Chapter 2

REVIEW OF LITERATURE

The first part of this chapter will review the characteristics of stretch-shortening cycle movement and repetitive jumping ability as a SSC type of movement since the repetitive speed vertical jumping is basically a SSC movement in nature. This is followed by a review on the definitions and assessments of power, speed and reactive strength. This is because one of the main purposes of this study is to validate the Speed Jump Test through the study of the correlation between the measured speed jumping ability and the measurement generated in the assessment of leg power, leg speed and reactive strength.

2.1 Stretch-shortening Cycle and Repetitive Speed Jump

Generally, muscular contraction can be divided into two types based on the nature of the contraction. An isometric contraction refers to the type of muscular contraction where the length of the muscle remains unchanged when tension is being developed. Isotonic contraction, on the other hand refers to the type of contraction where the length of the muscle changes during tension development. The isotonic contraction can be further divided into concentric and eccentric contraction. The concentric contraction is the type of contraction where the muscle shortens during tension development whereas eccentric contraction refers to the contraction where the muscle lengthens during tension development.

However, human movement repertoire seldom involves pure forms of isolated isometric, concentric or eccentric actions. Rather, the natural form of muscle function during movement is normally a combination of eccentric and concentric actions called the stretch-shortening cycle (SSC). This is because the body segments are periodically subjected to impact forces, such as during running or jumping or because force such as gravity acts by lengthening the muscle. In these phases, the muscle is contracting eccentrically (Schmidtbleicher, 1992). By definition of eccentric contraction, the muscles must be active during the stretching phase. This eccentric contraction is quickly followed by a concentric contraction. The transition phase in between the eccentric and concentric phase is the amortization phase.

The main focus of this study, the repetitive vertical jumping to a sub-maximal height is a type of SSC movement. This is because during landing, the major leg extensor muscles such as the triceps surae muscles and quadriceps will be stretched and undergo eccentric braking action before contracting concentrically. The characteristic of this type of SSC movement where speed or quickness is of major concern however, is unable to be explained in this review. This is because most of the study on SSC movement, such as those in the drop jump and counter movement jump, focused on the goal of attaining maximal height during rebound or reactive jump. Therefore, it is of major interests of this study too to investigate these different types of SSC movements where each has a different goal, to attain maximal reactive jumping height and to attain maximal reactive jumping speed.

2.2 Characteristics of Stretch-shortening Cycle Activities

As explained, an SSC movement is a unique type of contraction where the muscles involved are being stretched before they shorten. The stretch component of the muscles refers to the eccentric contraction, whereas the shortening component refers to the concentric contraction.

Many studies had investigated the effects of SSC on force production. Exercises that utilize SSC were compared to isolated concentric exercises. Asmussen and Bonde-Petersen (1974) investigated vertical jumps from five different starting positions. The first type of vertical jump was a squat jump (SJ) where the subjects started in a squatting position with a 90 degrees bend in the knees. The second vertical jump was a counter-movement jump (CMJ) where the subjects started from an erect standing position. They then performed an eccentric action at the hip and knees prior to a maximal vertical jump. The other three jump conditions were drop jumps (DJ) from three different standing heights of 0.233m, 0.404m and 0.690m. Their results indicated that both the CMJ and DJ resulted in an increase in vertical jump height. All the three DJ conditions showed an increase in vertical jump height as compared to the CMJ with the optimal dropping height of 0.404m.

Komi and Bosco (1978) studied the SSC by comparing three different vertical jumps. The first and second types of vertical jumps were the same as the SJ and CMJ as described previously in Asmussen and Bonde-Petersen (1974). The third type of vertical jump is the drop jump performed by dropping from boxes of different heights ranging from 20 to 100cm. They reported that SJ was significantly

lower in height of rise of the center of gravity and energy levels as compared to both the CMJ and DJ but no significant difference were observed between CMJ and DJ.

Bosco, Tarkka and Komi (1982) studied two different types of vertical jumps where subjects were required to perform a maximal plantar flexion movement with and without a preceding dorsiflexion movement. The vertical jump without countermovement represented the squat jump whereas the vertical jump with countermovement represented the countermovement jump. In order to ensure that all the movements were executed by the calf muscles through the ankle joint, the subjects were required to wear an orthopedic cast covering their hips and knees. They reported that both the height of rise of the center of gravity and the average force production were higher in countermovement jump than in the squat jump. The integrated electromyography (IEMG) activity patterns were the same in both jump conditions, indicated that the improvement in performance was due to the recoil of elastic energy.

Though the SSC has been universally accepted to enhance force production, the mechanisms that underlying the performance increment are however, often disputed. Scientists such as Komi, Bosco, Gollholfer and Schmidtbleicher and in fact most of the exercise scientists and coaches attributed the greater performance in SSC movement to elastic energy and increased muscle activation due to the well known stretch reflex mechanism.

Nevertheless, recent research findings by biomechanists such as Bobbert, Van Ingen Schenau, Walshe, Wilson and Ettema suggested that the performance enhancement seen in CMJ as compared to SJ is mainly due to the fact that

countermovement allows the extensor muscles to build up a higher active state and force level prior to shortening. While in SJ, the shortening starts as soon as the level of muscle stimulation is increased above the level that required for maintenance of the starting position and consequently less force and thus less work is produced over the first part of the shortening distance (Bobbert, Gerritsen and Litjens, 1996; Van Ingen Schenau, Bobbert and De Haan, 1997; Walshe, Wilson and Ettema, 1998). In addition, Bobbert (1996) disputed the explanation with regard to the storage and reutilization of elastic energy as the mechanism underlying SSC by arguing that an increase in the amount of elastic energy stored at the start of the concentric phase merely reduces the amount of the energy to be produced by the contractile elements if the concentric angular displacement is the same, reason being the lengthening of the series elastic elements will occur at the expense of the length over which the contractile elements can perform work. Therefore, the stored elastic energy may increases the efficiency of doing positive work but not the total amount of positive work that can be produced.

Schmidtbleicher (1992) categorized SSC movements into two categories based on the duration of the ground contact time, that of a long and a short SSC. Long SSC is characterized by a ground contact time of more than 250ms and large angular displacements in the hip, knee and ankle joints, such as those during countermovement jump and volleyball block jump. Short SSC, on the other hand, is characterized by a ground contact time that lasts 100ms-250ms and small angular displacement in the above cited joints. Examples of short SSC that are normally seen in sports are take-off in high and long jumping.

2.2.1 Stretch-shortening Cycle and Sprint Running Performances

Sprint running is generally divided into three phases, the acceleration phase, the constant velocity phase and the deceleration phase (Mero, Komi and Gregor, 1992; Moravec et al., 1988; Mero, Luhtanen, Viitasalo and Komi, 1981). During the constant velocity phase, maximal velocity is achieved and the additional power to maintain the velocity comes from the elastic component of the muscles (Cavagna, Komarek and Mazzoleni, 1971). They suggested that a sprint runner uses the work absorbed in his leg muscles at high speed during the eccentric phase to release further positive work and thus increase power output. In addition, Farley and Gonzalez (1996) reported that the body's spring systems accommodate to higher stride frequencies by adjusting the leg spring to become stiffer. This is because a stiffer leg spring will enable a runner to bounce more quickly and stiffly and therefore, will be able to transmit the work absorb during the eccentric phase to concentric phase at a faster rate.

2.2.2 Stretch-shortening Cycle and Jumping Performances

The role of SSC in augmenting various vertical jump performances has been studied and proven extensively (Anderson and Pandy, 1993; Asmussen and Bonde-Petersen, 1974; Bobbert et al., 1996; Komi and Bosco, 1978). Bosco et al., 1983 revealed that subjects rich in fast-twitch fibers in their vastus lateralis muscles are able to benefit more from SSC with high speed stretching phase and short knee angle displacement which will result in greater storage of elastic energy whereas subjects rich in slow-twitch fibers are able to benefit more from a large amplitude SSC where the transient period stretch and shortening is long. They suggested that fast twitch and slow twitch fibers are characterized by different viscoelastic properties that allow them to benefit differently from SSC. They then interpreted the

results as showing possible differences in sarcomere cross-bridge lifetimes between the fast twitch and slow-twitch fibers. Fast-twitch fibers have been shown to possess a fast cross-bridge cycle (Lannergren, 1976) and they even consider that the cross-bridges in fast-twitch fibers of an active muscle may be detached during long stretching phase and lost their elastic potential.

2.2 Power

In many sporting activities, time is always an important factor in determining winner and loser. There are many situations in which athletes are required to generate force or exert muscular effort in a short period of time, such as during jumping, running, throwing, striking and so on. The ability of an athlete to meet such demands requires the athlete to develop force and supply energy in a limited amount of time. At the cellular level, it depends on the athlete's body to supply adenosine triphosphate (ATP), a chemical which is the source of energy in muscular contraction.

The force-velocity relationship states that the force exerted by a muscle is greater when the contraction time is longer, since time is required to supply ATP to the muscles and thereby to create tension by the muscle's contractile components. Power has thus emerged as an important component in training and attracted much attention from researchers and practitioners in the field of sport and exercise science. Power is defined as the ability to generate as much force in the shortest time possible or simply the rate of doing work. Power as the rate of doing work can be expressed in the formula as follows:

Power = Work/time - *equation 2.1*

Since mechanical work performed is also equivalent to the product of force applied multiply by the corresponding distance moved in the direction where the force is being applied. The formula of power can also be written as:

Power = Force x Displacement / Time - *equation 2.2*

If we study from other perspective, we will find out that the distance moved (displacement) divided by movement time (Time) is actually equivalent to velocity of movement. Therefore, power can also be written as:

Power = Force x Velocity - *equation 2.3*

This is perhaps a more popular equation to most of the practitioners in the field of sport and exercise science that define power as the velocity at which a force is being applied. Internationally, the metric unit of power is Watt (w), which is equivalent to one joule/second. Some researchers discussed power relative to body mass and expressed power in Watts per Kilogram of body mass.

As a rule of thumb, the distance at which a force is being applied will always be limited by a person's size, shape and length of the limbs and is believed to be always constant. Hence, force and time are two main components that are often considered as the more significant determining factors of power. Force refers to the maximum tension that can be generated by an athlete, which is exhibited by the strength level of the athlete. Time on the other hand, refers to the time needed to

generate maximum tension, which is exhibited by the velocity of tension generation. For example, powerlifting is a sport that requires power performance at the force extreme whereas smashing in badminton is an example that requires power performance at the velocity extreme.

2.3.1 Power Assessment

Power can be assessed in many ways. From the most basic vertical jump field test that uses only chalk and measuring tape to sophisticated biomechanical and physiological laboratory equipments such as force platform, contact mat, isokinetic machine, cycle ergometer and treadmill. Among the tests that have been developed and claimed popularity in power assessment are Margaria Staircase Test, 30 seconds Wingate Anaerobic Test, Maximal Isokinetic Test and various Bosco Tests that used contact mat to measure power.

However, based on several studies conducted in their laboratory, Mayhew et al. (1994) concluded that there are no universally accepted power tests that can be interchanged. The selection of any power test should be based on the appropriateness and specificity in the performance of that particular sports. In this study, we used maximal countermovement vertical jump as our standard leg power assessment tool since it provides appropriateness and specificity in terms of energy supply and nature of movements performed including jumping movement, stretch-shortening cycle, muscles involved and arms movements. Arm movements and a countermovement are used, in this test to mimic the performance of the repetitive speed jump test which has used both arm movements and countermovement to provide resemblances during match sports specific activities.

2.3.2 Vertical Jump Test

The vertical jump test today has a research history beginning in 1921 with the development of the Sargent's Jump Test. Since the introduction of the Sargent's Jump Test, many variations have been applied to the test including uses of arms, a run or step and countermovement. Many scientists today use equipment such as video systems, contact mats or force platforms to measure vertical jump height and as an attempt to obtain a higher accuracy measurement and more information about the movement.

The Sargent's Jump Test basically involves measuring the difference between a person's standing reach and the maximal achievable height. The distance measured is the vertical jump height and is believed to be a reflective measure of the person's ability to apply maximum amount of muscle force in the shortest amount of time without a significant contribution from the aerobic energy sources (Semenick, 1990). The measured distance is then used to calculate the mechanical work performed by the subject using the following equation:

$$\text{Work (Joules)} = mgh \qquad - \qquad \textit{equation 2.4}$$

Where:

m = body weight of subject in kilograms (kg)
h = jump height reach – standing reach of a subject (m)
g = gravity ($9.8 m/s^2$)

This formula does not allow the calculation of power since there is no accurate measurement of the time duration of force exertion to produce the vertical jump.

Three power prediction equations have then been developed to estimate power output from the vertical jump test. The first and the most popular equation is the Lewis Formula. It was first introduced by Fox and Matthew (1974) and is written as:

$$\text{Power} = \sqrt{4.9} \times \text{Body Mass} \times \sqrt{VJ} \qquad - \qquad \textit{equation 2.5}$$

Where:

Power = Vertical jump power (kgm/sec)
Body Mass = body weight of subject (kg)
VJ = vertical jump height in meters (m)

The Lewis formula assumes that work done during the jump equals to the work done in lifting a body mass to a height equals to the jump height and the time factor to determine power is set equal to the time it would take a point mass to fall from rest a distance equal to the jump height (Garhammer, 1993).

Despite its popularity, the Lewis formula has never been validated and supported by published research. Harman et al., (1991) disputed the validity of the Lewis formula by arguing that the power calculated through the Lewis formula is that exerted by gravity on a body as it falls back to the ground from the highest point of the jump. Besides, the Lewis formula has never indicated whether peak or average power is being estimated. Garhammer (1993) also disputed the validity of the Lewis formula because one of the assumptions of the Lewis formula which assumes the time factor is equal to the time necessary for a specific mass to fall from rest for a distance equal to the jump height, does not actually relate to the actual

propulsion time to generate the take-off velocity, which is the determinant of the vertical jump height. In other words, a more massive person and a higher jump will result in a greater calculated work. However, a higher jump as compared to a lower jump will result in a greater time factor which will subsequently reduce the calculated power, as oppose to what should occur. Despite the weaknesses, Garhammer (1993) suggested that it might still be possible to use the Lewis formula to differentiate between higher and lower power output among a group of subjects.

Using 17 male subjects, Harman et al. (1991) compared the power output derived from the Lewis formula to the peak and average power output generated by a computer-interfaced force plate. They found that the power output derived from the Lewis formula has low standard deviation, which further suggested the formula minimizes individual differences. The Lewis formula was also found to underestimate peak and average power output by 70.1 $\pm$ 3.5 percent and 12.4 $\pm$ 18 percent respectively. Two regression-derived equations that better estimate peak and average power output and more closely reflect actual inter-subject variability have been developed then. The two formulas can be written as:

$$P_p = 61.9\ (VJH) + 36.0\ (BM) + 1{,}822 \qquad \text{-} \qquad \textit{equation 2.6}$$

$$P_{avg} = 21.2\ (VJH) + 23.0\ (BM) - 1393 \qquad \text{-} \qquad \textit{equation 2.7}$$

Where:

P_p = peak power

P_{avg} = average power

VJH = vertical jump height in cm

BM = body mass in kg

Johnson and Bahamonde (1996) discovered that the Harman et al.'s power prediction equation has several flaws. First being they developed the power prediction equation for peak and average power but performed two separate jump tests, one on a force platform and the other off the force platform. Secondly, Harman et al. used very few subjects to develop the equation. Johnson and Bahamonde then developed another power prediction equation using 69 male and 49 female subjects and stepwise multiple regression analysis. Variables used in the analysis are eight anthropometric measurements, vertical jump height and gender. However, only vertical jump height, body mass and body height were significant and the power prediction equations developed can be written as:

$$P_p = 78.5\ (VJ) + 60.6\ (BM) - 15.3(H) - 1{,}308 \quad - \quad \textit{equation 2.8}$$

$$P_{avg} = 41.4 \bullet VJ + 31.2 \bullet BM - 13.9 \bullet H + 431 \quad - \quad \textit{equation 2.9}$$

Where:

P_p = peak power output (W)

P_{avg} = average power output (W)

VJ = vertical jump height (cm)

BM = body mass (kg)

H = body height (cm)

2.4 Speed and Speed Assessment

Speed is an essential physical capacity in many sports (Baker and Nance, 1999; Bloomfield, Ackland and Elliot, 1994; Mero, Komi and Gregor, 1992; Young, McLean and Ardagna, 1995) and it is another performance component that is often being assessed apart from power. Speed refers to the ability to move the body or parts of the body through a range of motion in the least amount of time (Gambetta, 1990). As for running, it can be defined as the rate of covering the ground as quickly as possible. Speed test measures the body's displacement per unit of time (Altug, 1987). Tests that have been developed to assess speed are basically activity dependant, such as sprinting for running and sprint cycling for cycling. Several tests have been developed to assess sprinting speed including the 6 second run test, the shuttle run test and 40, 50 or 60 meters or yards dash tests.

Theoretically, the velocity-time curve in sprinting can be divided into three phases, the acceleration, constant velocity and deceleration phase. The acceleration phase continues for approximately thirty to fifty meters after the start for top sprinters, but may be shorter for less qualified athletes (Mero, Komi and Gregor, 1992; Moravec et al., 1988). This is followed by the constant velocity phase where the importance of the SSC ability has been reported before the deceleration phase when the supplied ATP is insufficient to maintain the maximal velocity. The invention of sophisticated equipment such as contact or switch mat and photocell sensors has enabled the assessment of speed to be carried out with ease and accuracy. Strengths and weaknesses in various phases can also be identified by placing several sensors at distances in between the dash distance.

The 40-meter dash is one of the most frequently used speed assessment test, including those in researches and games like basketball and rugby. (Paoule et al., 2000; Chelly and Denis, 2001 and Baker and Nance, 1999). Thus, this study will use the 40m-dash as our standard leg speed assessment tool.

2.5 Reactive Strength and Reactive Strength Assessment

Reactive strength refers to the ability to utilize effectively the stretch-shortening cycle. This type of strength quality is believed and considered independent (Schmidtbleicher, 1992). This means that it is possible for someone to have a high level of strength and rate of force development but may still have a poor level of reactive strength. Since the SSC has been discussed in detail in the previous section, we will concentrate on the review of the assessment of reactive strength. Generally, reactive strength or SSC ability is assessed in two ways. The first is the countermovement drop jump or drop jump for height where subjects are required to jump and land from a certain level of height and upon landing, they are allowed to perform a countermovement and then react by jumping as high as possible. This type of drop jump is characterized by a significantly higher jump height, larger knee angle displacement and longer ground contact time.

The second type of drop jump is the bounce drop jump or drop jump for maximum distance and minimum contact time. The performance in this type of drop jump is evaluated by comparing the index generated, which is the ratio of height jump and contact time. The bounce drop jump basically involves subjects jumping and landing from a certain level of height and jump immediately upon landing as high as possible. It is characterized by lower jump height as compared to countermovement drop jump, smaller knee angle displacement and shorter ground

contact time. The countermovement drop jump test and the bounce drop jump test are believed to give a reflective measure of the long and short SSC ability respectively as suggested by Schmidtbleicher, 1992 (Young, Pryor and Wilson, 1995; Young, Wilson and Byrne, 1999).