ABSTRACT

THE EFFECT OF STRETCH-SHORTENING CYCLE-INDUCED MUSCLE FATIGUE ON PREMOTOR REACTION TIME

Fifteen male, collegiate, physically fit students participated in an investigation to determine the effect of a stretch-shortening cycle (SSC)-induced fatigue on premotor reaction time (PRT). The latter was measured in two testing sessions where participants performed squat jumps (SJs) in a nonfatigued and a fatigued state. During the fatigue session and prior to execution of the SJs, a series of counter-movement jumps (CMJs) was done to induce a SSC-type fatigue of the lower extremities. CMJs were performed until the average vertical jump height (VJH) dropped by 10% of a previously recorded baseline. Performance of the SJs (nonfatigued and fatigued) required participants to jump as quickly and as forcefully as possible from a seated position (knee angle ≈ 110°) upon presentation of a visual cue. During all SJs, surface electromyographic (EMG) activity was obtained from the right vastus lateralis. PRT was defined as the time period between presentation of the visual cue and initiation of the corresponding EMG activity. ANOVA revealed that PRT was not affected by fatigue state. This was the case despite a significant decrease (p < 0.05) in the median frequency content of the surface EMG power spectrum in the fatigued state; an observation associated with muscular fatigue. It was concluded that when establishing a muscular fatigue state based on a 10% decline in vertical jump performance, central fatigue remains unaffected as indicated by the lack of change in PRT.

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May 2010
THE EFFECT OF STRETCH-SHORTENING CYCLE-INDUCED MUSCLE FATIGUE ON PREMOTOR REACTION TIME

by

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APPROVED

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Chapter 1

INTRODUCTION

A unique and current training modality used in athletic conditioning is plyometrics. Plyometrics may be defined as exercises in which recruited muscles first experience an active pre-stretch, which is then followed by a quick and powerful shortening (concentric) effort. Examples of plyometric exercises in which recruited muscles engage in a sequential pattern of active stretching followed by active shortening include the depth jump, skipping, single and double leg hops, alternate leg push-off, medicine ball throws, etc. When used correctly, plyometric training has consistently been shown to improve the production of muscle force and power, along with the performance of sport-specific skills (e.g., speed of running, swimming, throwing, jumping) (Kyrolainen et al., 2005; Linford et al., 2006; Myer, Ford, McLean, & Hewett, 2006; Toumi, Best, Martin, Guyer, & Poumarat, 2004; Trimble, Kukulka, & Thomas, 2000; Wilkerson et al., 2004; Wilson, Murphy, & Giorgi, 1996). These observations have led to the consistent inclusion of such types of training in athletic conditioning programs aimed to increase muscular power output.

When done repeatedly, plyometric efforts such as the ones mentioned above are likely to induce muscular fatigue (Avela & Komi, 1998a; Cutlip et al., 2005; De Lima, Tortoza, Da Rosa, & Lopes-Martins, 2004; Kuitunen, Kyrolainen, Avela, & Komi, 2007; Stroknik & Komi, 1998; Twist & Eston, 2005), compromise performance (Avela & Komi, 1998a, 1998b; Cutlip et al., 2005; Kuitunen et al., 2007; Twist & Eston, 2005), and decrease a muscle’s ability to respond to a certain stimulus accurately and effectively (De Lima et al., 2004;
Ozyemisci-Taskiran, Gunendi, Bolukbasi, & Beyazova, 2008). Because most sports activities also require the noted stretch-shortening cycle (SSC) pattern of muscle activation observed in plyometrics, by the end of sport practice and/or competition, the above-mentioned deteriorations (e.g., fatigue, compromised performance, increased reaction time) are expected.

The scientific literature has not addressed the effect of a sports-like (SSC-induced) fatigue on neuromuscular function and the associated reaction time. If the latter is indeed affected, so will an athlete’s ability to quickly and effectively respond to performance challenges. For example, a fatigued running back with a compromised (premotor) reaction time will display a longer time interval between recognizing a stimulus (e.g., incoming tackler) and initiating the corresponding muscle action (e.g., change running direction to avoid the tackler).

Reaction time consists of a recognizing component referred to as premotor reaction time and an executing component referred to as motor reaction time (Botwinick & Thompson, 1966). The premotor reaction time is more likely to relate to the effectiveness of neural drive to an active muscle, and is defined as the time interval between recognizing a stimulus and the beginning of the associated muscle action (Botwinick & Thompson, 1966). The motor reaction time is related to the effectiveness of an actual muscle contraction and is defined as the time interval between the beginning of a muscle action and the completion of an appropriate response (Botwinick & Thompson, 1966). Because of the two fractionated components (i.e., premotor and motor), reaction time should be analyzed separately in order to reveal whether a SSC-induced fatigue leads to alterations in the effectiveness of the neural drive (i.e., premotor reaction time) and/or the ensuing muscle contraction process (i.e., motor reaction time).
However, given the lack of equipment needed to measure motor reaction time, the present investigation only examined premotor reaction time (see Figure 1).

**Statement of the Problem**

As previously mentioned, no previous studies have determined the specific effect of a SSC-induced fatigue on premotor reaction. It was the purpose of the present study to impose this type of fatigue on collegiate, physically fit students and investigate the resulting delay in neural drive during jumping efforts.

**Research Hypothesis**

It was hypothesized that the premotor reaction time measured during jumping efforts would be longer in a fatigued state as compared to that measured in a nonfatigued state.

**Significance of the Study**

By knowing if an SSC-induced fatigue somehow alters reaction time, this study has the possibility to change the format of preparation before competition (e.g., less SSC activities during warm-up) or the extent of plyometrics use during practice. In addition, such information could be useful for individuals involved with athletic teams (coaches, athletic trainers, and team physicians), because SSC-induced fatigue may increase an athlete’s susceptibility to injuries (James, Dufek, & Bates, 2006; Mair, Seaber, Glison, & Garrett, 1996).

**Delimitations**

1. The subjects were male, collegiate, physically fit students.
2. The SSC-type fatigue was induced by a continuous double-legged jumping drill (i.e., counter-movement jumps).
Figure 1. Premotor reaction time. The blacked-out area indicates the premotor reaction time. The left (diagonal) arrow indicates the time of presentation of the visual cue (light turning on). The right (vertical) arrow indicates the onset of the corresponding surface EMG activity.
3. Reaction time was tested during concentric jumping efforts in response to a visual cue. It should be noted that during actual competition, athletes are exposed to many stimuli (visual and/or auditory) to which they must react.

4. Achievement of muscle fatigue was defined as a 10% decline in jumping performance from a previous baseline measure.

5. Premotor reaction time was measured from EMG-time traces obtained from the vastus lateralis.

Limitations
1. It was assumed that the volitional effort put forth during all testing sessions would be maximal.

2. Reaction time scores were limited to those noted during squat jumping efforts.

3. The technique used during the fatigue-inducing counter-movement jumps would likely be dissimilar between subjects. This might result in varying degrees of fatigue and thus, premotor reaction time.

Definitions of Terms
For the purposes of this study, the following terms are defined.

Central fatigue – fatigue associated with an insufficient neural drive to the muscle (Garrandes, Colson, Pensini, Seynnes, & Legros, 2007) that decreases muscular performance.

Counter-movement jump (CMJ) – a SSC-type jump in which subjects start from an upright position and then executes a (downward, eccentric) counter-movement followed by a quick and forceful pushing (concentric) effort.
Motor reaction time – the time interval between the beginning of a muscle action and the completion of an appropriate response (Botwinick & Thompson, 1966).

Peripheral fatigue – fatigue associated with changes beyond the neuromuscular junction that decrease muscular performance (Garrandes et al., 2007).

Physically fit individual – a person who regularly performs physical activities including, but not limited to resistance training, cardiovascular training, and high-velocity, ballistic muscle actions at least three times per week.

Premotor reaction time – the time interval between recognizing a stimulus and the beginning of the associated muscle action as indicated by the corresponding EMG activity (Botwinick & Thompson, 1966).

Reaction time – the time interval between recognizing a stimulus and completing an appropriate response (Botwinick & Thompson, 1966).

Stretch-shortening cycle (SSC) – a type of muscle action that involves an active stretching followed by active shortening (Komi, 2000).
Chapter 2

REVIEW OF THE LITERATURE

This chapter will examine relevant literature pertaining to the factors influencing efficiency of power production. In addition, this chapter will review literature related to exercise-induced fatigue and reaction time.

Stretch-shortening cycle (SSC) is performed during daily activities and competitive sports, and is a type of muscle action that involves an active stretching followed by active shortening. Typical examples of the SSC in physical activity are running, walking, and hopping. Recently, the SSC has been widely employed as plyometric training in various sports in order to enhance the performances. Although significant effects are induced by the SSC, a continuous SSC may induce muscle fatigue and then affect an athletic performance including reaction time. Most sports require an accurate and quick response to a certain stimulus. However, athletes are less likely to react accurately and quickly at the end of competition, because a repeated muscle contraction through competition leads to muscle fatigue. Therefore, muscle fatigue or damage induced by the SSC is a crucial factor to be considered in athletic performance in order to keep reaction time at a high level.

Effect of SSC

Muscular performance of the SSC involves the combination of an eccentric contraction (lengthening the activated muscle) in a short period of time and a concentric contraction (shortening the muscle), instead of an isolated eccentric or concentric contraction (Komi, 2000). Further, the SSC would maximize the
potential muscular ability associated with the increases in muscle activation (Komi, 2000; Trimble et al., 2000), storage of elastic energy, muscle stretch reflex and muscles stiffness (Avela & Komi, 1998a, 1998b; Komi, 2000; Myer et al., 2006; Toumi et al., 2004; Trimble et al., 2000; Wilkerson et al., 2004; Wilson et al., 1996).

A pronounced effect by the SCC is an increased power in explosive movements such as jumping, which resulted from significant increases in rate of force development (RFD) (Kyrolainen et al., 2005; Toumi et al., 2004; Wilkerson et al., 2004; Wilson et al., 1996). Although traditional weight training also increased the RFD, this form of training primarily enhanced muscular strength in the concentric phase of the SSC, which in turn increased the concentric RFD (Wilson et al., 1996). In contrast to the traditional weight training, plyometric training facilitated the eccentric RFD and force in the SSC, which could not be indentified from the weight training (Wilson et al., 1996). Therefore, Wilson et al. suggested that plyometric training appears to be beneficial for athletes in basketball, gymnastics, and track and field, which requires the rapid development of eccentric forces.

It has been documented that the increased RFD by plyometric training results from the neuromuscular alteration such as the greater muscle activation (Komi, 2000; Kyrolainen et al., 2005; Toumi et al., 2004). Kyrolainen et al. found that power training involving the SSC increases the height of the jump corresponding to the increased forces, RFD and electromyographic (EMG) activity during the first 10 weeks. Additionally, the result in this study showed no changes in myosin heavy chain, titin isoforms, muscle fiber distributions, and muscle fiber areas. This finding indicated that even though the muscular structures were not altered by the SSC during early week of the training program, the neuromuscular
performance was facilitated in order to produce greater muscle activity and power (Kyrolainen et al., 2005). Toumi et al. (2004) also found that the large increases in EMG activity during the early week of plyometric training program, and they suggested from this finding that the nervous system adaptation such as the increased motor unit activation and/or the firing frequency occurs from the plyometric training to a greater degree as compared to muscular adaptation such as hypertrophy. Furthermore, the motor unit activation in the SSC was greater than that in the voluntary isometric or concentric muscle contractions (Trimble et al., 2000), and this greater muscle activation peaked during or before the eccentric phase, which is known as preactivation (Komi, 2000).

The greater muscular activation identified by the higher EMG values in the eccentric phase of the SSC related to the fact that output of an active muscle-tendon complex is contributed by the storage of elastic energy accompanying the increased muscle stiffness (Komi, 2000; Kuitunen et al., 2007). It has been known that an active muscle-tendon complex during the SSC stores elastic energy in the braking (eccentric) phase, and releases and utilizes the energy in the shortening (concentric) phase for performance potentiation. (Komi, 2000). Thus, the muscle output utilizing the elastic energy in the final shortening phase of the SSC was greater than the isolated shortening contraction alone (Komi, 2000; Kuitunen et al., 2007). Furthermore, the muscle stretch reflex could contribute to the increased muscle activation and muscle stiffness (Avela & Komi, 1998a, 1998b), which in turn leads to the increased RFD (Komi, 2000). Additionally, a certain amount of tension to an active muscle-tendon complex was needed for the higher muscle stretch reflex and stiffness (Komi, 2000). Trimble et al. (2000) found that the waveform of EMG in preactivation and eccentric phase of the SSC is quite similar to the pattern seen in stretch reflex, suggesting that the muscle activation is
synchronized with the facilitation of muscle spindle that senses the stretching and provides the peripheral afferent feedback. This finding confirmed that the muscle stretch reflex could play a substantial role in the muscle activation and the force generation at the braking phase of the SSC (Komi, 2000; Trimble et al., 2000).

Therefore, the SSC has an advantage of efficiency to enhance the athletic performance such as jumping by increasing the RFD (Kyrolainen et al., 2005; Toumi et al., 2004; Wilkerson et al., 2004; Wilson et al., 1996), which is accomplished with the higher motor unit activation, storage of elastic energy, muscle stiffness and muscle stretch reflex (Avela & Komi, 1998a, 1998b; Komi, 2000; Myer et al., 2006; Toumi et al., 2004; Trimble et al., 2000; Wilkerson et al., 2004; Wilson et al., 1996).

**Fatigue Induced by Repeated SSC**

Even though the SSC has a number of positive effects for enhancing athletic performance, mechanical, neuromuscular, and metabolic fatigue are induced by a repeated SSC, which diminishes the advantages of the SSC and then reduces athletic performance (Avela & Komi, 1998a, 1998b; Komi, 2000; Myer et al., 2006; Toumi et al., 2004; Trimble et al., 2000; Wilkerson et al., 2004; Wilson et al., 1996). In other words, a long lasting or repeated SSC with a short resting time induced the muscle damage and fatigue, as traditional weight training does (Komi, 2000). The fatigue with isometric or concentric actions has been commonly discussed primarily from a metabolic aspect (Dartnall, Nordstrom, & Semmler, 2008; Komi, 2000; Ozyemisci-Taskiran et al., 2008; Pasquet, Carpentier, Duchateau, & Hainaut, 2000; Prasartwuth, Taylor, & Gandevia, 2005). However, the SSC-induced fatigue would be important to be considered from all the metabolic, neuromuscular, and mechanical components (Komi, 2000).
Regarding the metabolic fatigue, any type of muscle actions had various impacts on the muscular performance due to an insufficient energy production via metabolic sources to active muscles (Cutlip et al., 2005; Komi, 2000; Kuitunen et al., 2007). In other words, the metabolic fatigue induced by a long lasting SSC and other type of muscle actions is quite similar. It has been well documented that repeated muscle contractions lead to low level of cytosolic calcium and high level of exercise metabolites such as lactate acid (La) concentration. And then, due to the metabolic alterations, the fatigued muscles could not produce a high power or force as compared to healthy muscles at the beginning of an exercise, which in turn leads to the decrease in athletic performances. Kuitunen et al. (2007) found that a repeated submaximal jumping exercise led to the increases in La concentration related to the higher EMG activity and lower muscle stiffness. This finding indicated that the fatigued muscles, identified from the higher La concentration, need a higher level of muscle activation to maintain a required force or power for the jumping performance because the stored elastic energy may be less due to the lower muscle stiffness (Kuitunen et al., 2007). Accordingly, at the end of the SSC exercise, demands of energy from metabolic sources would be increased due to the limited elastic energy in the fatigued muscles, thus resulting in a faster progression of fatigue (Kuitunen et al., 2007). Additionally, the repeated SSC with the shorter rest time between sets led to larger force deficit as compared to the case of the longer rest time (Cutlip et al., 2005). Cutlip et al. suggested that this force deficit is due to the decrease in force-generating capability of muscle, which is attributed to the less metabolic sources to the muscles.

Regarding the neuromuscular fatigue, it has been reported that muscular performance is decreased with the repeated maximal SSC along with the decline of muscle stiffness, muscle activation, and muscle stretch reflex contribution for
power production particularly during the preactivation and eccentric phase (Avela & Komi, 1998a, 1998b; Kuitunen et al., 2007). Avela and Komi (1998b) found that the decreased eccentric peak muscle stiffness induced by the repeated SSC is closely related to the declined stretch reflex contribution. Avela and Komi (1998b) suggested that the declined muscle stiffness inhibits the muscle spindle activity that may be responsible for the stretch reflex sensitivity, resulting in less utilization of energy for power production. The declined muscle stiffness would be caused by the damage to muscle contractile fibers such as sarcomeres due to the repeated SSC as well as the case of pure eccentric contraction (Cutlip et al., 2005; Komi, 2000). The damage to muscle fibers has been known to be a greater degree with eccentric contraction than concentric contraction (Bottas, Linnamo, Nicol, & Komi, 2005; Prasartwuth et al., 2005), resulting that the declined muscle stiffness was seen primarily in the preactivation and eccentric phase (Avela & Komi, 1998b; Kuitunen et al., 2007). Thus, because the muscle fibers would not sustain the eccentric stretch loads during the SSC due to fatigue and damage, the active tension required for the muscle stiffness would be declined (Cutlip et al., 2005), and then the muscle could not store sufficient elastic energy. In consequence, the muscle length would be elongated during the eccentric phase due to the less active tension in fatigued muscles, even though the longer muscle length than optimum muscle length was inefficient to produce the tension and contraction (Cutlip et al., 2005). Further, although in the submaximal repeated SSC the muscle activation would be increased to compensate for contractile failure (Kuitunen et al., 2007), the neural input to the muscles would be decreased during the maximal repeated SSC, which was confirmed by the less EMG activity (Avela & Komi, 1998b). The high EMG activity was associated with the high muscle stiffness in the submaximal repeated SSC (Kuitunen et al., 2007), whereas the low EMG activity
during the maximal repeated SSC was related to the low muscle stiffness (Avela & Komi, 1998b; Kuitunen et al., 2007). Additionally, as well as the case of the declined muscle stiffness, the decreased EMG activity was distinct in the preactivation and eccentric phases, which in turn leads to the decreases in the eccentric and concentric forces and take-off velocity of jumping (Avela & Komi, 1998b). Avela and Komi (1998b) suggested that the declined EMG activity in the pre-activation results from fatigue of supraspinal centers due to the repeated SSC. In other words, the SSC-induced fatigue occurs in the neural function, resulting in less neural input to muscles. With the less muscle activation, the active tension for the muscle stiffness could not be gained (Cutlip et al., 2005). Therefore, the declined muscle stiffness, which resulted from the inhibition of muscle spindle, was primarily responsible for the decreased power production associated with the less neural input to active muscle and utilization of elastic energy from muscle stretch reflex (Avela & Komi, 1998b; Kuitunen et al., 2007).

Due to the metabolic and/or neural alterations, the mechanical performance such as jumping was also altered by the repeated SSC (Komi, 2000; Kuitunen et al., 2007). Kuitunen et al. found the longer ground contact time at the end of a repeated jumping exercise, resulting in the longer eccentric phase of the SSC. As the eccentric phase would be longer, the stored elastic energy would be utilized in the eccentric phase instead of the concentric phase, thus energy for power production during the concentric phase would be dependent on energy from metabolic sources to a greater degree because of the limited stored elastic energy (Kuitunen et al., 2007). In addition to the longer eccentric phase, the concentric force production time also increased with the repeated SSC because the fatigued muscles would be dependent on the neuromuscular system to compensate for the limited elastic energy by increasing the muscle activation (Avela & Komi, 1998b).
Central and Peripheral Fatigue, and Premotor and Motor Reaction Time

The physiological alterations induced by the repeated SSC would affect athletic performance by the decreases in RFD along with muscle stiffness and stretch reflex. The altered neuromuscular function would be more likely to be associated with reaction time, because athletes were required to maintain a high velocity of contraction via the efficient neural activation in order to react as quickly and accurately as possible. In other words, the neural drive should reach the optimum muscle without any disturbances. However, fatigued or damaged muscle induced by the repeated SSC would alter the neural activation at central and peripheral neuromuscular sites (Garrandes et al., 2007). Thus, athletes may not be able to deliver a quick response due to the fatigue.

Regarding fatigue due to exercise, it would occur at central and/or peripheral sites along the pathway of force production (Botwinick & Thompson, 1966). An insufficient neural drive to the muscle has been referred to as central fatigue, and changes beyond the neuromuscular junction have been referred to as peripheral fatigue (Botwinick & Thompson, 1966). Both central and peripheral fatigues were likely to be involved in declined force production (Dartnall et al., 2008; Kauranen, Siira, & Vanharanta, 2001). It has been reported that exercise induced a decrease in velocity of voluntary concentric contraction due to the peripheral fatigue in contractile properties (Garrandes et al., 2007; Ozyemisci-Taskiran et al., 2008). Kauranen et al. (2001) suggested that decreased strength of fatigued muscles was caused by changes in contractile muscle tissues due to the peripheral fatigue rather than central fatigue. Moreover, the central fatigue, such as a failure in activation of neurons (Prasartwuth et al., 2005) and action potential (Pasquet et al., 2000), was less likely to contribute to the muscular force generation. To put it simply, the peripheral fatigue is associated with the decreased
muscular function, and the central fatigue is associated with the altered neuromuscular function.

Reaction time also composes central and peripheral components that are important values when considering reaction time (Bottas et al., 2005; Ozyemisci-Taskiran et al., 2008). Reaction time has been defined as a time interval between recognizing a stimulus and completing an appropriate response (Bottas et al., 2005). Although many studies have investigated the effect of exercises on reaction time (Bottas et al., 2005; Botwinick & Thompson, 1966; De Lima et al., 2004; Devienne, Audiffren, Ripoll, & Stein, 2000; Ozyemisci-Taskiran et al., 2008), a majority of these studies did not analyze two fractions of reaction time, recognizing and executing fraction (Ozyemisci-Taskiran et al., 2008). The executing fraction has been referred to as a motor reaction time (MRT), which is the time interval between the beginning of muscle action and the completion of an appropriate response (Botwinick & Thompson, 1966). It has been suggested that MRT is influenced by peripheral fatigue, which in turn, leads to variations in reaction time (Botwinick & Thompson, 1966; Ozyemisci-Taskiran et al., 2008). However, it also has been suggested that peripheral fatigue has the potential to affect the recognizing fraction of reaction time (Dartnall et al., 2008; Ozyemisci-Taskiran et al., 2008). The recognizing fraction of reaction time has been referred to as premotor reaction time (PRT), which is the time interval between recognizing a stimulus and initiating of muscle action (Botwinick & Thompson, 1966). In contrast to the motor time, central fatigue was likely to play an important role in variations in PRT (Ozyemisci-Taskiran et al., 2008). On the basis of two fractions of reaction time, measurement of the PRT would allow researchers to analyze changes in the recognizing function after exercise apart from the MRT,
when considering the effect of exercise on the recognizing function of athletes related to the central fatigue (Ozyemisci-Taskiran et al., 2008).

Reaction Time in Athletic Performance

Generally speaking, well-trained individuals can perform a quicker response and movement as compared to sedentary individuals. Laroche, Knight, Dickie, and Lussier (2007) investigated the fractionated reaction time in relation to physical activity level among elderly women, and found the shorter MRT and higher EMG activity in high-active women. However, no significant difference in PRT between high- and low-active women was found (Laroche et al., 2007). These findings suggested that physical activity would influence the RFD, but not the ability of recognizing a stimulus and initiating the process of muscle contraction (Laroche et al., 2007). It is important to note that the muscles in this study were not tested at fatigued state (Laroche et al., 2007), which could be considered as a similar muscular state prior to an athletic competition. Etnyre and Kinugasa (2002) also investigated the fractionated reaction time to an auditory stimulus under the similar condition with prior to an athletic competition, and found that both PRT and MRT showed the improvement at 3 seconds after the maximum voluntary isometric contractions. The direction of muscle contractions was the same in the direction of isometric exercise and reaction time tasks, suggesting that facilitation of the neural information processing and the muscular response appeared to occur (Etnyre & Kinugasa, 2002). This effect on reaction time could be incorporated into a preparation period of actual athletic performance such as sprinters and probably baseball batters on deck (Etnyre & Kinugasa, 2002), but not into an explosive type of sports involving intermittent eccentric contractions through the competition. Regarding the explosive type of sports, it
has been reported that well-trained fencing athletes showed no positive effect of preparatory isometric contractions on the fencing performance in which athletes responded to a visual light stimulus as quickly as possible by pointing with a sword (Devienne et al., 2000). Devienne et al. suggested that this lack of a significant effect on PRT and MRT was due to less magnitude of load to the muscles, which was 50% of maximum voluntary isometric contraction. It was important to note that six subjects in this study showed a decrease in PRT whereas three subjects showed an increase in PRT (Devienne et al., 2000). This implied the variability of effects of preparatory submaximum isometric contraction on PRT.

Theoretically, it has been established that quick and accurate reaction are deteriorated due to central and peripheral fatigue. However, only a few studies have examined the reaction time with fatigued neuromuscular systems, which can be applied to the end of athletic competition involving intermittent explosive contractions (De Lima et al., 2004; Ozyemisci-Taskiran et al., 2008; Twist & Eston, 2005). De Lima et al. found that the increased blood lactate concentration after 3 and 5 minutes of judo, an explosive type of sport, did not influence the reaction capacity including speed of the response. Although the speed of the response was maintained after judo, the frequency of performance errors was increased (De Lima et al., 2004). Thus, fatigued athletes could possibly perform quick movement and response, but it is not an accurate and optimum response. In addition to explosive exercise, aerobic exercise also had no effect on reaction capacity (Ozyemisci-Taskiran et al., 2008).

Interestingly, it has been reported that dual and complex reacting tasks, requiring multiple attentions during physical activity, lead to decrease in reaction capacity (Devienne et al., 2000; Ozyemisci-Taskiran et al., 2008). On the other hand, it has been suggested that higher arousal state during physical activity leads
to an increase in the recognizing function, which in turn would enhance the process of reaction (Ozyemisci-Taskiran et al., 2008). Ando, Kokubu, Kimura, Moritani, and Araki (2008) found no difference in PRT between at rest and during moderate cycling exercise when the visual stimulus presented in the central portion of the visual field. As opposed to this stimulus, when the visual stimulus presented in the peripheral portion of the visual field, PRT significantly increased during the identical exercise (Ando et al., 2008). This study suggested that the increased arousal state due to the moderate cycling exercise narrowed the attentional focus to the central portion of the visual field (Ando et al., 2008). Regarding the MRT during the exercise, there was no difference between the visual conditions, suggesting that the arousal status would not alter the velocity of muscular contraction (Ando et al., 2008). Kauranen et al. (2001) also showed no effect of fatigued muscles on the MRT during both simple and complex reaction time test.

It has been suggested that MRT appeared to be directly associated with the peripheral fatigue (De Lima et al., 2004; Kauranen et al., 2001). In other words, a maintained muscular function without the peripheral fatigue would contribute to a remained quick movement. As opposed to MRT, PRT would be related to the central fatigue and be involved in the initiation of muscle activation for accurate response and coordination of movement instead of quick movement (Ozyemisci-Taskiran et al., 2008). Coaches and athletes have been interested in a type of training that enhances the accurate, coordinated, and quick movement. Although PRT might be difficult to show the improvement due to the short period of time, Linford et al. (2006) showed that the exercise program incorporating strength, power, and neuromuscular control significantly decreased PRT. Linford et al. (2006) suggested that the exercise program in this study enhances the sensitivity of
the muscle spindle, which in turn initiates the muscle activation more quickly. It was important to note that the subjects were required to respond to unpredictable stimuli, which may approximately correspond to the sports competition because athletes are not be able to predict the next opponent’s action (Linford et al., 2006). However, the exercise program was not assured, because PRT was measured during walking in this study (Linford et al., 2006) and competitive sports require high-speed movements.
Chapter 3

METHODS

This chapter describes the procedures that were necessary to fulfill the objective of this study. It is divided into sections that describe the participants, procedures, and statistical treatment of data.

Participants

Fifteen male, collegiate, physically fit students from California State University, Fresno (CSUF) between 20 and 32 years of age volunteered to participate in this investigation (see Table 1). The participants were informed of the risks and benefits involved, and signed a written informed consent prior to participation (see Appendix). The protocol for this investigation conformed to the CSUF policy on the use of human subjects.

Table 1. Profile Data for the Study of Relationships Between a Nonfatigued and Fatigued State

<table>
<thead>
<tr>
<th>Males (n=15)</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>23.6</td>
<td>± 3.42</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>179.144</td>
<td>± 9.65</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>86.948</td>
<td>± 15.83</td>
</tr>
</tbody>
</table>
Procedures

Participants were required to visit the Human Performance Lab (HPL) at CSUF, Department of Kinesiology, on 3 separate days each separated by 4 days. During their first visit to the HPL, the participants gave informed consent, were familiarized with the equipment used for data collection, and were given an explanation of the experimental procedures. The last two sessions were dedicated to collection of the dependent measures; the order of these experimental sessions was randomized.

Familiarization Session

During the participants’ first visit to the HPL, qualified personnel demonstrated the use of the mechanically braked Monark 818E bicycle ergometer (Monark-Crescent AB, Varburg, Sweden). Each participant’s seat height and handle bar position was established, as the ergometer was used for warming up during the subsequent sessions. Subjects were also introduced to operation of the switch mat (Probotics, Huntsville, AL, USA) that was used to collect vertical jump height (VJH) during jumping efforts. Upon an explanation of the proper jumping technique, subjects were asked to practice the squat jump (SJ) and then the counter-movement jump (CMJ).

Before practicing the SJ, the initial (seated) position was established. This required a knee angle of 110° while the upper thigh was parallel to the floor. The knee angle was achieved (or closely approximated) by placing weight plates (0.25-0.5 inch in thickness) under a bench’s legs until the sought angle was reached. The right knee angle was measured with a manual goniometer centered at the lateral epicondyle of the femur and aligned to the lateral malleolus and greater trochanter. The degree of trunk flexion was up to the subjects and was defined as the most comfortable position to initiate the SJ while the hands were gripped behind the
back. Once the SJ’s initial position was established and the needed setup was recorded, subjects were asked to jump as high and as forcefully as possible upon presentation of a visual cue (i.e., light turning on). A Lafayette reaction time apparatus (Lafayette Instruments, model 63035, Lafayette, IN, USA) was used to provide subjects with such visual cue upon the experimenter’s command. The (trigger) light switch was placed next to the experimenter, and the light response panel approximately 3 feet in front of the subjects at about mid-torso level. Subjects were reminded of the importance of a quick response to the light signal, as reaction time during squat jumping was the study’s dependent measure. Subjects performed five practice SJs, each separated by 1-minute rest period. Because the premotor reaction time (PRT) might be decreased when corresponding muscles were isometrically tensed prior to reaction (Devienne et al., 2000; Etnyre & Kinugasa, 2002), subjects were asked to practice the SJs with their quadriceps totally relaxed while maintaining the initial (seated) position. Subsequent practice of the CMJs required subjects to do three sets of four jumps, all while taking-off and landing on the Probotics switch mat. Within each set, all jumps were done in succession and as quickly and explosively as possible (i.e., with a very short eccentric-concentric transition). The rest between sets was 3 minutes. Subjects were reminded of the importance of achieving a consistent jumping technique (i.e., eccentric range of motion and quickness of eccentric-concentric transition) during practice. This was because a similar and consistent jumping technique was requested during subsequent testing sessions. Finally, because reaction time is affected (i.e., increased) by muscular fatigue (Ando et al., 2008; De Lima et al., 2004; Devienne et al., 2000), subjects were requested and required to refrain from any kind of lower-body physical activity until all subsequent testing was completed.
During the next two sessions, the PRT before squat jumping was measured under a fatigued and a nonfatigued state, respectively. In order to control for a possible learning and/or treatment effect, the sequence of the next two sessions was randomized. The nonfatigue testing session is described first.

**Nonfatigue Testing Session**

During this visit to the HPL, the skin over the prominent bulge of right vastus lateralis (VL) was shaved. Subjects were then asked to engage in a light warm-up consisting of 5 minutes of bicycle ergometry at a self-determined power out. After the warm-up, the shaved skin was abraded and cleaned with isopropyl alcohol and surface (bipolar) self-adhesive Ag/AgCl pre-gelled disc electrodes were placed longitudinally (3 cm apart) on the prominent bulge in alignment with the presumed fiber architecture (Pansky, 1996). All electrodes’ positions were carefully measured in each subject in order to ensure identical recording sites in this and the fatigue testing session. The BIOPAC’s electrode check feature was used to ensure that the interelectrode impedance is below 5,000 Ohms. Once the electrodes were in place, subjects performed four SJs from the same bench position recorded during the familiarization session (i.e., 110° knee angle, upper thigh parallel to the floor). The hands were gripped behind the back and trunk position was the same as before. Just like in the familiarization session, the rest between jumps was 1 minute. Once the Lafayette reaction time apparatus was set, subjects were asked to jump as forcefully and as quickly as possible after presentation of the light signal cue. In order to prevent the subjects from predicting the timing of the visual cue presentation, the light switch was covered and triggered at random time intervals (e.g., 3-10 seconds).
During the execution of the SJs, the surface electromyograph (EMG) activity from the right VL was recorded using a BIOPAC Systems Inc. (Santa Barbara, CA) electromyograph. The raw EMG signals were sampled at 1,000 Hz, amplified (x2500) and filtered (high pass, 30Hz; low pass, 500 Hz; and band stop, 60 Hz). The raw EMG signals were full-wave rectified and integrated (across intervals of 30 samples) using the Student Lab Pro software package. This procedure created integrated EMG scores (IEMG) measured in milli-volt-seconds (mVs). The required state of muscular relaxation while on the seated position was validated by a lack of EMG activity before each jump (see Figure 1, p. 4). From the EMG-time traces, the PRT was measured. This reaction time corresponded to the time period between presentation of the visual cue and the beginning of the associated muscle action as indicated by the corresponding EMG activity. These PRTs were measured using a technique previously established (Laroche et al., 2007; Ozyemisci-Taskiran et al., 2008) (see Figure 1, p. 4) and represented the scores obtained during a nonfatigued condition.

The Student Lab Pro software was also used to perform a Fast Fourier transformation (Harmonic analysis) on the respective raw EMGs to determine their spectral content resolution (signal power vs. frequency). This software was then used to determine the mean (MeanFreq) and median frequency (MedFreq) of the EMG spectral density function. This was because in the fatigued state, the frequency content of the surface EMG is expected to decrease (Mannion, Connolly, Wood, & Dolan, 1997; Roy et al., 1997; So, Chan, & Siu, 2002). Thus, assessment of these variables was done to verify the achievement of a fatigued state in response to the jumping protocol to be described in next section.
Fatigue Testing Session

During this visit to the HPL, subjects were asked to once again engage in a light, 5-minute warm-up in the Monark ergometer after the skin of the prominent bulge of the VL was reshaved. After the warm-up, subjects were asked to do one set of four continuous CMJs using the technique previously learned in the familiarization session (i.e., consistent eccentric range of motion and explosive eccentric-concentric transition). The jumps were done on the switch mat and the resulting average vertical jump height (VJH) was recorded. After a 3-minute rest, subjects performed additional sets of four continuous CMJs with a 15-second rest between sets until the average VJH dropped by 10% of that previously recorded. Consequently, each subject might perform a different number of fatiguing sets. For the purpose of this study, a 10% decrease in VJH was used as criteria to establish attainment of a fatigued state. This specific criterion was based on pilot data that examined the percent decline in VJH associated with a significant decrease in the frequency spectrum of the EMG signal occurs. For the sake of a establishing the fatigue-inducing effectiveness of the jumping protocol, the difference in the EMG frequency valuables between the nonfatigued and the fatigued conditions was compared.

Immediately after the muscular fatigue was identified, the shaved skin was abraded and cleaned with isopropyl alcohol and electrodes were placed as described before. The same series of four SJs were performed (same knee, trunk, and hand position) and from the EMG-time traces, the premotor reaction time (PRT) was measured. The obtained PRT scores represented those acquired during a fatigued condition.
Statistical Analysis

Statistical analyses of data were performed using the Statistical Package for the Social Sciences (SPSS, v 16). To test for differences in the dependent measures (PRT, MedFreq, MeanFreq) across levels of fatigued state (nonfatigued, fatigued) and trial (first, second, third, fourth), a 2 x 4 ANOVA with repeated measures on both experimental factors was used. In cases where multiple mean comparisons were appropriate, Tukey post-hoc procedures were used. To test for differences between the initial and final VJH obtained in the fatiguing protocol, a paired-sample T-test was used. The latter compared the difference between the mean height of the first set of four jumps and the mean height of the last set of four jumps. For all statistical tests, significance was set at $p < 0.05$. Descriptive statistics (means and standard deviations) were also calculated for all variables.
This chapter presents the results of the collected data as described in chapter 3. The results are organized into the following sections: (a) influence of fatigued state between trials on premotor reaction time (PRT), and (b) effectiveness of the fatiguing protocol.

### Influence of Fatigued State on Premotor Reaction Time

ANOVA results for PRT are presented in Table 2; the corresponding graphical results are presented in Figure 2. For this dependent measure, ANOVA revealed no significant main effect ($p > 0.05$) for treatment (nonfatigued vs. fatigued) or trial (first, second, third, fourth) (Table 2). In addition, ANOVA revealed no significant interaction between the above-mentioned experimental factors (i.e., treatment $\times$ trial) (Table 2). Therefore, regardless of trial, the PRTs between the nonfatigued and fatigued conditions were the same. These results also indicate that for both treatment conditions, the PRTs were the same among the four trials.

### Effectiveness of the Fatiguing Protocol

As indicated before, the main question addressed by the present investigation was how PRT is affected in a fatigued state. The protocol to induce such a state required subjects to perform sets of four continuous counter-movement jumps (with a 15-second rest in between) until the average vertical jump height (VJH) dropped 10% from that recorded in the first set.
Table 2. ANOVA Results of Premotor Reaction Time (PRT) by Trials for the Study of Relationships Between a Nonfatigued and Fatigued State

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Sum of Squares</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
<th>F-Ration</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRT</td>
<td>$7.254 \times 10^{-3}$</td>
<td>1</td>
<td>$7.254 \times 10^{-3}$</td>
<td>0.851</td>
<td>0.372</td>
</tr>
<tr>
<td>Trials</td>
<td>$1.087 \times 10^{-2}$</td>
<td>3</td>
<td>$3.624 \times 10^{-3}$</td>
<td>1.150</td>
<td>0.340</td>
</tr>
<tr>
<td>PRT x Trial</td>
<td>$6.037 \times 10^{-3}$</td>
<td>3</td>
<td>$2.012 \times 10^{-3}$</td>
<td>0.634</td>
<td>0.597</td>
</tr>
</tbody>
</table>

n = 15
* = significant, p < 0.05

Figure 2. Premotor reaction time (PRT) in microseconds (ms) for the study of relationships between a nonfatigued (N-Ftg) and fatigued (Ftg) state (n = 15)
According to the T-test statistic, the fatiguing protocol may have successfully fatigued the recruited (“jumping”) muscles, as the mean jump scores between the first and last set of four jumps were significantly different ($p < 0.05$) (Table 3). This observation seems to be validated by the significant decrease in the median frequency (MedFreq) of the EMG spectral density function noted in the fatigued state. As shown in Table 4 and Figure 3, ANOVA results for MedFreq revealed a significant main effect for treatment (nonfatigued vs. fatigued) ($p < 0.05$), but not for trial. ANOVA also failed to reveal a significant interaction between the two experimental factors (treatment x trial). Thus, regardless of trial, the MedFreq was significantly lower in the fatigued state. That is, the resulting rate of motor unit firing during the concentric (i.e., take-off) phase of the squat jumps was decreased in the fatigued state. The significant decrease in the surface EMG frequency spectrum of fatigued muscle was expected and has been previously reported (Mannion et al., 1997; Roy et al., 1997; So et al., 2002).

Table 3: T-test Results of Averaged Jump Height (JH) of Four Jumps in a Set for the Study of Relationships Between a First Set and Last Set During the Fatiguing Protocol

<table>
<thead>
<tr>
<th></th>
<th>1st JH Mean (± SD)</th>
<th>Last JH Mean (± SD)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.373 (± 3.1804)</td>
<td>19.261 (± 3.4010)</td>
<td>0.048*</td>
<td></td>
</tr>
</tbody>
</table>

n = 15
* = significant, $p < 0.05$

Similar to MedFreq, decrements in the MeanFreq were also expected in the fatigued state. However, ANOVA revealed no significant main effect ($p > 0.05$) for treatment (nonfatigued vs. fatigued) or trial (first, second, third, fourth) (Table 5, Figure 4). ANOVA also revealed a significant interaction between the two experimental
Table 4. ANOVA Results of Median Frequency (MedFreq) for the Study of Relationships Between a Nonfatigued and Fatigued State

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Sum of Squares</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
<th>F-Ration</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>MedFreq</td>
<td>1443.651</td>
<td>1</td>
<td>1443.651</td>
<td>6.267</td>
<td>0.025*</td>
</tr>
<tr>
<td>Trial</td>
<td>10.405</td>
<td>3</td>
<td>3.468</td>
<td>0.051</td>
<td>0.985</td>
</tr>
<tr>
<td>MedFreq x Trial</td>
<td>145.768</td>
<td>3</td>
<td>48.589</td>
<td>0.887</td>
<td>0.456</td>
</tr>
</tbody>
</table>

n = 15
* = significant, p < 0.05

Figure 3. Median frequency (MedFreq) for the study of relationships between a nonfatigued (N-Ftg) and fatigued (Ftg) state (n = 15)
* = significant, p < 0.05
factors (treatment x trial) (Table 5). Subsequent multiple comparison tests (Tukey) did not establish differences in MeanFreq scores across the levels of the experimental factors (Figure 4). The lack of a significant decrease in this frequency variable was likely the result of the large standard deviations noted and thus, the substantial intersubject variation in this dependent measure (Vincent, 2005).

Table 5. ANOVA Results of Mean Frequency (MeanFreq) for the Study of Relationships Between a Nonfatigued and Fatigued State

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Sum of Squares</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
<th>F-Ration</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>MeanFreq</td>
<td>123.911</td>
<td>1</td>
<td>123.911</td>
<td>1.364</td>
<td>0.262</td>
</tr>
<tr>
<td>Trial</td>
<td>29.843</td>
<td>3</td>
<td>9.948</td>
<td>0.539</td>
<td>0.658</td>
</tr>
<tr>
<td>MeanFreq x Trial</td>
<td>354.595</td>
<td>3</td>
<td>118.198</td>
<td>3.306</td>
<td>0.029*</td>
</tr>
</tbody>
</table>

Note: n = 15
* = significant, p < 0.05

Figure 4. Mean frequency (MeanFreq) for the study of relationships between a nonfatigued (N-Ftg) and fatigued (Ftg) state (n = 15)
Chapter 5

DISCUSSION, SUMMARY, AND CONCLUSIONS

This chapter will present a discussion of the results obtained from the present investigation. The discussion is followed by a summary statement and a list of conclusions drawn from the findings of this study.

Discussion

The focus of this investigation was to determine the specific effect of a stretch-shortening cycle (SSC)-induced fatigue on the premotor reaction time (PRT). More specifically, this investigation was converged to determine the resulting delay in neural drive during jumping efforts upon presentation of a visual stimulus.

Results of the present investigation (Table 2, p. 28; Figure 2, p. 28) showed that regardless of the state of fatigue in the corresponding muscles, the PRT did not change. These findings are in agreement with the results of previous investigations (Klimovitch, 1977; Kroll, 1974; Paasuke, Ereline, & Gapeyeva, 1999; Woods, Furbush, & Bigland-Ritchie, 1987), which found no changes in PRT after fatiguing exercises. It has been suggested that central fatigue is likely to play an important role in neuromuscular function and thus, explain variations in PRT (Ozyemisci-Taskiran et al., 2008). Because PRT is indicative of the integrity of the central drive (Yeung, Au, & Chow, 1999), results of the present investigation suggest that when fatigue is induced by SSC exercises, the neural drive originating from the motor cortex does not affect the excitation of muscle. However, it should be noted that the activation of muscles upon a presentation of a
visual stimulus involves transmission of neural impulse via ascending (i.e., toward the motor cortex) and descending (i.e., away from the motor cortex) pathways. That is, once subjects in the present investigation perceived the visual cue (i.e., light turning on), the incoming impulse was first perceived by the primary visual cortex, and then relayed in the following sequence: (a) premotor cortex; (b) motor cortex; (c) cerebrum; (d) basal ganglia; (e) brainstem; (f) spinal cord; (g) interconnecting neurons (and their synapses); and (h) skeletal muscles (Shumway-Cook & Woollacott, 2001). Thus, the lack of changes in PRT during the fatigue trial may be explained by a possible impairment in one (or more) of the above-mentioned neural transmission sites, along with a compensatory increase in others. However, this proposed explanation cannot be verified as presently there are no techniques that can measure during in vivo condition the change in the activity levels (if any) among the components of the neural transmission relay chain.

The PRT recorded after maximal isometric contractions has showed only minor (nonsignificant) variation between power-trained, endurance trained, and untrained men (Paasuke et al., 1999). In addition, previous investigations using non-power-trained subjects have shown that after a fatiguing exercise, force production decreased but PRT remained unchanged (Klimovitch, 1977; Kroll, 1974; Paasuke et al., 1999; Woods et al., 1987). The physically fit subjects in the present investigation also showed no changes in PRT after the fatiguing exercise. Thus, it seems that the effects of fatigue on PRT may not be associated with the subjects’ trained state.

In the present investigation, a light signal was used as a visual stimulus that the participants focused on before initiating the jumps. The light was placed at the central portion of their visual field. Ando et al. (2008) compared PRT when a visual stimulus was presented in the central and peripheral aspect of the subjects’
visual field. These authors found that PRT increased when responding to a peripheral stimulus and did not change when responding to a centrally placed stimulus (Ando et al., 2008). It should be noted that Ando et al. measured PRT while subjects rode an ergometer at 65% peak oxygen uptake (Ando et al., 2008). Nevertheless, it could be that a stimulus presented in the central aspect of visual field may be less likely to delay an expected response, whereas a stimulus presented in the peripheral aspect of visual field may be more likely to do so. Since athletes must respond quickly and appropriately to various stimuli presented in both, the central and peripheral aspects of the visual field, future investigations may want to measure PRT under similar conditions.

The majority of investigations examining the effect of fatigue on PRT have relied on protocols of submaximal and maximal isometric contractions, or submaximal and maximal concentric contractions to induce fatigue and record PRT (Klimovitch, 1977; Kroll, 1974; Paasuke et al., 1999; Woods et al., 1987). In order to impose a different, athletically related fatigue response, we used a SSC fatiguing (jumping) protocol, which involved more complex and intense steps (i.e., preactivation, stretch reflex, restitution of stored elastic energy) as compared to the more traditional protocols mentioned above. The expectation was to induce a compromise in neural input (i.e., central fatigue) and muscle function (i.e., vertical jump height). The criteria to establish a fatigue state in the participants was a 10% decline in vertical jump height (VJH) during a set of continuous jumps. As indicated in the Table 2 and Figure 2 (p. 28), PRT scores remained unchanged, implying a lack of effect on central fatigue in response to the previous 10% decline in jumping ability. Thus, future investigations should reassess the criteria to establish a fatigued state based on the quantity and nature of fatiguing exercises.
Doing so may allow for a more accurate evaluation of exercise protocols on PRT and central fatigue.

Although the fatiguing protocol of the present investigation had no effect in PRT scores, the median frequency (MedFreq) scores (Table 4, p. 30, Figure 3, p. 30) showed a significant decrease. As indicated before, such a decline in the frequency spectrum of the EMG signal is indicative of muscular fatigue (Mannion et al., 1997; Roy et al., 1997; So et al., 2002). More specifically, the decline in the MedFreq and the associated decrease in motor unit firing rate have been associated with fatigue of the fast-twitch motor units (Gardiner & Olha, 1987). Thus the criteria of the fatiguing protocol in the present investigation (i.e., 10% decline in VJH) proved to be successful in inducing muscular but not central fatigue. We recommend that future investigations address the establishment of a fatigue state (or threshold) that influences both, central and muscular fatigue. The need to address other possible factors (e.g., mental distractions, stresses) that may alter the neural drive during physical activity (Bowyer, Moran, Hsieh, Manoharan, & Young, 2007; Coombes, Cauraugh, & Janelle, 2007; Fales, Barch, Rundle, Mintun, & Snyder, 2008) should also be investigated.

**Summary**

Fifteen male, collegiate, physically fit students participated in an investigation to determine the effect of a stretch-shortening cycle (SSC)-induced fatigue on premotor reaction time (PRT). The latter was measured in two testing sessions where participants performed squat jumps (SJs) in a nonfatigued and a fatigued state. The two testing sessions were separated by 4 days and their sequence randomized. During the fatigue session and prior to execution of the SJs, a series of counter-movement jumps (CMJs) was done to induce a SSC-type
fatigue of the lower extremities. CMJs were performed until the average vertical jump height (VJH) dropped by 10% of a previous baseline. A fatigued state was presumed then. Performance of the SJs (nonfatigued and fatigued) required participants to jump as quickly and as forcefully as possible from a seated position (knee angle ≈ 110°) upon presentation of a visual cue (light turning on). During the SJs, surface electromyographic (EMG) activity was obtained from the right vastus lateralis, and from the EMG-time traces, the PRT was measured. PRT was defined as the time period between presentation of the visual cue and initiation of the corresponding EMG activity. The surface EMG records were also used to derive the mean (MeanFreq) and median frequencies (MedFreq) of the power spectrum. ANOVA revealed that PRT was not affected by fatigue state. This was the case despite a significant decrease (p < 0.05) in the median frequency content of the surface EMG power spectrum in the fatigued state; an observation associated with muscular fatigue (Table 4, p. 30, Figure 3, p. 30). However, in the case of MedFreq, ANOVA failed to establish significant differences between the fatigued and non-fatigued state (Table 5, p. 31, Figure 4, p. 31). This might be explained by the large standard deviations in the corresponding means. It was concluded that when establishing a muscular fatigue state based on a 10% decline in vertical jump performance, central fatigue remains unaffected as indicated by the lack of change in PRT. The possible factors leading this unaffected central fatigue and PRT might be the following: (a) a compensatory increase in neural transmission relay chain (i.e., from eyes to neuromuscular junction); (b) location of the visual stimulus (i.e., central vs. peripheral visual field); and (c) insufficient amount of stresses loading on muscles (i.e., 10% decline in VJH). We recommend that future investigations address the establishment of a fatigue state (or threshold) that influences both, central and muscular fatigue.
Conclusions

Within the limitations of this study, the following conclusions were drawn:

1. In response to a 10% decline in VJH induced by the fatiguing (jumping) protocol of the present investigation, the PRT of vastus lateralis during SJ performance was not affected.

2. The above-mentioned fatiguing protocol proved to be successful in inducing muscular fatigue based on the noted decline in frequency spectrum of the surface EMG signals.

3. Thus, the fatiguing protocol was successful in inducing muscular fatigue but not central fatigue.

In closing, results of the present investigation did not establish an association between PRT and a SSC-induced fatigue. Given that the fatiguing protocol of the present investigation (i.e., 10% decline in VJH) seems to induce only muscular fatigue, it is suggested that future investigations examine PRT during a fatigued state that influences both, central and muscular fatigue. Possible methods to induce such fatigued state may require higher physical loads, mental stresses, and visual distractions during fatiguing activities.
REFERENCES
REFERENCES


APPENDIX
CONSENT FORM FOR HUMAN SUBJECTS

California State University, Fresno

Project Title: THE EFFECT OF STRETCH-SHORTENING CYCLE-INDUCED MUSCLE FATIGUE ON PREMOTOR REACTION TIME.

Principal Investigator(s): Jacobo Morales (Professor, Dept. of Kinesiology) & Daisuke Shibata (Graduate Student, Dept. of Kinesiology).

The purpose of this study is to investigate the effect of muscular fatigue induced by a continuous stretch-shortening cycle activity on premotor reaction time in power-trained athletes. You were selected as a possible subject in this investigation because of your gender and training status (i.e., male, collegiate power-trained athlete).

If you decide to participate, we will require your attendance at the Human Performance Laboratory (HPL) located in South Gymnasium, room 139 on three separate days to participate in a familiarization session and two data collection sessions. These three sessions will be separated by at least four days.

During your first visit to the HPL (i.e., familiarization session), you will give informed consent, will be introduced to the equipment used for data collection and will be given an explanation of the experimental procedures. Following your orientation, you will be introduced to operation of the mechanically braked Monark 818E bicycle ergometer that will be used for warm-up. You will be also introduced to operation of Probotics switch mat that will be used to collect vertical jump height and ground time during squat and countermovement jumping efforts. The protocol of squat jumps will require you to seat on
a bench with a knee angle of approximately 110°, a comfortable degree of trunk flexion, hands gripped behind your back, and both legs relaxed. From this initial position, you will be asked to jump as high and forcefully as possible upon presentation of a visual signal placed in front of you. Subsequent practice of the counter-movement jumps will require you to perform 4 jumps in succession and as quickly and explosively as possible (i.e., with a very short downward-upward transition). Finally, you will be requested and required to refrain from any kind of lower-body physical activity (e.g., squatting, running, jogging) until all testing is completed.

Each of the two subsequent visits to the HPL will consist of one of the following data collection sessions (in random order): (1) squat jumps with non-fatigued muscles (non-fatigued testing session), and (2) squat jumps with fatigued muscles induced by counter-movement jumps (fatigued testing session). While performing the squat jumps, electromyographic (EMG) data will be collected from your right vastus lateralis (VL). This will require placement of electrodes on your right thigh after shaving and abrading the necessary skin area.

During the non-fatigue testing session, the skin over the prominent bulge of your right VL will be shaved. You will then be asked to engage in a light warm-up consisting of 5 minutes of bicycle ergometry at a self-determined intensity. After the warm-up, the shaved skin will be abraded and cleaned with isopropyl alcohol and surface (bipolar) self-adhesive Ag/AgCl pre-gelled disc electrodes will be placed longitudinally (3 cm apart) on the prominent bulge. Once the electrodes are in place, you will perform 5 squat jumps from the same bench position recorded during the familiarization session (i.e., 110° knee angle). The hands will be gripped on the back and trunk position will be the same as before. Just like in the familiarization, the rest between jumps will be about 1 minute. You will be asked
to jump as forcefully and as quickly as possible after presentation of a light signal cue. During the execution of the squat jumps, the surface EMG activity from the right VL will be recorded using a BIOPAC Systems Inc. (Santa Barbara, CA) electromyograph. From the EMG-time traces, the PRT will be measured. This reaction time will correspond to the time period between presentation of the visual cue and the beginning of the associated muscle action as indicated by the corresponding EMG activity.

During the fatigue testing session, you will be asked to once again engage in a light, 5-minute warm-up in the Monark ergometer after the skin of the prominent bulge of the VL is re-shaved. After the warm-up, you will do 1 set of 4 continuous counter-movement jumps using the technique previously learned in the familiarization session (i.e., consistent eccentric range of motion and explosive eccentric-concentric transition). The jumps will be done on the switch mat and the resulting average vertical jump height will be recorded. After a 3-minute rest, you will perform sets of 4 continuous counter-movement jumps with a 15-second rest between sets until the experimenter asks you to stop. Afterwards, the shaved skin will be abraded and cleaned with isopropyl alcohol and electrodes will be placed as described before. The same series of 5 squat jumps will be performed (same knee, trunk, and hand position) and from the EMG-time traces, the premotor reaction time will be measured.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. You may request a copy of your results at any time. If you give us permission by signing this document, results from this study will be made available to the general public through submission to scientific journals and presentations at professional conferences. It is the intent that
publication/presentation of the results will add to the body of knowledge in the related fields of exercise physiology.

Benefits associated with participation in this study include: (1) direct assessment of your reaction time (i.e., your neural conduction velocity); (2) direct assessment of your vertical jump height and ground contact time during jumping (i.e., capability of power production); and, (3) estimation of your anaerobic fitness level during the counter-movement jumps. Possible risks include physical discomfort and soreness of recruited musculature associated with the counter-movement jumps. In addition, you may feel an irritation on the skin area that will be shaved, abraded, and cleared with isopropyl alcohol for the electrodes placement.

Your decision whether or not to participate in this study will not be reflected in your future relations with California State University, Fresno. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without penalty. The Committee on the Protection of Human Subjects at California State University, Fresno has reviewed and approved the procedures for the present research. The Committee may be reached at (559) 278-2083.

If you have any questions/comments, please discuss them with Dr. Jacobo Morales or myself, Daisuke Shibata. For future contact, Dr. Jacobo Morales can be reached at (559) 278-5168 (jacobob@csufresno.edu), and I (Daisuke Shibata) can be reached at (412) 983-3888 (shibata@csufresno.edu). We will be happy to address any questions or concerns you may have.

You will be given a copy of this form for your record.

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE IN THIS STUDY. YOUR SIGNATURE INDICATES THAT YOU HAVE
DECIDED TO PARTICIPATE, HAVING READ THE INFORMATION PROVIDED ABOVE.

______________________________  ____ ________________________
Date        Signature

______________________________  ____ ________________________
Signature of Witness (if any)   Signature of Investigator
California State University, Fresno

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Daisuke Shibata

Type full name as it appears on submission

April, 4 2010

Date