1.1 Strength Evaluation in Team Sports

1.1.1 The Concept of Strength Related to the Field of Sports

Mechanically, force is defined as any action by a material body on another capable of causing changes in the state of rest or movement. The human being can move, oppose external loads and adapt to the environment due to its ability to generate strength from its muscle mass. Therefore, from a physiological point of view, muscular strength constitutes a key neuromotor capacity that can occur in different forms depending on the individual conditions and objectives in which each exercise is performed. In fact, different values of muscular force can exist according to the type of action performed (dynamic or isometric), the velocity, the weight moved or the mechanical characteristics of each exercise (Knuttgen and Kraemer, 1987, in Naclerio, 2011).

In most sports settings, strength is applied to accelerate, decelerate or to oppose the loads determined by the body itself, an implement or the action of an adversary, performing fundamentally dynamic actions where the resistance to be overcome is constant or isoinertial. Therefore, and given the great importance of muscular strength on sports performance and on health, the assessment protocols and criteria that are most commonly used for assessing levels of strength in dynamic isoinertial movements, will be analyzed. These are a key tool for properly diagnosing, programming and controlling strength training sessions (Naclerio, 2011).

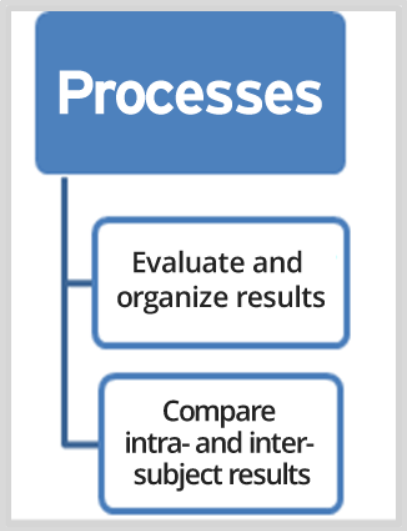
1.1.2 Strength Assessment: Concepts and Objectives

The objective of this development is that the professional involved with training that is oriented toward strength (neuromuscular) training is able to manage a basic strength evaluation methodology - within sport at various skill levels - that would enable the professional to carry out two very important processes (Figure 1).

The professional must:

- Assess and organize the results.
- Compare them both intrasubject and intersubject.

Figure 1: Processes to be Performed by the Professional in the Context of Strength Assessments in Sport



Source: Prepared by the author.

This is why the classification of values obtained in the tests should be intrasubject and intersubject. In other words, when we have subjects with different characteristics within a team, the tests are used to check on the evolution of the player himself (intrasubject); but they can also establish groups of players with similar characteristics in order to determine relationships and comparisons (intersubjects).

In the context of the processes mentioned above (assess and sort results, and compare intrasubject and intersubjects), it will be very important to take the following considerations into account:

- The conditional tests should not be used as predictors of performance, but as indicators and predictors for the control and progress of the player's physical condition.
- Internal load data would be needed to understand the internal condition of the player and be able to make a plan or proposal for training loads.
- It is interesting to monitor in order to get as close as possible to the athlete's condition. Therefore, both external and internal load data should be

considered, so that the view of the exercise professional making the assessment reflects as closely as possible the athlete's current condition and fitness.

Therefore, the strength evaluation, which forms a part of training monitoring, may seek objectives such as those presented by González Badillo and Rivas Serna (2002):

1) Oversee the training process as well as changes in performance.
2) Assess the relevance of strength and power on the specific performance area.
3) Define the strength and power needs.
4) Define the athlete's profile: strengths and weaknesses.
5) Verify the relationship between progress in strength and power and the specific performance: the relationship between the changes.
6) Predict outcomes.
7) Prescribe the most appropriate training, depending on:

    a. The needs for strength and power in the sport as well as the subject's own needs.
    b. The results of tests carried out so far.
    c. Assessment of the influence of strength and power over other qualities.
    d. Differentiate between athletes from the same level as well as different sports levels.
    e. Contribute toward the identification of talents. (Heredia Elvar, Chulvi Medrano, Ramón and Pomar, 2006).

All training including strength evaluation as well as its monitoring, is a complex and multifactorial process that involves obtaining an amount of information that is key for sports training. It cannot be otherwise.

> Training control cannot be confined to a single parameter, e.g. the value of 1RM (as will be discussed later). However, when the training is oriented toward healthy fitness, we should rethink the intended objectives, making them not so complex initially, and obtaining data that is relevant to the overseeing and prescription of training for that purpose.
>
> Coinciding with the contribution made by Heredia Elvar (2005), the current approach in programs oriented toward neuromuscular fitness should consider a series of prerequisites in advance. In so doing, it must:

1) Help to determine the neuromuscular training area or zone in which the subject is going to develop the program (depending on the phase).
2) Ensure a direct transfer between the data obtained and its application to the training prescription.

3) Avoid situations involving potential risk of injury, ensuring safe and correct execution.
4) Allow progress between measurements to be checked and, logically, the assessment of the effects of the training. For this case, it is equally important to obtain feedback as positive reinforcement for the athlete. (Heredia Elvar, Chulvi Medrano, Ramón and Pomar, 2006).

The following aspects must be considered within a neuromuscular fitness program, in accordance with the structure of the FC Barcelona performance area (Seirul·lo Vargas, F., 2013):

1. Ensure healthy joint stability and control for the human athlete. Coadjuvant work.
2. Ensure variability in the proposals with regard to load levels and articulation ranges. Coadjuvant or optimizing work.
3. Interrelate the conditional structure with the rest of the structures to optimize the complex system (i.e. the human athlete). Optimizing work.

Before developing the proposed strength evaluation, and following González Badillo and Gorostiaga Ayestarán (1996), we will make a brief review of the methods for measuring strength and its manifestations. We would like to keep in mind an approach that is more applicable to sports training, considering the existing measurement methods according to the type of muscle activation measured:

- Measurements in Isokinetic (Concentric-Eccentric) activations.
- Measurements in isometric activations.
- Measurements in isoinertial activations (free weights), with or without additional measurement instruments and jumps (intense SSC) (Heredia Elvar, Chulvi Medrano, Ramón and Pomar, 2006).

It is important to point out that these measurements give us information about the athlete's (or player's) physical condition, but we cannot extrapolate this data to relate it with sporting performance.

1.1.3 Measurements in Isokinetic Activations

> Isokinetic dynamometers have been used in rehabilitation—especially on the knee—as a means of performing both concentric and eccentric dynamic exercises. These make it possible to work all the strength potential of the muscle, in all degrees throughout the arc of movement (González Moro, 2004 as cited in Heredia Elvar, Chulvi Medrano, Ramón and Pomar, 2006).

"Isokinetic exercise can be used to quantify the capacity of a group of muscles to generate a force or torsional moment and as a form of exercise to restore strength levels after an injury, or simply as training" (Tlatoa Ramirez, 2014).

It is important to understand that this type of test is performed during a rehabilitation stage in order to help resolve a particular problem. If these tests are performed with a healthy athlete and produce asymmetric values between limbs or warning signs, several other parameters must be taken into account before concluding that the athlete needs to improve or change some strength levels.

It must be understood that the athlete (or player) creates compensations in order to adapt to an environment that, by definition, generates decompensations, but these do not always have to be injurious. In case they are not injurious, that decompensation must be understood as the athlete's adaptation to his environment, since, if his motor structure is altered via external adaptations, he runs the risk of altering his proprioceptive information and modifying patterns that cause mismatches, and that this in turn, ends up having a negative effect on the player and his performance as an individual within the team.

Some of the features of this type of measurement are:

- The velocity of movement of the activated body segments remains constant.
- They allow us to assess movements in rotation, which in many cases are not quantifiable by other types of dynamometers.
- The resistance generated by the dynamometer is of the same order of magnitude as the muscular force applied throughout the range of movement.
- It allows optimal loads to be used on the muscles and the force (torque in joint movements) to be assessed in dynamic conditions.
- It is useful in injury recovery and rehabilitation. It is of little use for sports training since isokinetic movements are almost never found in any sports discipline.

The main components of isokinetic dynamometers are (Gonzalez Moro, 2004):

Table 1: Main Variables to Take into Account in Isokinetic Dynamometry (González Moro, 2004)

Variable	Characteristics
Speed of Motion	Slow speeds (up to 60%) Fast speeds (above 180%)
Range of Motion	Established for each joint and motion. Limited by specific pathology.
Type of Contractions	Concentric. Eccentric
Workout Pace	Continuous. Superimposed or contraction to contraction

Source: Heredia Elvar, Chulvi Medrano, Ramón and Pomar, 2006.

Table 2: Physical Quantities Used in Isokinetic Dynamometry (Gonzalez Moro, 2004)

Force (newton)	Product of the mass displaced by the acquired acceleration. What the muscle actually does.
Moment (newton x meter)	When force is exerted along an axis of rotation. It is the torsional moment and indicates the external result.
Work (joules)	Force exerted by the distance of displacement. It is the transferred energy. Graphically, it is represented as the area under the moment curve.
Power (watts)	It is the work done over time. Useful for repetitive tasks.

Source: Heredia Elvar, Chulvi Medrano, Ramón and Pomar, 2006.

The most commonly used units in isokinetic assessment are those derived from the torsional moment. They can be expressed as the mean moment throughout the range of movement; the maximum moment reached and the angular position of the path in which the maximum moment is exercised. The moment of each angle can be studied by obtaining the specific angular moments (González Moro, 2004).

Moments or forces performed can be expressed individually or in relation to the antagonist muscle groups. This allows to obtain the torque ratios of the hip, knee and shoulder flexors/extensors or the torque ratios of the external rotators/internal rotators of the shoulder. This way of expressing results allows us to detect possible strength deficits and muscular imbalances (Gonzalez Moro, 2004).

The main **advantages** of isokinetic assessment are (González Badillo and Rivas, 2002; González Moro, 2004):

- It allows us to compare agonist and antagonist muscles.
- It allows measurement of isometric, concentric and eccentric actions.
- It is possible to compare limbs with each other (e.g. imbalances), bilateral discrepancies, as well as assessing general muscular weaknesses, local atrophy and areas of weakness.

According to P. Kannus (1994 cited by Gonzalez and Rivas, 2002), the main **disadvantage** of these isokinetic measurements is that it is an unnatural movement. In addition to and in light of numerous studies (Gleeson and Mercer, 1996 cited by Gorostiaga and Rivas, 2002), isokinetic measurements must be carefully taken (i.e. for the impact on the data due to significant levels of measurement errors, depending on the measurement angle, less reliability in relation to higher velocities, etc.).

In addition, there are two major drawbacks for not assessing that option as plausible for use by the trainer:

- The validity of this diagnosis, at the specific level—whether for a movement in our daily lives or when practicing a sport—since it is virtually impossible to maintain a constant speed of movement via the axis of a given joint. As previously mentioned, this test is to be taken into account within the rehabilitation stage; it can serve as a guide, but never as the sole parameter to take into account.
- Its enormous cost and the need for preparation by the personnel in charge. (Heredia Elvar, Chulvi Medrano, Ramon and Pomar, 2006).

1.1.4 Measurements in Isometric Activations

Isometric force is described as the force or maximum torque produced by a peak voluntary isometric contraction (Mac Dougall, Wenger and Green, 1995). We can also say that it relates to application of a maximum voluntary muscle activation against an insurmountable resistance (Gonzalez Badillo and Gorostiaga Ayestarán, 1995).

Remember that these measurements are still part of the monitoring of the player as an individual (adjuvant training).

Specially designed equipment can be used for their evaluation, including dynamometers that are currently on the market or that are made-to-order. There are other, more economical adapted procedures which can also be used. Among the former are the dynamometers, strength platforms and isokinetic machines. In the second case, free weights are used, with progressive loads, until an impossible-to-mobilize resistance is reached. The former offer greater precision, but the use of free weights is more economical.

With regard to equipment or instruments that we will need to evaluate, Avis et al. (1985) and Secher (1975) recommend building a structure that allows for the evaluation of the specific movement pattern of the sport (if the subjects being evaluated are athletes), in order to respect the principle of specificity (to be clear on this point, it is very difficult to adhere to this principle of specificity when this, in terms of sport as a whole, by concept, is the variability of the game itself, where a technical-tactical situation is never repeated exactly during the competition). Thus, the structure would need to be equipped with a force transducer (load cell) that features an effort indicator. The readout apparatus can be an oscilloscope or a high precision graphical register. Currently, the analysis of the force or torque signal is performed through specific software and provides, in graphical form, the maximum force or torque values as well as values related to the rate or speed of development (Viitasalo, Saukkonen and Komi, 1980).

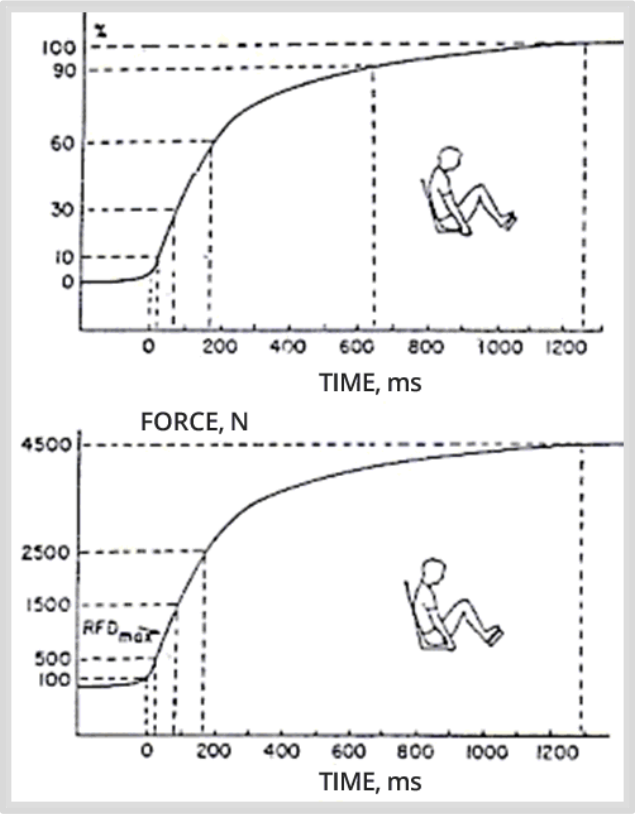
With regard to equipment calibration, Mac Dougall, Wenger and Green (1995) propose calibration with familiar weights. They state that the calibration must be performed across the entire working range of the instrument. Systematic calibration during a period of time will help establish the stability of the system, and will indicate the ideal calibration frequency. It is advisable to perform a calibration before each assessment session, especially when a lot of time has passed between one session and the next.
The key measurements in the isometric test are:

a) The maximum force or torque.
b) The rate or speed of force development
c) The rate or speed of muscle relaxation.

a) Measurement of Maximum Force or Torque

Force is measured as maximum force (Newtons, or N), or as the maximum (Newton per meter, or N/m) torque (torsional moment) developed during a maximum voluntary contraction (Figure 2).

Figure 2: Force and Time Curve During a Maximum Voluntary Isometric Contraction



Source: González Badillo, J. J., y Ribas Serna, J. (2002) [Gonzalez Badillo, J. J., and Ribas Serna, J. (2002)]

The implementation of the test can be performed:

- With a progressive activation or contraction until reaching peak force.
- With a very fast muscular activation or contraction, trying to reach the maximum force in the shortest possible time.

For the measurement of the maximum force or torque, both forms can be used, but some authors, like Mac Dougall, Wenger and Green (1995), propose that the contraction must last long enough for the subject to be able to reach maximum force.

The time required to reach the maximum force depends on several elements (the adaptability of the evaluation program, the angle of movement evaluated, the

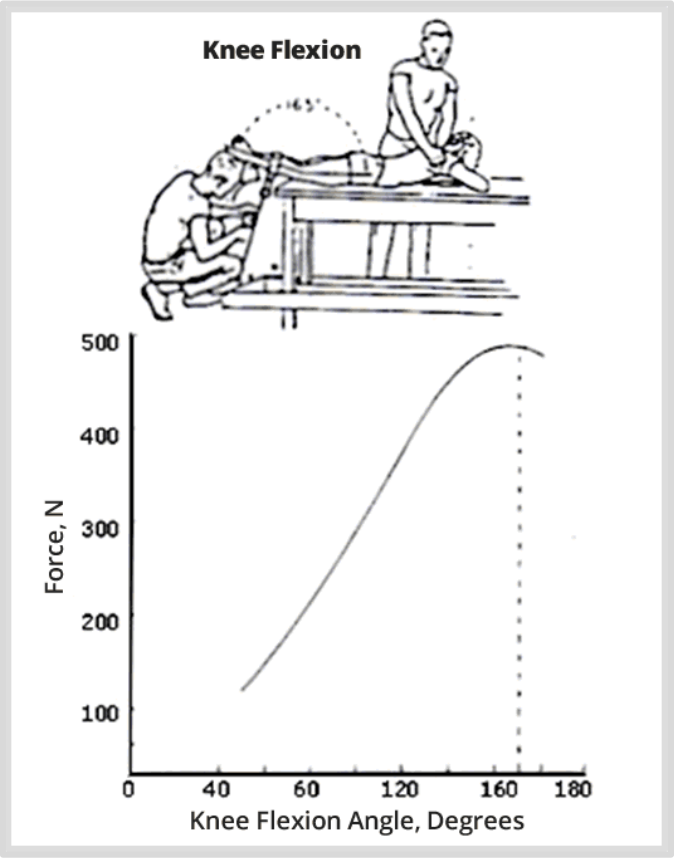
characteristics of the subjects, the instructions they receive, etc.). In general, any subject can achieve the maximum force with contractions lasting 5 seconds (Hood and Forward, 1965). Therefore, the assessment protocols include contractions that last between two to five seconds (Andersen and Henckel, 1987).

It must be taken into account that, although it may take up to 5 seconds to reach the maximum strength, 90% of the maximum strength is often reached in less than 2 seconds (Hakkinen, Komi and Alén, 1985). González Badillo y Gorostiaga Ayestarán (1995) [Gonzalez Badillo and Gorostiaga Ayestarán (1995)] recommended contraction durations of between 3 to 5 seconds, repeated two to five times, and then, from these, taking the best result. It is important to keep in mind that once the maximum force is reached, it could only be maintained for a maximum period of 1 second (Hislop, 1963).

With respect to the rest periods between the various attempts, periods ranging from 15 and 20 seconds have been used (Tornvall, 1963), up to a total of 5 minutes (Viitasalo, Saukkonen and Komi, 1980). Shorter times lead to fatigue after two or three repetitions (Hood and Forward, 1965), so rest periods of 90 seconds seem to be the most suitable (Murria et al, 1977 in Mac Dougall, Wenger and Green, 1995). Mac Dougall, Wenger and Green (1995) propose pauses of one minute between repetitions.

Standardization of body position for the assessment is totally necessary. In the evaluation of a single joint, it is necessary to standardize the articulation angle of the test movement and the articulation angles of the adjacent body parts (Lunnen, Yack and Leveau, 1981). For example, in a knee flexion strength test, it is necessary to standardize the angle of the knee joint because the force can vary significantly over the degree of mobility (Figure 3).

Figure 3: Isometric Force Curve



Source: MacDougall, Wenger and Green, 1995

The image shows how joint position influences the isometric force of the knee flexor muscles. It is very important to standardize the angles of articulation in the isometric force measurement (Prentice, 1990, in MacDougall, Wenger and Green, 1995).

In the case of Figure 3, the flexion torque will be affected by the angle of the hip, depending on whether the subject is lying face up or face down (Houtz et al., 1957)**.** Another factor of influence has to do with whether one uses a manual restraint (to do this, there must be a correlation between gages, i.e., correlation intra and inter gages) or straps.

> There is no strict rule regarding the optimal position for the test movements for one or several joints; a given motion may be ideal for one particular sport. However, it is clear that the selected protocol has to be repeated, without difficulty, every time one performs the test (Mac Dougall, Wenger and Green, 1995).

b) Measurement of the Rate or Speed of the Force Development (Force-Time Curve)

The rate (RFD) or the speed (SFD) of the force development is a measure of the pace at which force or torque develops. The units are in newton per second (N.s-1) and newton per meter per second (N.m.s-1) respectively.

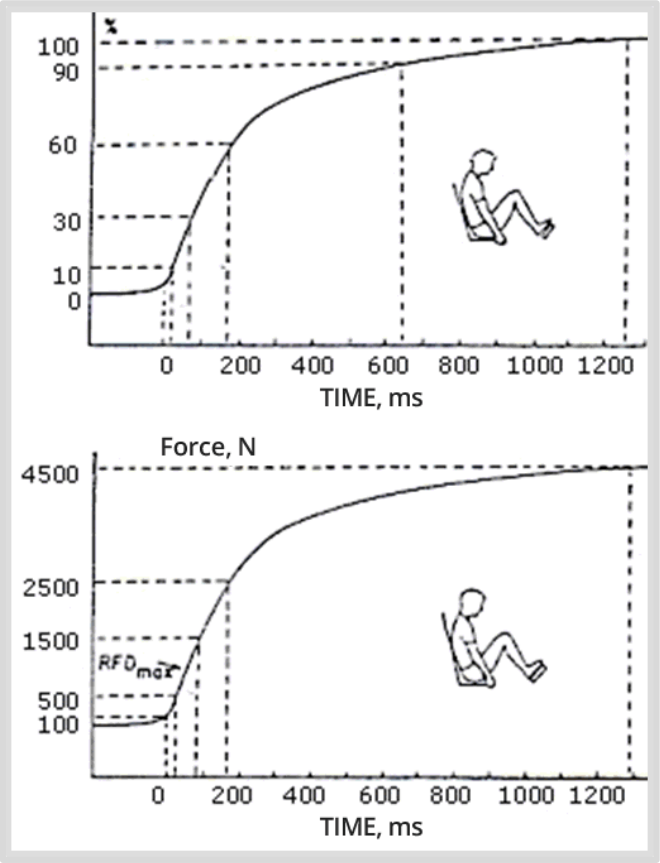
The most commonly used method to measure the RFD or SFD is to divide the peak force (PF) collected in a force-time record, by the time taken to reach the PF. The calculated value will be the mean RFD during contraction.

According to Mac Dougall, Wenger and Green (1995), this approach has at least four drawbacks:

- The first is that it is difficult to determine the precise moment in which the force departs from the base line.
- The second is that, if the force log shows a uniform progression toward the maximum (as in Figure 4), it is difficult to determine the precise point at which it reaches the PF (i.e. the moment when the peak force value is reached).
- The third is that, near the PF, irregular force readings usually appear (with dips and bumps). For example, at 800 ms, a PF of 95% can be consistently achieved. However, in an inconsistent log, the real maximum can take place in the first second of a contraction, and drop to a third in the following contraction, varying the mean RFD considerably.
- The fourth is that the calculation of the mean RFD does not produce the instantaneous peak RFD (for example, during a period of five seconds).

The first three drawbacks can be overcome by setting an arbitrary starting point (for example, 10% of the PF) on the baseline, and an end point (for example, 90% of the PF) below the PF level, where the contraction is still uniform (Figure 4).

Figure 4: Measurement of the Rate of Force Development (RFD)

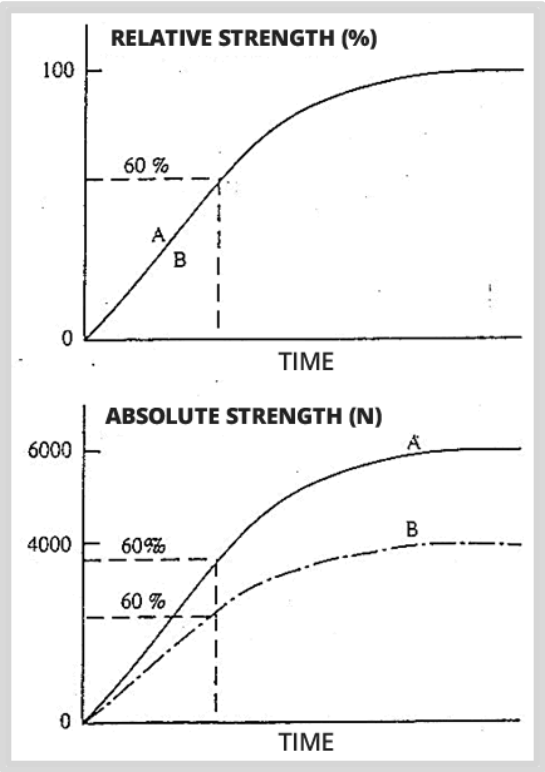


Source: Gonzalez Badillo, J. J., and Ribas Serna, J. (2002)

In Figure 4, the RFD is measured as the elapsed time from 10% to 30%, 60% and 90% of the peak force (PF). In Figure 5, the absolute RFD is measured as the time elapsed from an absolute force of 100 N to forces of 500, 1,500 and 2,500 N. The maximum RFD is determined through computer analysis of the force-time signal and takes place at 30% of the PF (Vitasalo, Saukkonen and Komi, 1980, and Hakkinen, Alen and Komi, 1984, in MacDougall, Wenger and Green, 1995).

Alén, Hakkinen and Komi (1984) have measured the time from 10% of PF to 30%, 60% and 90% of PF (100% maximum voluntary contraction). Following this method, the RFD is inferred from the attempts needed to reach the different percentages, and not through the calculation of the mean RFD during the different periods. However, although two athletes may reach 60% of the PF at the same time, one can be stronger than the other. Distinctions can be made between the two athletes by including in the analysis the attempts that were necessary for achieving various levels of absolute force (Alén, Hakkinen and Komi 1984) (Figure 5).

Figure 5: Rate of Force Development (RFD) in Two Athletes (A and B) Who Had Similar Relative Force-Time Readings



Source: Alén, Hakkinen and Komi, 1984.

With regard to absolute force, however, athlete A displayed a greater force at 60% of PF. The evaluation took into account records of absolute and relative force-times (Mac Dougall, Wenger and Green, 1995).

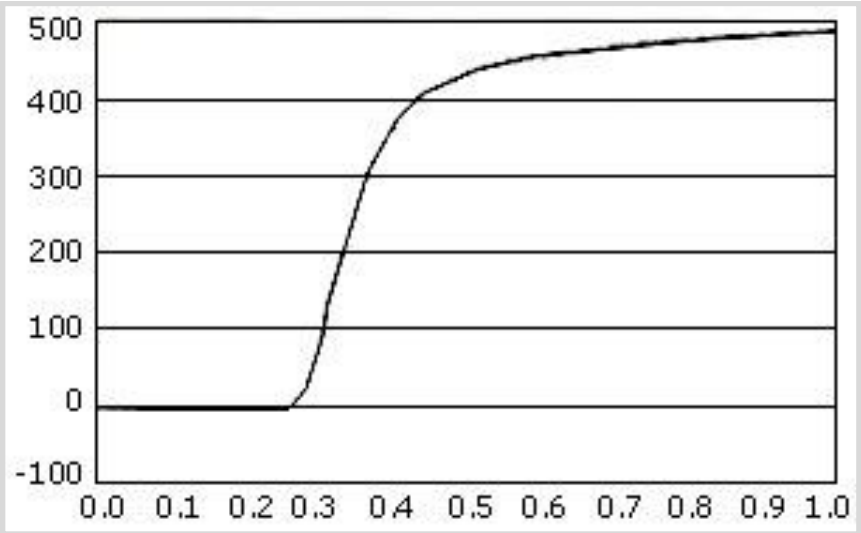
With regard to the fourth drawback, the peak RFD is currently calculated by the same software that detects the largest increase of force during intervals of short duration (e.g. five seconds) (Viitasalo, Hakkinen and Komi, 1981), presenting it as the peak RFD. For example, in the study of Viitasalo, Hakkinen and Komi, P.V., (1981), in a unilateral knee extension, the peak RFD was 7,410 N.S-1 (mean) and took place at 31% of PF, which turned out to be 699 N. Likewise, one would also have to protocolize what time band is used to determine the peak RFD.

In the force-time analysis (Figure 6), it is very important to include measurements of the contraction at the beginning (for example, 30% of PF) and at the end (for example, 90% of PF) because the necessities of a sport and the effects of training may be specific to a particular phase of the contraction (Alén, Hakkinen and Komi, 1984; Hakkinen, Komi and Alén, 1985; Thorstensson, Karlson, Vitasalo, Luhtanen and Komi, 1976).

The increase of the force per unit of time (RFD) up to 70% is a way to measure explosive strength. This percentage of maximum isometric force is reached within a time near 100 or 120 ms. Thus, Gorostiaga Ayestarán and Gonzalez Badillo (1995) suggest, in the measurement of RFD, that the increase of force per unit of time will be measured in 100 ms. This would allow us to take this result as a measure of

explosive strength or of the rate of strength development (RFD) (Gonzalez Badillo and Gorostiaga Ayestarán, 1995).

Figure 6: Force-Time Curve for Obtaining the RFD (Gorostiaga Ayestarán and Gonzalez Badillo, 1995)



Source: Gonzalez Badillo and Gorostiaga Ayestarán, 1995

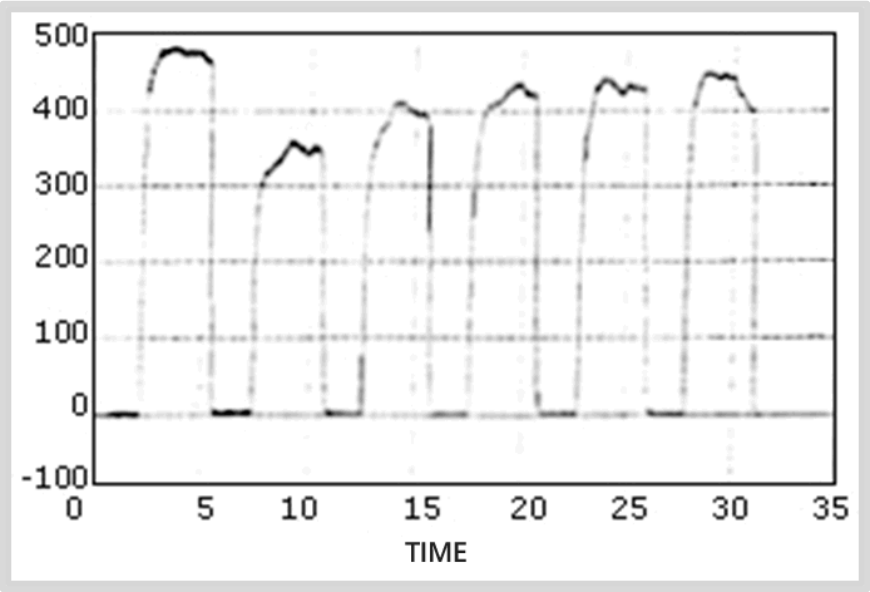
In general, the consulted literature on the RFD agrees with the estimation that, the maximum isometric force occurs when approximately 30% of the maximum isometric force is developed.

The recommendations regarding the position of the subject for measurement of maximum isometric force are fully applicable to RFD measurement.

With regard to the number of tests, some prior warm-up contractions must be carried out and, followed by three to five tests (Hakkinen, Komi and Kauhanen, 1986). Fatigue may have a significant effect on the RFD (Royce, 1962; Viitasalo and Komi, 1981) and, therefore, the rest periods between one repetition and another should be at least one minute (Mac Dougall, Wenger and Green, 1995), although, sometimes, breaks of five minutes were prescribed (Viitasalo, Saukkonen and Komi, 1980, in Mac Dougall, Wenger and Green, 1995).

González Badillo and Gorostiaga Ayestarán (1995) concluded, after having worked on measuring hand pressure strength (i.e. hand grip), that a recovery time of one minute between different attempts is sufficient in order to allow maximum strength to be determined for each one. The maximum force peak was reached by two seconds and was maintained for a very short time (Figure 7).

Figure 7: Force-Time Curves from a Maximum Isometric Strength Test with Three Attempts Separated by a Recovery Time of One Minute (González Badillo and Gorostiaga Ayestarán, 1995)



Source: González Badillo and Gorostiaga Ayestarán, 1995.

c) Measurement of the Rate or Velocity of Relaxation

The relaxation rate is not usually measured on a regular basis like the RFD, but it can provide very useful information on sports movements that require a prompt suspension of the contraction. The procedures described for the RFD can be applied to this measurement.

The maximum rate of relaxation can be measured in the same way as the time it takes to reach determined percentages or absolute PF values during the relaxation phase. For example, relaxation times from 85% to 60%, 30% and 10% have been measured (Alén, Hakkinen and Komi, 1984; Hakkinen, Alén and Komi, 1984). In the isometric extension of the knee, the maximum RFD of 7,410 N.s-1 occurred at 31% of the PF while the maximum rate of relaxation of 7,040 N.s-1 occurred at 58% of the PF (Vitasalo, Saukkonen and Komi, 1980).

An important contribution of Hakkinen and Myllylä (1990) is that the relaxation time increases, i.e. relaxation is slower after fatigue. As stated earlier, relaxation time is very important among those sports that require a quick interruption of the contraction.

For carrying out these types of tests with the best possible reliability and accuracy, a force "transducer" (load cells) would be required and, if possible, support from IT with respect to data collection and subsequent processing. Regardless of the software being used, it will be important to know which variables are being monitored and where they come from.

The value of the isometric measurements raises some issues that should be considered as potential disadvantages for their application in sports training programs:

- Their application must be performed in the angle in which peak force occurs on the specific gesture that is intended to be assessed. This implies a relationship in dynamic performance, which is questionable. In addition, there seems to be little relation between the neuromuscular, structural and mechanical adaptations between static and dynamic exercises (González and Rivas, 2002).
- It is widely accepted and documented that (isometric) exercises with a high static component are contraindicated for people with cardiovascular disease, essentially due to the high increase of systolic blood pressure that is generated and to their potential as inducers of ischemia during the exertion (Pate et al., 1991; Jiménez, 2003). (Heredia Elvar, Chulvi Medrano, Ramón and Pomar, 2006).

This is not usually the case for athletes, but it is necessary to point out this disadvantage.