BIOMECHANICAL ANALYSIS AND TRAINING ADAPTATIONS OF DIFFERENT LUNGE PROTOCOLS

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ABSTRACT

This research consisted of four studies that were conducted as acute and chronic studies. Study 1 and Study 3 were conducted to analyse the biomechanical responses of different lunge protocols. Study 2 and Study 4 were conducted to determine and compare the chronic effects of different lunge training programs on physical performances [lunge one repetition maximum (1RM), vertical jump, standing broad jump and change of direction] and muscle architecture. Study 2 and Study 4 also attempted to determine whether there is any relationship between muscle architecture and physical performance. Kinematics, kinetics, muscle activity and fascicle behaviour of both dominant and non-dominant limb were determined and compared between; i) step forward lunge (SFL) and jump forward lunge (JFL) among fifteen university badminton players (Study 1) and ii) 30% 1RM (30FL) and 70% 1RM (70FL) among thirty untrained men (Study 3). Eight weeks effects of different lunge training on physical performance and muscle architecture were determined and compared among thirty recreational badminton players (Study 2) and 30 untrained men (Study 4). Results in the acute studies showed muscle activity, force output and fascicle behaviour were greater during JFL compared to SFL and during 70FL compared to 30FL. Results in chronic studies showed the improvement of lunge 1RM, vertical jump and standing broad jump were greater among JFL compared to SFL training (Study 2) and 70FL compared to 30FL (Study 4). Results also showed that eight weeks of lunge training were enough to induce changes in muscle architecture. Overall, this research provides the findings that showed the different in biomechanical responses of different lunge protocols and the existing relationship between muscle architecture and lunge performance. Besides that, this research also demonstrated how the different in responses later brought to different adaptations in physical performances and muscle architecture adaptation.

ANALISIS BIOMEKANIK DAN ADAPTASI LATIHAN *LUNGE* DENGAN PROTOKOL YANG BERBEZA

ABSTRAK

Penyelidikan ini terdiri daripada empat kajian yang telah dijalankan secara akut dan kronik. Kajian 1 dan Kajian 3 telah dijalankan untuk menganalisa tindak balas biomekanik semasa protokol senaman *lunge* yang berbeza. Kajian 2 dan Kajian 4 telah dijalankan untuk menentukan dan membandingkan kesan kronik latihan *lunge* yang berbeza terhadap prestasi fizikal [satu ulangan maksimum *lunge* (*lunge 1RM*), prestasi lompatan dan ketangkasan] dan seni bina otot. Kajian 2 dan Kajian 4 juga bertujuan untuk menentukan sama ada terdapat hubungan antara seni bina otot dan prestasi fizikal. Kinematik, kinetik, aktiviti otot dan tingkah laku fasikel otot semasa protokol senaman *lunge* yang berbeza dikenalpasti dan dibandingkan antara; i) *lunge* melangkah (SFL) dan *lunge* melompat (JFL) dalam kalangan 15 pemain badminton universiti dan ii) 30% *1RM* (30FL) dan 70% *1RM* (70FL) dalam kalangan 30 lelaki tidak terlatih. Lapan minggu kesan latihan *lunge* yang berbeza terhadap prestasi fizikal dan seni bina otot dikenalpasti dan dibandingkan dalam kalangan 30 pemain badminton rekreasi (Kajian 2) dan 30 lelaki tidak terlatih (Kajian 4). Keputusan dalam kajian akut menunjukkan aktiviti otot, penghasilan daya dan tingkah laku fasikel otot didapati lebih besar semasa JFL berbanding SFL (Kajian 1) dan semasa 70FL berbanding 30FL (Kajian 3). Keputusan dalam kajian kronik menunjukkan peningkatan prestasi fizikal adalah lebih tinggi dalam kalangan kumpulan JFL berbanding SFL (Kajian 2) dan 70FL berbanding 30FL (Kajian 4). Hasil kajian juga menunjukkan bahawa lapan minggu latihan *lunge* mencukupi untuk menyebabkan perubahan pada seni bina otot. Secara keseluruhan, penyelidikan ini menunjukkan terdapat perbezaan dari segi tindak balas biomekanik dan adaptasi latihan yang disebabkan oleh protokol *lunge* yang berbeza. Implikasi kajian juga menunjukkan terdapat hubungan antara seni bina otot dan prestasi *lunge* dan bagaimana perbezaan tindak balas dalam latihan *lunge* membawa kepada adaptasi yang berbeza dari segi prestasi dan seni bina otot.

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ABBREVIATIONS

1RM	One Repetition Maximum
30FL	30 % One Repetition Maximum Forward Lunge
70FL	70 % One Repetition Maximum Forward Lunge
BF	Biceps Femoris
CG	Control Group
COD	Change of Direction
EMG	Electromyography
FL	Fascicle Length
GM	Gluteus Maximus
IFa	Absolute Impact Force
IFr	Relative Impact Force
JFL	Jump Forward Lunge
LG	Lateral Gastrocnemius

MANOVA	Multivariate Analysis of Variance
MCFa	Absolute Mean Concentric Force
MCFr	Relative Mean Concentric Force
MEFa	Absolute Mean Eccentric Force
MEFr	Relative Mean Eccentric Force
MG	Medial Gastrocnemius
MVIC	Maximal Voluntary Isometric Contraction
MT	Muscle Thickness
PA	Pennation Angle
PCFa	Absolute Peak Concentric Force
PCFr	Relative Peak Concentric Force
RF	Rectus Femoris
RM	Repetition Maximum
SFL	Step Forward Lunge
SPSS	Statistical Package of Social Science
ST	Stance Time
TPF	Time to Peak Force
VL	Vastus Lateralis

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VM	Vastus Medialis

CHAPTER 1

INTRODUCTION

1.1 Background of Study

As a way to enhance performance in sports, apart from in-field or in court training, athletes are recommended to adopt strength training into their training routine. Strength training is a type of physical exercise performed to improve muscular strength by gradually increasing the ability to resist force through the use of free weights, machines, or the person's own body weight. Strength training sessions are designed to impose increasingly greater resistance, which in turn stimulates development of muscle strength (Fleck & Kraemer, 2014). Strength training is now widely recognized for its great value for all those interested in optimizing health, fitness and functionality.

Mounting evidences of health benefits from resistance training lends support to its importance in helping individuals to achieve positive adaptation including strength (Kadir, Nadzalan, Yusof, Aiman, & Shapie, 2014; Manolopoulos et al., 2015; Schoenfeld et al., 2014; Shultz et al., 2015), muscular endurance (Aagaard et al., 2011; Manimmanakorn, Hamlin, Ross, Taylor, & Manimmanakorn, 2013; Radaelli et al., 2015), power (Kadir et al., 2014; Lockie, Murphy, Schultz, Knight, & de Jonge, 2012; Van Roie, Delecluse, Coudyzer, Boonen, & Bautmans, 2013), speed (Appleby, Cormie, Cormack, & Newton, 2013; Veliz, Requena, Suarez-Arrones, Newton, & de Villarreal, 2014), and change of direction (Johnson, Burns, & Azevedo, 2013; Sole, Moir, Davis, & Witmer, 2013). The usage of strength training as a part of training to improve performance in sports have been well established such as badminton in which majority of elite badminton athletes adopt strength training in their training program (Sturgess & Newton, 2008). However, it is important to note that strength training need to be well planned as it has been shown that different training programs might stimulate different adaptations (Bloomquist et al., 2013; Earp, 2013; Farup et al., 2012).

In parallel to the expansion of body of knowledge, the strength training programs that is planned to be developed can be referred to a lot of sources which has been proven in researches that had been conducted over the years (Fleck & Kraemer, 2014; Ratamess et al., 2009). Through various researches, the concept of specificity in training has received considerable mention and attention over the past decade (Fleck & Kraemer, 2014). Thus, it is important to analyse the movements performed in a specific sport as the more similar the training activity is to the actual sport movement, the greater the likelihood of positive transfer to performance (Fleck & Kraemer, 2014).

Most movements in sports involve an athlete to split apart their feet so that one foot is in front of the other (Keogh, 1999). Several benefits evolved when performing exercises with one limb such as the ability to reduce bilateral deficit (Sale, 1988), detection of muscular imbalances and the greater proprioceptive demand while performing the split position (Tippett & Voight, 1995). Looking at the criteria of one limb splitted, lunge exercise seems to be an appropriate exercise to be used in training. Additionally, to better train the body to become functional in various directions, lunge exercise is suggested to be included in the training program (Bennie & Hrysomallis, 2005; Sturgess & Newton, 2008; Yap & Brown, 2000).

One of the most performed lunge technique is the forward lunge. Forward lunge started with a front step followed by a backward push. In order to enhance its effectiveness, the forward lunge should be performed with the lead leg been brought as far as possible to the front as in descent phase, the knee should not exceed the toe.

The forward lunge (Figure 1.1) exaggerates the movement that occurs in the lower body during the gait cycle (Crill, Kolba, & Chleboun, 2004). The forward lunge involves: a) hip flexion, extension, and adduction, b) knee flexion, extension, and abduction, c) tibial internal rotation, d) talar plantar flexion and adduction and e) calcaneal eversion (Crill et al., 2004). There are various types of lunge pattern exercises that have been used as assessment tools for measuring strength, flexibility, and balance (Cook, 2003; Crill et al., 2004; Thijs, Van Tiggelen, Willems, De Clercq,

& Witvrouw, 2007). Hybrids of the forward lunge have been used to screen the functional movement of the lower extremities (Cook, 2003; Kritz, Cronin, & Hume, 2009). Given the relevance of the lunge pattern to sport and the necessity of the strength and conditioning specialist to load the movement pattern to enhance performance, lunge training could be one of the most specific resistance exercises to many athletes. However, in order to achieve desired outcomes, the lunge training could be adjusted as different lunge training have also demonstrated different adaptations (Jönhagen, Halvorsen, & Benoit, 2009).

Figure 1.1. Forward lunge used in this study

Badminton is one of the sports that involved a lot of lunge movement in the game. Since its inclusion as an official sport in the 1992 Olympic Games in Barcelona, badminton has increased its popularity worldwide. Badminton is an intermittent sport characterized by multiple intense actions (Sturgess & Newton, 2008) including fast accelerations, decelerations and many explosive movements with changes of direction over short distances (Baker, 1996; Chin, Steininger, So, Clark, & Wong, 1995; Chin et al., 1995; Hughes & Bopf, 2005).

A video-based pilot study had confirmed the relatively high frequency of lunging, approximately 15% of all movements, in a competitive singles games (Farrokhi et al., 2008). The important of lunge in a game could be seen when the player want to retrieve a drop shot where the player need to do a deep lunge to get to the shuttlecock. Sturgess and Newton (2008) had highlighted the importance of the ability to accelerate from receiving stance to retrieving a drop shot. Athletes should accelerate quickly with the lunge to the shuttlecock because reaching the drop shot late will either result in an error or will enable the opponent to easily attack a poorly returned shot. However, having just a good acceleration is not enough as the strength to perform the lunge and maintain stability to reach the shuttlecock is also needed as this will allows them to; a) reach difficult shots; b) execute an effective return shot; and c) conserve energy by executing the shot with comfortable body posture (Sturgess & Newton, 2008).

The usage of lunge as an important movement was not only in badminton, but also in other sports such as during reaching the ball in other racquet sports (tennis and squash), defending or attempting to steal the ball in football and many more.

Throughout the consistency of lunge used in sports, lunge exercises should be used widely as training exercises during strength training program. The inclusion of lunge as training exercises should be beneficial as it will allow athletes or individuals to train and improve their ability for the movement and as a way to overload the athletes or individuals, various methods of lunge could be implemented during training sessions (Baechle & Earle, 2008). This includes putting some weights and includes ballistic movement during the exercise.

Previous studies have shown that different lunge techniques have cause different mechanics during the movement (Escamilla et al., 2010a; Farrokhi et al., 2008; Gresham-Fiegel, House, & Zupan, 2013; Jönhagen et al., 2009; Kim & Yoo, 2013). For example, Flanagan, Wang, Greendale, Azen, and Salem (2004) found the lateral lunge targeted the ankle plantar flexors, producing greater dorsiflexion angles, joint moments, impulse and mechanical energy expenditure compared to forward lunge. In contrast, forward lunge was found to target the hip extensors, producing a greater flexion angle, peak joint moment, joint power, and mechanical energy expenditure compared to lateral lunge. In line with Flanagan et al. (2004), Riemann, Congleton, Ward, and Davies (2013) also found forward lunge to target the hip extensors while lateral lunge prompted greater ankle flexion and greater ankle and knee extensor kinetic contributions.

Previous studies had been conducted on comparing the muscle activity during lunge with different methods (Jönhagen, Halvorsen, et al., 2009; Parker, 1996; Sorensen, 2009) and equipment (Jakobsen, Sundstrup, Andersen, Aagaard, & Andersen, 2013; Kim & Yoo, 2013). Research on lunge has examined the muscle activation on different legs (Thorlund, Damgaard, Roos, & Aagaard, 2012), in fatigue conditions (Longpré, Acker, & Maly, 2014), ratio of muscle activation (Harput, Soylu, Ertan, Ergun, & Mattacola, 2013; Irish, Millward, Wride, Haas, & Shum, 2010), different muscle activation across genders (Hale, Hausselle, & Gonzalez, 2014), and how this compared to other exercises (Fauth, Garceau, Wurm, & Ebben, 2010; Garceau et al., 2010). As such, Kim and Yoo (2013) compared the use of variety of foot wedge boards on vastus medialis (VM) and vastus lateralis (VL) muscle activities and the VM/VL ratios among 20 asymptomatic males. Result demonstrated the use of medial and posterior wedge boards during the lunge exercise can selectively strengthen the VM muscle. All these studies showed that performing different protocols of lunge exercise will provide different acute biomechanical response.

Several studies had also been conducted on the biomechanics of lunge specific to sport. Williams and Kuitunen (2010) conducted a study aimed to determine and compare the ground reaction forces produced during simulated forehand and backhand lunge shot among experienced juniors and developing juniors in squash. Results demonstrated no significant differences between any variables tested when comparing forehand and backhand, thus showed similar force magnitude and kinematics were produced although participants were using alternate legs during the lunge movement. Due to slightly straighter leg with a more flat-footed strike during landing among developing junior group, it was found that this group produced higher impact loading forces and lower initial impact forces. The development junior group has been shown tended to begin knee flexion later, after the foot was completely flat on the ground, suggesting the inexperienced players had not yet developed the appropriate coordination and movement skills, or strength, to reduce this aspect of the impact force (Lees & Hurley, 1995).

Researches on the chronic effects of lunge were not well established. Not many researches have been conducted on determining the effects of lunge as a single training exercise. Bloomfield (2009) in his study examined the effectiveness of six weeks lunge training on balance control among elderly women. Results demonstrated that the exercise group managed to perform lunge with lower forward trunk velocities, lower forward pelvis velocities, lower medial-lateral trunk velocities, and shorter step lengths compared to control group after training. The authors concluded that lunge training would benefit elderly women in terms of improving medial-lateral trunk stability during a lunge by decreasing peak medial-lateral trunk velocity.

Training different kind of lunge might provide different adaptations. For example, study by Jönhagen et al. (2009) have found that a six weeks period of training with walk forward lunge improved hamstring strength, whereas training with jump forward lunge improved sprint running performance. The different of adaptations could be attributed to several factors such as different structural adaptations (Earp et al., 2010) imposed by the different stimuli that was caused by the different methods of training.

Lack of information existed on the fascicle behaviour during lunge movement. Several studies have been conducted on investigating the fascicle behaviour during movements (Finni, Ikegawa, & Komi, 2001; Finni, Ikegawa, Lepola, & Komi, 2003; Ishikawa, Finni, & Komi, 2003; Ito, Kawakami, Ichinose, Fukashiro, & Fukunaga,