FINAL WORK

Sabunim Gustavo Balbis

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STRENGTH, WORK AND POWER

What is Speed?

Velocity indicates the rate of change of position of a body, and is measured in m/s (meters per second). Its variation, the acceleration, indicates the rate or change of velocity and it is measured in m/s^2 (meters per second squared). A body is said to be moving at constant speed if its speed does not change (its acceleration is 0). Velocity (as well as position and acceleration) is a vector quantity. This means that it has a module, an application point, sense and direction. One way to understand the vectorial aspect is to imagine a 100 meter sprinter. If Usain Bolt covers that distance in 9.57 seconds, we're talking about the modulus of speed. If we say that he walks them on the main track, he gives us an idea of direction. The meaning indicates that he runs through them from the start to the finish, and not the other way around.

What is Force?

Force is a muscular effort that is made on a body in order to change its velocity vector, that is, to accelerate it. The greater the effort we make, the greater the change in the state of the body, so experience tells us that this relationship is directly proportional. We know that according to our effort, the body will change its velocity vector (not only how fast it moves, but also its sense and direction). Likewise, experience tells us that the constant of proportionality is related to the size of the body. The same result is not obtained by applying a force to a small object (a chair for example) as to a more massive one (a car). This proportionality factor represents the resistance of the body to change its speed (inertia). In physics this relationship is indicated according to Newton's Second Law: $F = m * a$ and its unit is Newton (Kg/seconds squared).

What is work?

We say that a force does work if, when applied to a body, the latter moves. We can see this with the same examples from the previous point. Moving a chair does work that depends on the force I exert and the distance the chair moves. If I apply a force to a massive object (a train car) then there is no work, since the object is not moving, even though I am applying a force. Another example is holding a 10-kg weight with your arm outstretched, 1 meter above the ground. As long as we don't let go of the weight and keep it in our hand, we are making a force, but there is no work. At the moment of releasing it, the force of gravity does work on those 10 Kg while it travels the meter to the ground. In physics, work is described by the formula $L = F * d * \cos \theta$ and is measured in Joules (Newton * Meter)

What is Power?

Power indicates the amount of energy that is transferred per unit of time. Energy is a somewhat abstract concept, but it can be defined as a quantifiable property that must be transferred to a body for it to move. Therefore if a force does work, then it is transferring energy onto a body. In particular, the energy that a body obtains when moving is called Kinetic Energy, and it is proportional to the square of the speed. Returning to our example of moving a chair, let's assume two scenarios:

Move a chair 10 meters in 10 seconds
Move the same chair 10 meters in 1 second

In both cases, the work is the same, but the power is 10 times greater in the second case.

We can take previous definitions to understand what power is:
We know that velocity is the change in position
We know that work is force * distance.
We can think of the power P as equal to the applied force times the velocity (P = F *V), if the force is constant.

Power can also be thought of as the change in kinetic energy, that is, the square of the change in speed.

In Taekwondo we talk about the importance of movements with power, both for forms and for combat.

Let's think of a (retractable) fist bump. A low-power blow is equivalent to a slow movement (low speed), which transfers little energy if it hits the opponent. For example, it will not be able to stop an attack, nor break a board. On the contrary, a powerful movement is a high-speed movement, which at the moment of impact will have the ability to move a body or break a table since it transfers more energy.

Another example of the effect of speed can be seen in the act of rotating the wrist when punching. When making this movement, rotational speed is printed (in addition to the transition speed), which increases the kinetic energy and the work of the fist. Therefore, a punch with rotation is more powerful than a punch without rotation, even though the hand is moving at the same speed.

Application of the concept of torque or moment in strength training in ITF Taekwondo

One of the elementary principles of sports training is specificity, which tells us about the criteria to be taken into account when selecting exercises based on the requirements of each sport discipline; although the definition is broad and refers to all variables that influence a training program of a given athlete (physiological, metabolic, biomechanical, etc.) we will focus on the biomechanical analysis trying to analyze and understand the needs of combat sports in general.

Bearing this in mind, we can highlight the following points when selecting the strength exercises to use without disregarding the current training phase (general, specific, competitive):

- Type of muscle contraction involved
- Used Movement Patterns
- Velocity and accelerations of segments and angles involved in each movement
- Momentum and force impulse
- Magnitude of the generated tension
- Rate of force development
- Time of force application
- Kinematic chains and muscle groups involved

CONCEPT OF FORCE

Mechanics defines force as any action of a material body on another, which causes changes in its state of rest or movement, and can move it, stop it, change its velocity or distort it. According to Newton's second law, the applied force is determined by the product of the mass of the object and its acceleration, having a vectorial character determined by the sum of the forces involved.

However, as a physical quality, force is manifested as a functional capacity that is expressed by the joint action of the nervous and muscular system to generate tension, transmit traction forces on the skeletal system or apply it on other bodies to be able to perform movements, oppose, overcome or react to external forces (Siff and Verkhoshansky, 2000; Bosco, 2000).

TORQUE OR MOMENT

In rotary motion, the amount of force applied does not depend on gravitational action but on the moment of inertia, which is the angular equivalent of inertia (mass) and represents the resistance offered by an object when rotating around its axis. When a rigid body rotates around its axis must be considered, in addition to the mass, the radius of gyration since these two factors determine the resistance of the body to the changes of rotational motion through a given axis (Gutiérrez, 1998; Enoka, 2002). Bearing in mind then that the resultant force is expressed by the product of mass and acceleration, in the case of rotary movements the force will be the product of the inertial mass ($m_¡$) and the tangential acceleration ($a\chi$) suffered by each particle of the body that rotates by the action of the applied force ($F\chi$), being the tangential acceleration the product between the radius of the body ($r_¡$) and its angular acceleration ($\alpha_¡$).

$$F\chi = m_¡ \text{ x } r_¡ \text{ x } \alpha_¡$$

$$F\chi = m_¡ \text{ x } a\chi$$

If the moment of force ($T_¡$) is determined by the product of the applied force ($F\chi$) and the radius of gyration ($r_¡$), multiplying $m_¡$ and $a\chi$ by the radius ($r_¡$) gives the following formula for the moment of force:

$$T_¡) = m_¡ \text{ x } r_¡^2 \text{ x } \alpha_¡$$

As an example, let us take the case of a wrench:

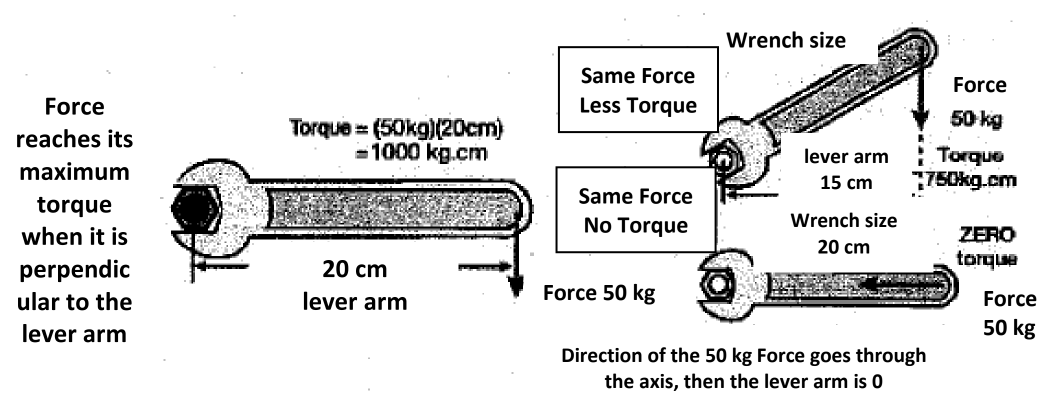

Fig. 1. *Diagram of different moments of torque produced by a wrench as a function of the force vector and the lever arm.*

The 3 situations represented in Fig. 1 show how the same force can provoke two torques or moments different in magnitude and even annul the same one. Although this principle is respected in all the exercises that we can program, each muscle involved in a movement and therefore that movement, can develop different moments depending on the biomechanics applied to it.

If we analyze the possible scenarios to improve or optimize the torque we find 3 possibilities:

a) increase inertial mass

b) optimize the radius of gyration
c) increase the angular acceleration

APPLICATION TO TRAINING

Without getting into physiological concepts in terms of sports performance, the increase in muscle mass carries with it an increase in muscle strength. Taking the example of the wrench and making a parallel to the hip joint (axis) and the gluteus (lever arm) the increase in muscle size will lengthen the lever, increasing the torque produced with the same force (fig. 2):

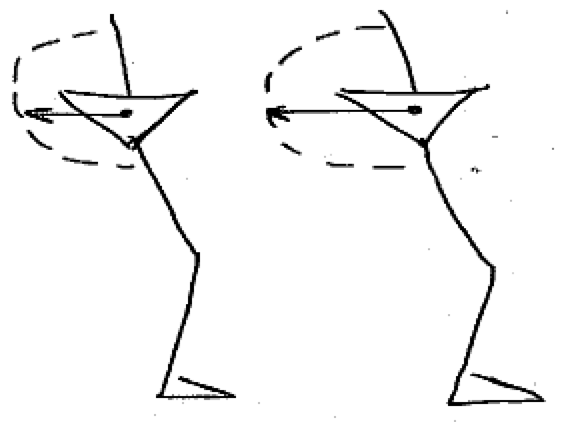

Fig. 2. *Diagram of the concept of torque or moment applied to the hip joint and the gluteus.*

In the wrench example, we saw that it is in the perpendicular where we find the radius of gyration with the major advantage to produce a greater torque with the same force; in case we want to generate the same torque with a greater angle of rotation, the only choice would be to produce more force. This translates into the so-called mechanical disadvantage, a point in the range of motion at which the greatest amount of force must be applied to sustain a given torque, which is limiting for isoinertial exercises (Frost et al., 2010), and therefore the same amount of force is not applied throughout the whole range of motion.

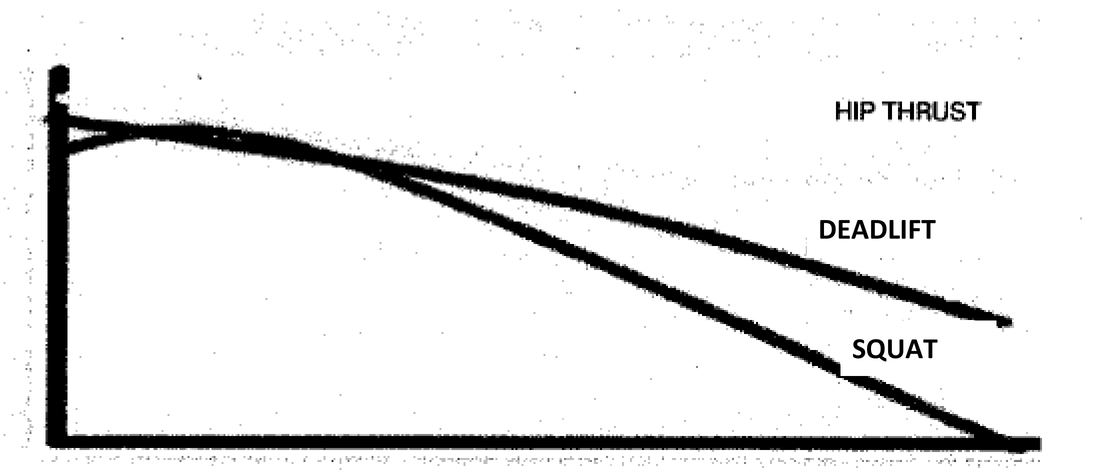

Fig. 3. *Momentum/angle curve for three hip extension exercises (Hip Thrust/yellow; Deadlift/green; Squat/red) with 245 kg load.*

In Fig. 3 we can observe that the yellow line (Hip Thrust) /maintains a higher torque during the whole movement and even increasing it in the last degrees of extension; on the contrary, the parallel squat presents a higher torque while the hip flexion is higher. As a practical implication, it would be necessary to analyze the type of torque the actions of the sport present in order to be able to match with the choice of exercises or to decide how to modify these curves.

A given exercise develops the force of a muscle at a specific point on the torque curve, which corresponds to the point at which the external torque curve of the exercise offers the greater challenge to that muscle's internal torque. If the sport requires strength and power at a different point in the joint range of motion of the selected training exercise, the result will be suboptimal (Contreras et al., 2013).

PRACTICAL APPLICATIONS IN TAEKWONDO

Although taekwondo is a martial art, more and more people are focusing on its sporting side. Therefore, from a sporting point of view, taekwondo is a contact sport where both fists and feet can be used. According to the rules, kicks to the torso are awarded 2 points, kicks to the face 3 and punches 1, being so that kicks represent between 70% and 80% of the actions of the fight (Serina and Lieu, 1991), and within them, the round kick is the most used (Kim, 2002; Zemper, 1994).

Kicks and punches in TKD are sequential actions because they are complex movements with several body segments (trunk, thigh, leg, arm, foot, hand) linked by different joint nucleus. In this sequence, the body segments involved acquire a high speed at its distal end (Gutierrez, 1999).

Joint		MT [N·m] Taekwondo n = 8
Elbow	F	57.5 ± 14.5
Joint	E	36.6 ± 8.6
Arm	F	50.5 ± 16.8
Joint	E	57.7 ± 18.3
Knee	F	115.1 ± 26.2
Joint	E	252.1 ± 73.8
Hip	F	98.5 ± 28.2
Joint	E	450.6 ± 142.1
Trunk	F	136.3 ± 35.8
	E	401.9 ± 136.0

Fig. 4. *Maximum torque generated in different joints in TKD practitioners. Note the fundamental role of hip extensors (Busko et al, 2013)*

These explosive actions demand high levels of strength and speed (Topal et al, 2011). Several authors have investigated the effects of TKD training on strength and power values (Casolino et al, 2012; Fong and Ng, 2011; Balsom et al, 1994; Baquet et al, 2001), however not many articles have been published in the opposite direction. Two relatively recent works (Haddad et al, 2009 y Topal et al, 2011) suggest emphasizing complementary strength training sessions in order to increase their strength, speed and power values mainly through the performance of specific exercises from a biomechanical point of view.

The role of the lower limbs is fundamental even in boxing, where it has been reported that more experienced boxers use 22,1% more lower limb contribution than novices (38,6% vs. 16,5%), which is related to the strength of the punch (Lenetsky et al, 2013). Filimonov et al even divided the sample according to fighting style (knockout punchers, sprinters and counterpunchers) finding the highest contribution of lower limbs in the group of knockout punchers. On the other hand, the hip joint is involved not only in the kicks but also in the displacements and in the blows with the hands (Lenetsky et al, 2013).

Although kinetics and kinematics of each action has a unique pattern, we can conclude that the horizontal displacement as well as the horizontal applied force against the ground play a fundamental role as well as the participation of the hip extension in these actions (Lenetsky et al, 2013; Chang et al, 2013; Gorski et al, 2014)).

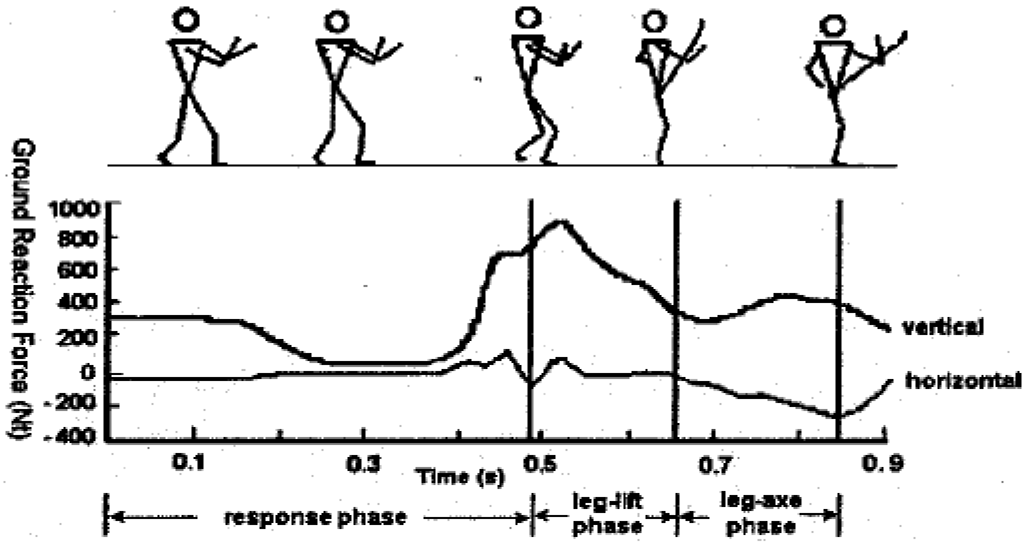

***Fig. 5. Ground reaction force** in a downward kick (Tsai and Hung, 2000). Even in predominantly upright kicks horizontal forces are important.*

Analyzing one of the most characteristic techniques of Taekwon-do, which stands out for being one of the kicks that generates more power, the *Yop Chagui* or side kick you can see a great contribution of the muscles of the hip, mainly the extensors (Gluteus) both in the leg that hits and in the standing leg, since in a large proportion of actions, the technique is performed with an approach to the opponent that requires horizontal displacement and therefore, an extension of the hip in both members.

In this kick, the extension of the hip is performed in the anteroposterior plane and against a horizontal force vector seeking to impact with the hip fully-extended, giving the leg a longer range of motion so that it reaches its maximum acceleration and therefore its maximum force at the moment of impact.

Fig. 6. *Application of the side kick in an ITF Taekwon-do Sparring competition.*

It is important to consider the hip joint not only in the lower body. Cheraghi et al. analyzed the kinetics of the straight punch in boxing by describing the biomechanics of both the arm and the lower limb (hip, knee and ankle).

Variable	Mean±SD	min to max
FistXDisplacement (m)	0.655±0.07	0.516 to 0.766
FistMaxV (m/s)	7.8±1.5	6.1 to 9.4
Fist Duration (s)	0.310±0.06	0.212 to 0.404
ElbowMaxV (m/s)	6.7±1.5	4.3 to 8.5
ShoulderMaxV (m/s)	3.1±0.6	2.1 to 3.8
HipXDisplacement (m)	0.278±0.06	0.196 to 0.348
HipMaxV (m/s)	1.6±0.2	1.1 to 1.8
FistYDisplacement (m)	0.125±0.06	0.019 to 0.179
FistZDisplacement (m)	0.056±0.05	-0.018 to 0.144
SelectiveDistance (m)	0.496±0.08	0.387 to 0.648

TABLE1. *Selected kinematic variables from the starting position to the moment of impact. Max: maximum; V: velocity; Anteroposterior direction; Y: vertical direction; Z: medial-lateral direction; Selective distance: perpendicular distance between the front foot and the target. (Cheragui et al., 2014).*

Variable	Mean±SD	min to max
Shoulder		
OnsetAngle (°)	20±4	14 to 28
ImpactAngle (°)	86±5	81 to 93
MaxAngle (°)	90±5	84 to 100
MaxAngleTime (s)	0.002±0.01	0.020 to 0.008
Hip		
OnsetAngle (°)	203±3	200 to 209
MinAngle (°)	195±6	188 to 205
ImpactAngle (°)	196±7	188 to 208
MaxωAngle (°)	209±4	203 to 217
Maxω (°/s)	103±50	50 to 185
MaxωTime (s)	0.148±0.04	0.220 to -0.084
MaxAngle (°)	211±4	205 to 219
MaxAngleTime (s)	0.109±0.03	0.148 to -0.060
EccAngleDisplacement (°)	9±4	4 to 15
ConDuration (s)	0.153±0.12	0.084 to 0.448
ConAngleDisplacement (°)	17±5	10 to 27

TABLE2. *Angular kinematics of the shoulders and hip from the stop position to the moment of impact. Min: Minimum; Max: Maximum; ω: Angular velocity; Ecc: Eccentric phase; Con: Concentric phase (Cheragui et al., 2014).*

As main conclusions they found that the contribution of the lower body, supporting the study of Filimonov, is fundamental to generate force in the blow; that the change of weight in the anteroposterior direction is generated by the movement of the hip (28 cm of displacement) and that the hip joint both at the beginning and at the end of the blow moves in wide angles (188-208 degrees), with an average displacement of 26 degrees (eccentric-concentric) and at the moment of the fist impact it occurs at 196 degrees of hip extension (average value). The leg movement generates momentum in the kinematic chain of blow developing a higher speed in the fist; for all this the author concludes the indispensable role of specific training of lower body.

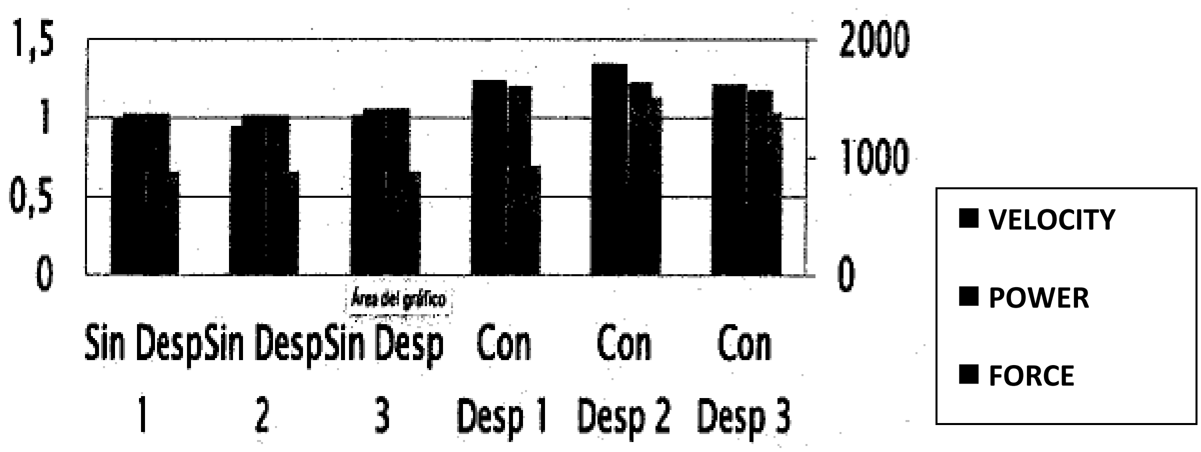

Fig 7. Force, Velocity and Power values *of 3 circular kicks with and without displacement (Carbone, 2014, unpublished data). The displacement of center of mass raises the kinetic variables of the kicks.*

For all the above, if the sport requires actions such as fast horizontal displacements, as in the case of ITF Taekwon-do, the selection of exercises should be manipulated to adapt the internal torque curve to the external torque curve of the activity. Such actions (explosive horizontal displacements) require high levels of power and strength in hip extension but in most open angles, including 180 degrees and more (hyperextension), therefore if we only use the squat, which develops strength in the highest angles of flexion, it would produce a sub-optimal development of strength in the range of motion required by the sport. The use of elastic bands or chains could be a way to manipulate the exercise to modify the external torque (Frosty and col., 2010), or the choice of exercises with an external torque at specific angles as the Hip Thrust might be a more advisable option considering the influence of different force vectors on the specificity of training (Contreras, 2012).

Fig 8: Hip Thrust *starting and ending position.*

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