Int. J. Morphol.,
40(2):334-338, 2022.

Rate of Force Development and Stretch-Shortening Cycle in Different Jumps in the Elite Volleyball Players

Tasa de Desarrollo de Fuerza y Ciclo de Estiramiento-Acortamiento en Diferentes Saltos en Jugadores de Voleibol de Élite

Kosta Goranovic[1]; Jovica Petkovic[1]; Rasid Hadzic[1] & Marko Joksimovic[2]

GORANOVIC, K.; PETKOVIC, J.; HADZIC, R. & JOKSIMOVIC, M. Rate of force development and stretch-shortening cycle in different jumps in the elite volleyball players. *Int. J. Morphol., 40(2)*:334-338, 2022.

SUMMARY: As it is currently played, volleyball is a game in which success depends in large measure on the athleticism of the participants. The aim of this research was to point out the importance of the cycle of stretching and shortening in different jumps for elite volleyball players. Thus, it is common for volleyball athletes to place considerable emphasis on jump training. Not surprisingly, overload injuries of the knee and ankle joints, both acute and chronic, occur frequently among volleyball players and are related to the volume of jump training and skill repetition. Understanding the biomechanics of jumping is therefore a prerequisite for designing effective training programs which minimize the risk of overuse injuries that may result from excessive jumping, and the repetitive mechanical loading of muscles and joints that are involved in jump training Muscles acting about a joint function naturally through a combination of eccentric (lengthening) and concentric (shortening) activations. In the lower limb, the stretch-shortening cycle is a reflex arc in which the tendomuscular system acting about the knee or ankle is eccentrically preloaded (stretched) in the loading or impact phase of the jump before concentrically shortening in the push-off or take-off phase.

KEY WORDS: Explosive movement; Ground reaction force; Muscular preactivation.

INTRODUCTION

Volleyball is one of the most popular team sports in the world. The game is characterized by short, explosive movement patterns, quick, agile positioning, jumps, and blocks. Although a match may last for up to 3 hours, volleyball is considered an anaerobic sport, with metabolic demands met mainly by phosphagen energy processes (Sattler *et al*., 2012). In volleyball, a player's maximal height above the net is a key determinant for successful attacking and blocking, and thus, for performance. The critical factors for this maximal height are anthropometric characteristics (body height and arm length) and vertical jumping ability. While the former cannot be modified, an athlete's jumping ability can be significantly improved through training. Volleyball coaches, therefore, seek for the most effective and most efficient exercises to improve their players' jumping ability (Ruffieux *et al*., 2020).

The most common jump types in volleyball, i.e., for attacking and for blocking, can be classified as countermovement jumps. More precisely, the block jump often resembles a "shortened version" of a countermovement jumps due to time constraints, which prevent the players from performing a classic countermovement jumps. The attack jump on the other hand, which is performed with a run-up, can be regarded as a combination of a drop jump and a countermovement jumps (Sattler *et al*.). Countermovement jumps and drop jumps are stretch-shortening cycle (SSC) movements, which involve a high-intensity eccentric contraction immediately before a rapid concentric contraction (Van Hooren & Zolotarjova, 2017). Thus, in order to maximize performance in these jumps, it is important to quickly switch from yielding work to overcoming work and to rapidly develop maximal forces during the concentric phase (Bobbert, 1990).

Rate of force development (RFD) is a basic measure of explosive force, i.e. the ability of an athlete to develop maximum force as quickly as possible. The better the athlete

[1] University of Montenegro, Faculty of Sports and Physical Education, Montenegro.
[2] Institute of Sports and Sports Medicine, Montenegro.

Received: 2021-12-12 Accepted: 2022-01-18

is in terms of strength development, the more strength he can develop in a shorter time interval. The time interval of the rate of force development is the most common and most reliable form of explosive force estimation (Ranisavljev & Stefanovic´, 2020). Depending on the duration of SSC in the realization of movement, exercises can be divided into slow cycle exercises (≥250 ms) and fast cycle exercises (≤250 ms) (Tuner & Jeffreys, 2010). Different movements that require the manifestation of explosive force have different durations, so the SSC in countermovement jump is about 500 ms. Movements characterized by higher amplitudes (countermovement jump) most often belong to the slow SSC movements, while movements of lower amplitudes are most often focused on the fast cycle (sprint, drop jump) (Ball *et al*., 2010). In slow cycle movements where the speed of movement is lower, there is a longer time for force development than in fast cycle movements. It is for this reason that higher force is manifested in slow cycle movements, but the rate of force development is lower than in fast cycle movements (Kawamori *et al*., 2006). The aim of this paper is to point out the importance of SSC in different jumps in elite volleyball players.

Rate of force development. Maximal strength is a vital component in producing the high levels of force needed in sport. However, the time required to complete many sport specific skills is shorter than that needed to express maximal strength. More specifically, a minimum window of approximately 300 milliseconds is necessary to produce maximal muscle force; however, force application during skills such as sprinting, jumping, throwing, and kicking lasts approximately 30–200 milliseconds. Accordingly, the rate at which force is developed within those short periods dictates the gross amount of force applied during the skill. As previously noted, a greater force applied over a given period creates a greater impulse, thus facilitating greater momentum and, subsequently, a higher power output. Interestingly enough, muscular power has been repeatedly shown to be a differentiating factor in athletic success. Although many studies have attributed improvements in performance to enhanced power production, it may be more accurate to ascribe this development to greater RFD, as it can be viewed as the underpinning mechanism in producing greater power outputs (Taber *et al*., 2016). Therefore, as noted by Stone *et al*. (2002) RFD is perhaps the most central factor to sport success across a wide spectrum of events.

Stretch-shortening cycle. The stretch-shortening cycle (SSC) is a common phenomenon in many naturally occurring movements and has long been identified as a performance-enhancing mechanism. It is defined as the rapid stretching of a pre-activated muscle prior to shortening of that same muscle. This speed aspect is important because the time for muscles to produce high forces during SSCs in vivo is often limited and would require muscles to shorten at very high velocities, impeding their capacity to produce high forces. To cope with this, the muscles rely on tendons to store elastic energy, extending the time available for active muscle contractions, allowing the muscle to shorten at lower velocities, which forms a large component of the performance enhancement from a SSC (Aeles & Vanwanseele, 2019).

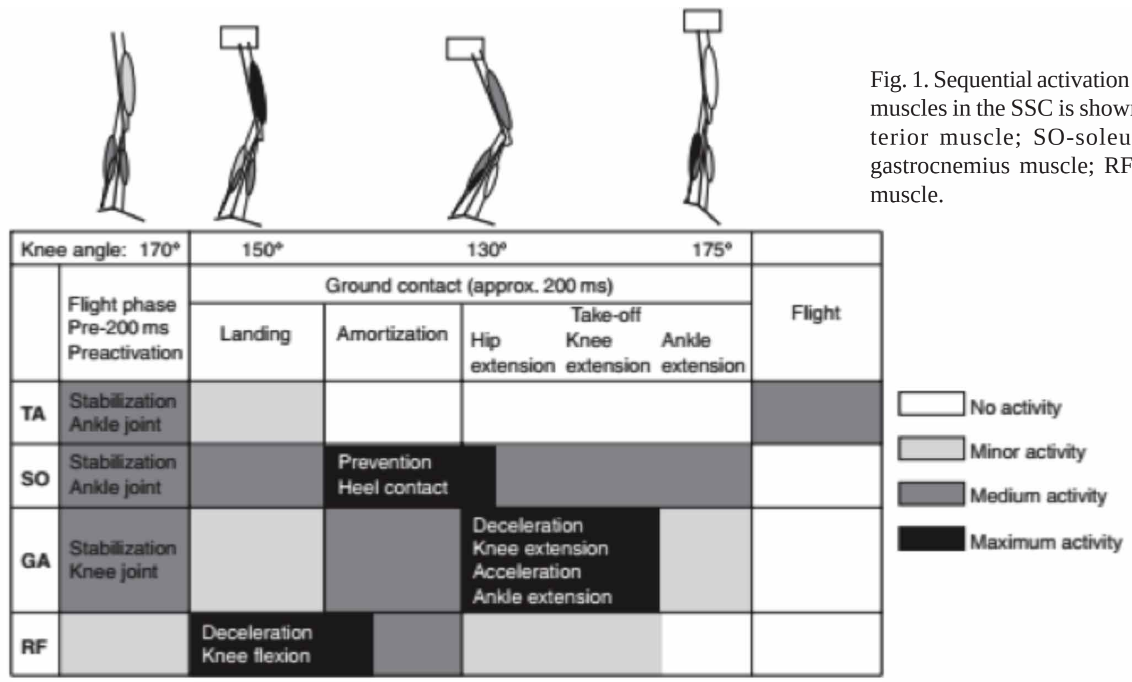

Fig. 1. Sequential activation of the lower limb muscles in the SSC is shown. TA-tibialis anterior muscle; SO-soleus muscle; GA-gastrocnemius muscle; RF- rectus femoris muscle.

All jumps associated with the basic volleyball skills of spiking, blocking, and (jump) serving are characterized by the same general pattern of muscular activation. The concentric action of muscles functioning during the push-off phase is prepared by a preceding eccentric action that occurs during the loading phase. Furthermore, for skills such as the spike in which the athlete follows a more-or-less programed approach to the ball, the extensor muscles are activated in preparation for the loading phase, thereby stiffening the joints of the lower limbs in anticipation of ground contact. Following ground contact, the body's center of mass is stabilized and decelerated on its downward movement in the vertical plane. A powerful push off is possible only if the transition phase between eccentric preloading and reflex concentric activation is short and the angular displacement of the knee and ankle joints is small. In Figure 1 sequential activation of the lower extremity muscles in the SSC is shown.

In Figure 2 is demonstration of the importance of the short coupling time between eccentric and concentric phases for performance potentiation in the concentric phase of SSC. (a) Longer delay (0.9s) was allowed between the eccentric and concentric phases. The potentiation effect on the concentric phase was reduced. (b) Concentric action is preceded by eccentric (-) action, but no delay is allowed when contraction type is changed from stretch to shortening. The eccentric (stretch) phase begins in the middle of the movement from the 175° (knee in an extended position) to the 90° position. Note the clear force potentiation in the concentric phase (+) compared with the condition on the right. (c) Pure concentric contraction of the knee extension from 100° to 175° (Komi, 1993).

Concentric potentiation occurs only if the transition is fast, or "reactive." If the transition is slower or delayed, no enhancement of the concentric phase occurs. There are three different forms of jumping that have been well investigated biomechanically: the drop jump, the squat jump, and the countermovement jump (Gollhofer & Rapp, 1993). The drop jump, in which the athlete drops from a height and quickly rebounds into the air, is performed most commonly during jump training, but also characterizes the quick repetitive block jumps often required of the middle blocker. The drop jump is considered a reactive jump, with tightly coupled eccentric and concentric phases. Squat jumps are typically performed by blockers, who must react quickly to the opponent's attack. Little preload is possible for this type of jump, in which the athlete remains in a crouched position before jumping. The countermovement jump is typified by the classic spike jump, in which the athlete completes his or her approach with a final closing step, then eccentrically loads the quadriceps and calves by flexing at the hips, knees, and ankles before pushing off with a concentric activation of those muscle groups. The countermovement jump is a slower, non-reactive jump with little potentiation of the concentric phase (Reeser & Bahr, 2003).

During a drop jump, the ground reaction force (GRF) rises in proportion to the drop height. Not only does the load/ GRF increase with greater drop height, but the athlete's heels also increasingly contact the ground when attempting to rebound rapidly into the take-off phase of the jump. This is exemplified by the shape of the force curve, which changes markedly with varying drop height: the higher the load, the more the maximum force peaks, indicating greater heel strike on the force plate (Fig. 3). Conversely, from a lower drop

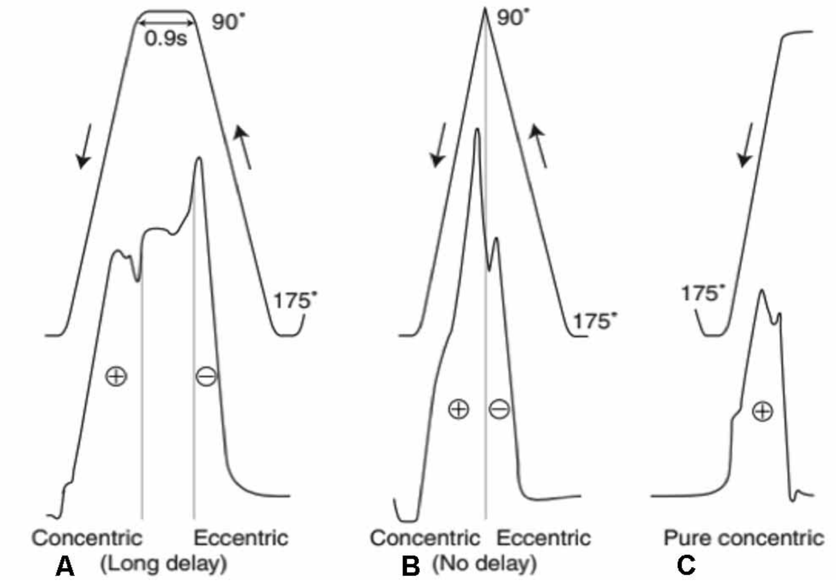

Fig. 2. Importance of rapid coupling between the eccentric and concentric phases of the jump.

height the athlete is able to perform the drop jump only on the forefoot without their heels touching down. With higher loads the time of ground contact (heel strike) increases, and consequently an increasing amount of energy is dissipated. The energy lost through heel strike can be compensated for only by greater concentric phase muscular activation during push off. Increasing heel contact with the floor also results in a progressively passive landing. Rather than absorbing the GRF of landing primarily through eccentric loading of the musculature, more force is transmitted to the bony structures of the lower extremity, potentially increasing the athlete's risk for lower limb injury (Reeser & Bahr).

As discussed, in a drop jump (or in the final closing step of a spike approach), some of the lower extremity muscles are activated before ground contact in order to stiffen the joints in preparation for touch down. Neither the timing nor the duration of preactivation is greatly affected by the loading height (Fig. 4). Therefore, preactivation depends very little on the loading condition or type of jump performed. Preactivation seems to represent a preprogramed muscular activation functionally necessary for preparation of the landing. As already mentioned, preactivation is also essential for energy potentiation and thus is an important element of a powerful push off. Comparing the activation patterns of selected muscles acting about the ankle and knee joints during different jumping conditions, it is clear that a remarkable amount of muscular preactivation occurs before ground contact (Reeser & Bahr).

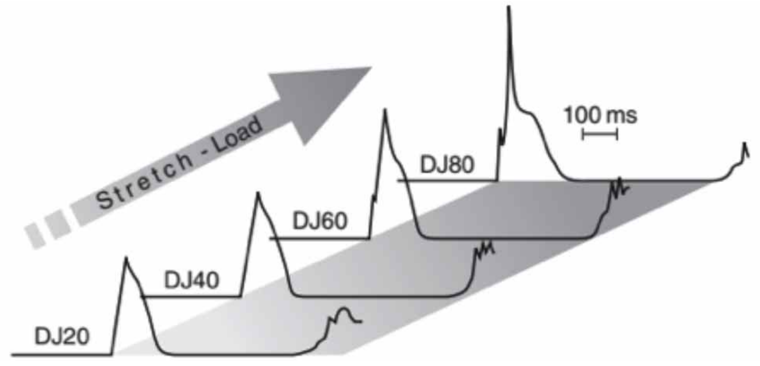

Fig. 3. Drop jump of different falling heights (20-80cm).

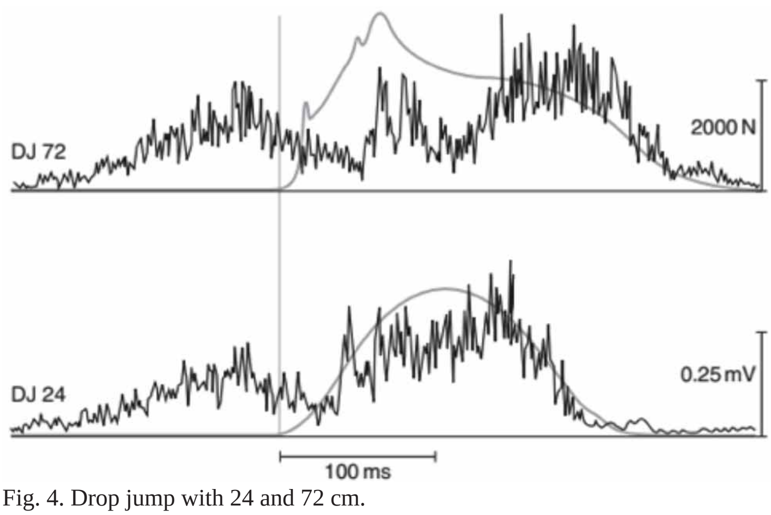

Fig. 4. Drop jump with 24 and 72 cm.

CONCLUSION

The different types of volleyball jumps can be separated into two groups on the basis of ground contact time. A drop jump from low height in which no heel contact occurs results in a fast, reactive form of SSC. A countermovement jump, such as a spike jump, results in a slow, non-reactive type of SSC. The power output during the concentric phase in the SSC and thereby the performance of jumping is largely dependent on the load accepted during the eccentric phase. With higher loading, the ground contact time is prolonged and thus the whole SSC lasts longer. Since energy potentiation is basically related to the short range elastic stiffness due to the formed muscle cross-bridges, such a reactive movement is possible only if the ground contact time does not exceed approximately 200ms. If ground contact is prolonged because of higher loading during the eccentric phase, a fast reactive reversal of the movement is not possible, and the coupling of the movement is divided up into an isolated eccentric landing and a concentric countermovement-like take off. The energy of the eccentric phase cannot be used for the concentric push off, and must be absorbed. Energy absorption is facilitated by strong eccentric muscle contraction. However, if the initial load is too great, the additional GRF is transmitted to bony and ligamentous structures. Proprioceptive training may enhance joint stiffness, thereby reducing the athlete's risk of overload injuries. Repeated energy absorption by passive structures increases the risk of overload injury. At the same time, jumping performance decreases, because energy potentiation and thus fast, reactive movement is impossible. The amount of loading within the SSC that can be tolerated by the athlete during the eccentric phase is dependent on the athlete's individual motor performance. Tolerance against eccentric loading allows energy potentiation in a fast, reactive movement reversal in order to perform a powerful concentric push off.

GORANOVIC, K.; PETKOVIC, J.; HADZIC, R. & JOKSIMOVIC, M. Tasa de desarrollo de fuerza y ciclo de estiramiento-acortamiento en diferentes saltos en jugadores de voleibol de élite. *Int. J. Morphol., 40(2)*:334-338, 2022.

RESUMEN: Actualmente, el voleibol es un juego en el que el éxito depende en gran medida del atletismo de los participantes. El objetivo de esta investigación fue señalar la importancia del ciclo de estiramiento y acortamiento en diferentes saltos para jugadores de voleibol de élite. Es común que los atletas de voleibol pongan un énfasis considerable en el entrenamiento de salto. No es sorprendente que las lesiones por sobrecarga de las articulaciones de la rodilla y el tobillo, tanto agudas como crónicas, ocurran con frecuencia entre los jugadores de voleibol y estén relacionadas con el volumen de entrenamiento de saltos y la repetición de destrezas. Comprender la biomecánica del salto es, por lo tanto, un requisito previo para diseñar programas de entrenamiento efectivos que minimicen el riesgo de lesiones por uso excesivo que pueden resultar de un salto excesivo y la carga mecánica repetitiva de los músculos y las articulaciones que están involucrados en el entrenamiento del salto. Los músculos que actúan sobre una articulación funcionan de forma natural a través de una combinación de activaciones excéntricas (alargamiento) y concéntricas (acortamiento). En el miembro inferior, el ciclo de estiramiento-acortamiento es un arco reflejo en el que el sistema tendomuscular que actúa sobre la rodilla o el tobillo se precarga (estira) excéntricamente en la fase de carga o impacto del salto antes de acortarse concéntricamente en el despegue o toma. -fase de apagado.

PALABRAS CLAVE: Movimiento explosivo; Fuerza de reacción del suelo; Preactivación muscular

REFERENCES

Aeles, J. & Vanwanseele, B. Do stretch-shortening cycles really occur in the medial gastrocnemius? A detailed bilateral analysis of the muscle-tendon interaction during jumping. *Front. Physiol., 10*:1504, 2019.

Ball, N. B.; Stock, C. G. & Scurr, J. C. Bilateral contact ground reaction forces and contact times during plyometric drop jumping. *J. Strength. Cond. Res., 24(10)*:2762-9, 2010.

Bobbert, M. F. Drop jumping as a training method for jumping ability. *Sports Med., 9(1)*:7-22, 1990.

Gollhofer, A. & Rapp, W. Recovery of stretch reflex responses following mechanical stimulation. *Eur. J. Appl. Physiol. Occup. Physiol., 66(5)*:415-20, 1993.

Kawamori, N.; Rossi, S. J.; Justice, B. D.; Haff, E. E.; Pistilli, E. E.; O'Bryant, H. S.: Stone, M. H. & Haff. G. G. Peak force and rate of force development during isometric and dynamic mid-thigh clean pulls performed at various intensities. *J. Strength Cond. Res., 20(3)*:483-91, 2006.

Komi, P. V. *Elastic Potentiation of Muscle and its Influence on Sport Performance*. In: Baumann, W. (Ed.) Biomechanics and Performance in Sport. Schorndorf, Karl Hoffmann Verlag, 1993. pp.59-70.

Ranisavljev, I. & Stefanovic, D. *Theory and Technology of Fitness Training.* Belgrade, University of Belgrade, Faculty of Sports and Physical Education, 2020.

Reeser, J. C. & Bahr, R. *Handbook of Sports Medicine and Science*. Volleyball. Oxford, Blackwell Science, 2003.

Ruffieux, J.; Wälchli, M.; Kim, K. M. & Taube, W. Countermovement jump training is more effective than drop jump training in enhancing jump height in non-professional female volleyball players. *Front. Physiol., 11*:231, 2020.

Sattler, T.; Sekulic, D.; Hadzic, V.; Uljevic, O. & Dervisevic, E. Vertical jumping tests in volleyball: reliability, validity, and playing-position specifics. *J. Strength Cond. Res., 26(6)*:1532-8, 2012.

Stone, M. H.; Moir, G.; Glaister, M. & Sanders, R. How much strength is necessary? *Phys. Ther. Sport, 3(2)*:88-96, 2002.

Taber, C.; Bellon, C.; Abbott, H. & Bingham, G. Roles of maximal strength and rate of force development in maximizing muscular power. *Strength Cond. J., 38(1)*:71-8, 2016.

Tuner, A. & Jeffreys, I. The stretch-shortening cycle: proposed mechanisms and methods for enhacement. *Strength Cond. J., 32(4)*:87-99, 2010.

Van Hooren, B. & Zolotarjova, J. The difference between countermovement and squat jump performances: a review of underlying mechanisms with practical applications. *J. Strength Cond. Res., 31(7)*:2011-20, 2017.

Corresponding author:
Marko Joksimovic
Institute of Sports and Sports Medicine
Savska 5
Podgorica, 81000
MONTENEGRO

E-mail: nicifor007@outlook.com