position so to be able to move up onto the ball carrier in a stable, strong defensive body position.

1.2 Poor defensive spacing

This aspect of defensive error s indicates the ability of the opposition's defensive line to organise the spacing between the players who form the

defensive line. An inability to have appropriate spacing between players will have a marked influence on each player's ability to effectively enter the collision site and to dominate the defensive collision.

1.3 A defensive line that has an uneven line of press

If a defensive line does not move forward towards the ball carrier in an even line, it will create "gaps" through which the ball carrier can move which will give the ball carrier an edge when the collision takes place. The defenders will thus be less effective in their ability to execute a dominant tackle.

1.4 A defender who overtracks the ball carrier and moves out of his or her defensive line

This situation often happens when defenders do not work together in an organised defensive line and rush onto the ball carrier. When a defender overtracks, he moves outside the line of the ball carrier and finds him or herself unable to execute a dominant tackle. The defender's centre of mass falls outside his or her level of stability and is thus not adequately balanced into the collision.

1.5 A missed tackle

It can often happen in a collision that the defender falls off the tackle. It can occur for many reasons but most often occurs due to poor technique or lack of commitment into the collision.

2. The distance the defender/s moved until entering the collision site

This aspect of the equation plays a vital role in the ability of the defender to have sufficient momentum to be able to dominate the tackle situation.

3. The time transpired till defender/s entered the collision site

This figure will also play a part in the determining of the defender/s velocity into the tackle situation.

4. The velocity of the defenders/s into the collision

The amount of velocity plays an important role in regards to the amount of momentum that the defender/s can impart to the collision. This will influence the amount of impact that occurs at the collision area.

5. The mass of the defender/s into the collision

The defender/s amount of mass will determine the defender/s ability to stand strong in the tackle situation and not “slide off” the tackle situation. A one-on-one situation is easier to calculate, however if the ball carrier runs into a “double hit” the extra mass of the defenders will make it extremely difficult for the ball carrier to dominate the collision.

6. The momentum of the defender/s into the collision

This value will be used in the discussion in order determine the velocity change when comparing the ball carrier s momentum to the defenders momentum. It represents the amount of velocity either the ball carrier or the defender takes into collisions.

7.4 KEY FACTORS PRESENT AT THE IN CONTACT SITUATION AS THE COLLISION TAKES PLACE

This section of the discussion focuses on the actual collision site where the ball carrier/s and defender/s meet.

1. In which collision channel did the collision takes place

The channel area where the specific collision takes will be notated in order to identify in which channel most collisions takes place. Once this has been established, coaches can make use of this information to attack this channel.

1.1 Channel 1 (1st Pillar)

This collision takes place when the ball carrier runs at the defender who is positioned directly next to the ruck.

1.2 Channel 2 (2nd Pillar)

This collision takes place when the ball carrier runs at the defender who is positioned next to the player who is at 1st pillar.

1.3 Channel 3 (3rd Pillar)

This collision takes place when the ball carrier runs at the defender who is aligned on the flyhalf position who is at 3rd pillar.

1.4 Channel 4 (4th Pillar)

This collision takes place when the ball carrier runs at the defender who is aligned on the inside centre position who is at 4th pillar.

1.5 Channel 5 (5th Pillar)

This collision takes place when the ball carrier runs at the defender who is aligned on the outside centre position who is at 5th pillar.

1.6 Channel 6+ (6th Pillar)

This collision takes place when the ball carrier runs at the defender who is aligned out wide at the 6th + pillar.

2. Was the defender/s stationary when the collision took place?

This aspect will have a significant impact on the ability of the defender/s to generate sufficient momentum in order to be able to significantly dominate the tackle situation.

3. Where was contact made with the defender/s?

This will be an indication of where collisions predominantly took place. The reason why this can be of importance is that the most effective area on the defender's body will be able to be identified so that ball carriers will be able to run at them aiming for that specific zone of the defender's body. The following zones on the defenders body will be identified as target areas and will be used as the indication of the optimal area of the body to run at:

3.1 Non dominant collision, insufficient mass into the collision (Side of body - Forearms)

3.2 Dominant collision, sufficient mass into the collision (Side of body – shoulder to elbow)

3.3 Dominant collision, maximum mass into the collision (Centre of the body)

4. Was the tackler beaten?

This is a vital indication of the yardage the ball carrier makes after the collision takes place. This is important in that it shows the level of significance of the collision and if it was dominant or not. This will be evaluated by evaluating the collisions using the following parameters:

4.1 The ball carrier dominated the collision by achieving greater than 1metre forward momentum

4.2 The ball carrier dominated the collision by achieving less than 1 meter forward momentum

5. The body action of the ball carrier through or out of the collision

This specific indicator will make a comparison between linear and angular momentum out of the collision. This will be achieved by identifying the type of body action out of the collision. It will be achieved by evaluating the situation according to the following factors:

5.1 An inward spin by the ball carrier out of the collision;

5.2 The ball carrier comes straight out of the collision; or

5.3 An outward spin by the ball carrier out of the collision.

6. The yardage of the ball carrier after the collision has taken place

This will be an indication of the relative go forward momentum of the ball carrier after the collision has taken place.

7.5 THE VELOCITY CHANGE COMPARISON BETWEEN BALL CARRIER/S AND THE DEFENDER/S, AND THE RELEVANT COLLISION ANGLES

This section will focus on the comparison between the ball carrier and the defender at the specific collision. It will indicate the level of difference between the two both players.

1. What was the ball carrier's momentum into the collision?

This value has been determined from previous notation sheets and is imperative for the success of this study.

2. Was it a leached ball carry into the collision?

This factor will play an important role in the evaluating of the collision. The leached ball carry implies that two players are bound onto each other to drive the ball carrier through the tackle of the defender.

3. What was the defender's momentum?

This value will be used in order to compare it with the ball carrier's momentum. The player with the greater value should be more adept to dominating the collision.

4. Was it a double hit by the defenders?

This factor will affect the defenders momentum into the collision and if the tackle is executed effectively will result in the defenders dominating the collision. The defenders will thus be able to drive the ball carrier backwards.

5. What was the velocity change?

This value will indicate which player, ball carrier or defender, dominated the collision?

6. Which player executed the dominant force?

This will indicate which player was dominant at the impact and thus dominated the collision?

7. The collision angle of the ball carrier onto the defender

This will indicate the predominant collision angles that took place between the ball carriers and the defenders. Such an observation can greatly influence the type of running lines implemented by ball carriers in order to be more efficient during impact at collision situations. The following collision angles will be used as references:

7.1 A 180' collision (i.e., a front on collision);

7.2 A 157, 5' collision;

7.3 A 135' collision;

7.4 A 112, 5' collision;

7.5 A 90' collision; or

7.6 A 67, 5' collision (i.e., a from behind collision.)

7.6 THE POST - CONTACT EVALUATION OF THE TRY SCORED

This final section will evaluate the final pertinent factors that played a major role in the successful scoring of the try that has been evaluated. The following observations are to be made:

1. In which channel did the final line break or where the defender was beaten take place?

This observation will be able to show which areas of the field are the most vulnerable and through which area most line breaks or dominant collisions took place. The following channels have been identified for evaluation:

1.1 Channel 1 (2m)

1.2 Channel 2 (5m)

- 1.3 Channel 3 (10m)
- 1.4 Channel 4 (20m)
- 1.5 Channel 5 (30m)
- 1.6 Channel 6+ (40+m)

2. The number of passes between the last collision and the try being scored

This will indicate the average number of passes required in order to ultimately score a try.

3. The total number of passes for the try to be scored

The emphasis of a teams need to pass will be observed by notating the average number of passes required for a try to be scored.

4. The total number of phases before the try is scored

This value will show the value of phase play to be able to score tries. The average number of phases will be established, and show how defences can be broken through the scrambling of defences.

5. The total field distance covered by the attacking team for the try to be scored

It will show the average distance from which most tries are scored. It can be an indication of from which zone on the field a team should apply attack, and possibly in which zones teams should play for field position.