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THE EFFECT OF WEARABLE RESISTANCE ON KINEMATICS AND KINETICS OF TYPICAL FOOTWORK TECHNIQUE IN BADMINTON

YU LIN



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THESIS SUBMITTED IN FULFILLMENT OF THE REQUIREMENT
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RECOGNITION

I would like to express my gratitude to all those who helped me complete this thesis. Firstly, I would like to express my deepest appreciation to my supervisors, Prof. Nur Ikhwan bin Mohamad and Dr. Ali bin Md Nadzalan. Their guidance, support, and insight enabled me to face and solve problems that I experienced during my doctoral program. In addition, they encouraged me to have confidence and expand my perspectives as a researcher. I especially appreciate their responsibilities for taking care of my thesis.

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ABSTRACT

This thesis investigated an acute intervention with wearable resistance (WR) training in badminton-specific typical footwork (left-forward (LF) backhand lunges and right-forward (RF) forehand lunges), aiming to improve performance, minimize fatigue and reduce injury risks. Eighteen male university level badminton athletes participated in this project. Kinematics and kinetics were measured during LF and RF with the WR on the lower limb. Different WR loading were recorded with unload (0%), and with loading equivalent to 3%, 6% and 10% of body mass (BM) while performing typical badminton footwork. A larger hip range of motion (ROM) in the sagittal plane while smaller frontal ROM during RF compared with LF. Knee showed smaller frontal and horizontal ROM during LF compared with RF. Ankle had larger dorsiflexion and ROM during RF than LF with moderate WR loadings. Ankle frontal ROM during RF were smaller than LF. Hip showed smaller flexion and internal rotation moments but larger adduction moments during RF compared with LF. RF had larger abduction smaller internal rotation and larger external rotation moments in the knee. Smaller dorsiflexion and plantarflexion moments, inversion and eversion moments was found compared with LF. Under incremental WR loadings, difference was found, indicating different strategies responding the increased WR, suggesting the program of WR training intervention should be tasks-based. LF rely on hip to facilitate movements, whereas RF rely on knee and ankle joint to generate power. LF may exert more loading to knee, thus a slow and gradual increment of WR load should be considered to prevent over loading injuries. Findings may assist the development of badminton-specific movements training program, particularly on badminton court to mimic real-match scenarios, to enhance movement-specific fitness level and reduce motor fatigue, thus improving the on-court performance and minimizing potential injury risks.





KESAN RINTANGAN BOLEH PAKAI KE ATAS KINEMATIK DAN KINETIK TEKNIK PERGERAKAN KAKI DALAM BADMINTON

ABSTRAK

Tesis ini mengkaji intervensi akut latihan khusus pergerakan kaki dalam badminton bagi langkah pukulan belakang tangan kiri (LF), dan langkah pukulan belakang tangan kanan (RF) dengan rintangan boleh pakai (WR), bertujuan meningkatkan prestasi, mengurangkan kelesuan dan mengurangkan risiko kecederaan. Lapan belas pemain badminton lelaki peringkat universiti terlibat dalam projek ini. Kinematik dan kinetik diukur sewaktu LF dan RF dengan WR dibahagian bawah tubuh. Bebanan WR yang berbeza direkodkan bagi tiada bebanan (0%), dan dengan bebanan yang setara dengan 3%, 6% dan 10% daripada berat badan (BM) sewaktu melakukan pergerakan kaki biasa badminton. Dapatan menunjukkan julat pergerakan (ROM) pinggul yang besar di satah sagital sementara ROM lebih kecil di bahagian hadapan sewaktu RF berbanding LF. Lutut menunjukkan ROM hadapan dan langkah hadapan lebih kecil sewaktu LF berbanding RF. ROM sendi buku lali hadapan RF lebih kecil berbanding LF. Pinggul menunjukkan fleksi dan momen putaran dalam lebih kecil tetapi momen tarikan ke dalam lebih besar sewaktu RF berbanding LF. RF mempunyai tolakan keluar yang besar dengan putaran dalam kecil, dan momen putaran luar lebih besar di lutut. Dorsifleksi bersama momen plantarfleksi, momen inversi dan momen eversi didapati lebih kecil berbanding LF. Di bawah peningkatan bebanan WR, perbezaan ditemui, menunjukkan perbezaan strategi dalam tindakbalas kepada peningkatan WR, mencadangkan intervensi program latihan WR seeloknya bersifat khusus kepada tugas. LF bergantung kepada pinggul untuk membantu pergerakan, manakala RF bergantung kepada lutut dan sendi buku lali untuk menghadilkan kuasa. LF mungkin menghasilkan lebih beban kepada lutut, oleh itu peningkatan sedikit demi sedikit secara pelahan-lahan beban WR perlu dipertimbangkan untuk mengelakkan kecederaan lebihan bebanan. Dapatan mungkin membantu pembangunan program latihan pergerakan khusus badminton, terutamanya dalam gelanggang bagi menyerupai senario pertandingan sebenar, untuk meningkatkan tahap kecergasan khusus mengikut pergerakan dan mengurangkan kelesuan motor, sekaligus meningkatkan prestasi dalam gelanggang dan mengurangkan risiko kecederaan.





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LIST OF ABBREVIATIONS

ASIS	Anterior Superior Iliac Spine
BM	Body Mass
BWF	Badminton World Federation
CHS	Club Head Speed
CMJ	Counter Movement Jump
CT	Contact Time
FT	Flight Time
FV	Vertical Ground Reaction Force
GRF	Ground Reaction Forces
LF	Left Forward Backhand Lunge
LVRT	Light Variable Resistance Training
LWR	Limb Wearable Resistance
PCA	Principal Component Analysis
PSIS	Posterior Superior Iliac Spine
RF	Right Forward Forehand Lunge
SF	Step Frequency
SPSS	Statistical Packages for the Social Science
SL	Step Length
SSC	Stretch-Shortening Cycle
UL	Loading of Unload
UWR	Upper Wearable Resistance
WR	Wearable Resistance



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- I. Ethics
- II. Data Collection
- III. Papers

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Badminton is a sport involving hand grasping a racket to hit the ball (called shuttlecock in badminton) over a net in the middle court. This sport often involves two “singles” players (with one player in each side of the net on court) and/or four “doubles” players (with two players in each side of the net on court). The sport had a history of over 2000 years and modern badminton was firstly developed at around 1850s. The sport of badminton was firstly included into Olympic event in the 1992 Barcelona Olympic Games. The sport now includes five different matches as per athletes on court and different genders, specifically the male and female singles, male and female doubles, and mixed doubles. The badminton is one of the most widely played sports in the world with high popularity in most Asian countries (such as China, Japan, Korea, Malaysia and Indonesia), European countries (such as Denmark and UK), and other continental



or countries as well. The Badminton World Federation (BWF) reported that there are over 30,800 registered players from 170 regions and/or countries participated in the international competitions or tournaments around the world (Badminton World Federation, 2021).

The sport is currently governed by the Badminton World Federation (BWF), which was originally formed as the International Badminton Federation (IBF) in 1934 with nine founding countries, including England, Ireland, Scotland, Wales, Denmark, Holland, New Zealand, and France. Now, there are 176 member associations in the five continental (badminton Asia, badminton Europe, badminton Pan American, badminton confederation of Africa, and Badminton Oceania) confederations around the world (Badminton World Federation, 2021). As documented from the Badminton World Federation (BWF) tournament, the BWF organized several badminton events or matched globally, including the badminton competition at the Olympic Games in co-operation with the International Olympic Committee (IOC) every four years, the BWF world championships every year and the BWF world junior championships every year to identify potential young badminton players, the BWF para-badminton world championships every two-year, the BWF Thomas cup for male team and the BWF Uber Cup for female team every two-year, the BWF Sudirman Cup every two-year, and the BWF world senior championships every two-year (Badminton World Federation, 2021). There are also plenty of regional, national and continental badminton competitions, or tournament being held in many countries every year.

Badminton is the fastest racket sport, which requires a high fitness level with comprehensive skills of motion speed and agility, endurance and stamina, strength and





power, and delicate hand skills and racket touches. The formal badminton games are often played on a rectangle indoor court, and the scores are achieved by hitting the shuttlecock with racket and landing within the opponent's court (including on lines as well). While recreational badminton may be played anywhere, commonly found as a recreational activity during casual occasion on a beach, yard or any open field. Due to the passionate and enthusiastic spirit from this sport, the badminton players, either elite athletes or novice amateurs, aimed to improve their skills and techniques. Players of lower-level watched the recorded game video of the world-top athletes to study, analyze and imitate movement skills, including net shot, net lift, net kill, back-court clear, drop shot, and smash, etc. However, few people pay attention to the footwork techniques in professional athletes, with quite a few studies focusing on hand techniques but not enough on footwork. The footwork drives badminton players to move in a proper position on the badminton court and facilitate the next shuttlecock shot, hit, strike, or smash according the position where the shuttlecock is returned from the opponent.

Base on the fact of the crucial role of badminton footwork and neglectance from many badminton players, therefore, it is commonly observed clumsy footwork but skilled hand techniques among badminton players in badminton venues or court. They usually hit the shuttle fast and powerful, but their footwork is messy when they start moving slowly, and sometimes they even lose balance while moving. In fact, badminton is a kind of sport requiring high flexibility of movements. During singles badminton match, athletes performed movements of immediate initiation and stopping, constant forward court, backward court, left court, and right court moving, steering, and leaps on a 35 square-meters (singles) court (Xiao, 2011). All required the physical capability of movement speed and agility, which may affect the shot accuracy and quality, thus





influencing the athletic performance. Wei (2008) analyzed the movement statistics of Chinese badminton team players in the 17 international badminton singles game between 2005 and 2006. It was found that the frequently used footwork in men and women athletes were the left backcourt kick-off, right-forward lunging step, left-forward lunging step, right forehand step, and sudden stop, fast move, jump, quick run. Most basic action involved stretching in lower limbs (Jiang, 1997), which further consolidate the importance of footwork during badminton playing.

The development and application of biomechanics technology provide technical support for the study of human movements. The technology includes traditionally employed 2D video analysis, 3D motion capture, and inertial measurement unit (IMU) wearables. There are also several musculoskeletal modeling approach, such as the open access OpenSim musculoskeletal modelling platform. This technique is recently employed in our study of patellofemoral joint loadings during directional badminton lunging steps (Yu et al., 2021), and the further muscle activation and contribution for joint loadings are revealed to facilitate the understanding of the lunge movements. With the help of modern science and technology, the characteristics of athletes, technical movements could be recorded with more detailed information, and the improper technical movements could be corrected and improved from detailed analysis of athletes' technical movements, thus laying a foundation for the improvement of sports performance.

Lunge step is one of the most frequently executed footwork in badminton and accounts for over 15% of the total number of movements during a single game (Kuntze, Mansfield, & Sellers, 2010). As for the footwork training for badminton players,





various means and methods emerged endlessly. For example, the traditionally and commonly used included, 1) carrying out the single footwork and group footwork training repeatedly; 2) fixed-line training on the court; and 3) multi-shuttle training (exercise the moving footwork while practicing the sense of the shuttle). The above three methods of badminton footwork training were relatively single and boring, and the effect on the improvement of performance was slow as reported in the literature (Lei, 2016).

At present, the research of badminton footwork training is mostly on “fixed footwork training.” Fixed footwork training is important, but also difficult to avoid the repeated single mode of training. Badminton footwork is associated with a number of physical qualities. The efficient footwork training methods should not start from the point of simple stimulation exercises. It should be more stimulus to practical application, from the speed, endurance, strength, flexibility, and comprehensive training. It should also adopt various stimulus practices means close to the actual competition. A more significant effect from training is the power of the lower extremities and trunk cores, which have key roles in controlling fast-moving (Chen, Mok, Lee, & Lam, 2015; Huang, Lee, Tsai, & Liao, 2014; Lin, Hua, Huang, Lee, & Liao, 2015; Thijs, Tiggelen, Willems, Clercq, & Witvrouw, 2007). Badminton-specific speed training improves the quality of the athlete's footwork (Yu, Zhao, 2012). Based on the strength of the sensitive quality, it is the premise of the movement with flexible footwork on the badminton court (Chen, 1998). Tsai (2007) and Huang (2014) confirmed that during the badminton footwork movements, Rectus Femoris and Vastus Medialis activity levels increased. While performing the kick-off step, the activity levels of the Quadriceps and Gastrocnemius increased.





Badminton requires players to be agile in all aspects of the footwork, yet a weak link existed. According to different physical levels, athletes should be specific for resistance training to develop strength in the lower extremity. Yang (2016) suggested that the fast contraction and strong plyometrics combined training could be helpful for players with poor smash and vertical jump abilities and the stretch or defects in lower limb strength. Training includes jumping squat, deep squat, high turn, jump legs, jump on one foot, etc. For players with poor lateral moving ability and weaknesses in the speed-sensitive link, it is necessary to solve this problem through lateral moving reinforcement training and speed training, including lateral jumping, elastic rope, load lateral footwork, etc. For players with poor ability to move in the backcourt and weakness in coordination and flexibility, it needs to be solved through the backward step strength training and speed training, including backward hop, elastic rope, backward step with load, etc. The purpose of high-intensity resistance training is to increase the strength and explosive force of the lower limbs, to improve the agility and strength of footwork, and improve performance. During the direct training of footwork ability, several training options are available to increase speed and agility adaptation. However, this adaptation needs to be specific for the sport and athlete requirements (Baker, 1996). Though non-specific training plays a role in certain phases of a periodized plan, the transference of non-specific strength and power to speed and agility is usually minimal (Cronin, Ogden, Lawton, & Brughelli, 2007). Based on the principle of training specificity, training options should replicate the characteristics of a sporting action so that training adaptations will optimally transfer to the sporting action (Cronin & Hansen, 2006).





Wearable resistance (WR) training involved attaching external load directly to the body during sporting movements and has been incorporated into physical training programs for decades (Bosco, 1985; Bosco, Rusko, & Hirvonen, 1986; Ropret, Kukolj, Ugarkovic, Matavulj, & Jaric, 1998). Encouraging upper body WR training outcomes included acutely increased leg stiffness and running economy after a series of loaded stride outs (Barnes, Hopkins, McGuigan, & Kilding, 2015) and significantly improved vertical jump performance after three weeks of training (Bosco, 1985; Bosco et al., 1986). Recent advances in WR technology (i.e., the LilaTM ExogenTM compression-based suit) Wearable resistance (WR) is a form of external loading which enables high-velocity sport-specific movements to occur with an external load attached to different sections of the body (Macadam, Cronin, & Simperingham, 2017a). This form of training incorporated an added load but facilitated movement and acceleration through a sport-specific full range of motion. This specificity of movement promotes intermuscular coordination, which has been shown to increase transference to sports performance. The form of loading has been previously used in other sport-specific actions such as sprint-running, jumping, and power cleans without unduly affecting the kinematics of the actions (Macadam, Cronin, & Simperingham, 2017a; Macadam, Simperingham, & Cronin, 2017b; Marriner, Cronin, & Macadam, 2017).

Lower limb WR can be used to provide a rotational overload to the hip and knee joints during running. The limb loading will change the inertia properties of the limb, potentially resulting in changes to movement mechanics (Martin & Cavanagh, 1990). Thus, it is important to understand how lower limb WR changes the footwork in badminton movement mechanics prior to further investigating its application as a training tool. Although this form of loading has yet to be examined during the footwork





in badminton, its application in sprints and jumping studies have been evaluated. The purpose of this project was to compare the acute changes in kinematics and kinetics effects while wearing the wearable resistance (WR) to the lower limb, with WR loading of unload (UL, **0%BM**), or equivalent to **3%**, **6%**, or **10%** body mass (**BM**) in typical (Left-forward and Right-forward lunges) footwork techniques of badminton.

1.2 Problem Statement

In the training of athletes' speed, various means and methods emerged endlessly. No matter the high-intensity resistance training (Melick, 2013), squat jump and reverse squat jump (Kraemer, Hakkinen, Triplett-Mcbride, et al., 2003). The purpose was to increase the lower limb strength and explosive force (Alemdaroglu, 2012), so as to improve athletic performance. In a direct training of speed ability, the resistance sprint training has received more attention and acceptance from both the athletes and the trainer (Corn, Knudson, 2003; Lockie, Murphy, Spinks, 2003; Zafeiridis, Saraslanidis, Manou, et al., 2005).

Currently, there are many forms of this kind of training with extra resistance, and the following six were commonly used, for example, wearing a weight belt or vest (Clark, Stearne, Walts, Miller, 2010), adding body weight (Smirnov, 1978), pulling a parachute (Alcaraz, 2008), running uphill (Paradisi, Cooke, 2006), treadmill resistance (Ross, Ratamess, Hoffman, et al., 2009), and pulling a heavy object (Lockie, Murphy, Spinks, 2003). Among all these techniques, the additional weight directly on the limb link training method has aroused wide attention in recent studies and training





application. In frescoes in ancient Greece, there are records of athletes holding halteres in the long jump (Lenoir, Clercq, Laporte, 2005; Minetti, Ardigo, 2002).

Computer simulation research and biomechanical experiment research have confirmed that the extra load with appropriate quality of handholding would improve the long jump performance (Butcher, Bertram, 2004). Weight-bearing running training is the running activity with an extra load of a specified mass attached to a specific position of the human body. The size, distribution, and attachment position of the added mass may affect the ground reaction force and ultimately affect the performance of the movement. In fact, weight-bearing running is a relatively common means of special speed training (Bennett, 2009; Zhang, 2006).



role of muscle stretching and contraction, thus improving the muscle rigidity in the buffer stage and increasing the muscle's capacity to bear the load. However, the implementation of this training method may also bring several negative effects. The kinematic parameters of running (speed, range of motion) may be complicated by the fact that weight is applied directly to the body. Will the kinematic parameters of lower limbs change as well? As a major sport event with strict requirements on lower limb movements in competitive sports, does this change promote or hinder athletic performance? These are the problems that athletes and coaches pay close attention to. If this training mode affects the original technical movement or even causes the sports injury in training, then the positive effect of this training mode would lose its significance.





The scientific basis and practical application value of the training with additional weight limbs were controversial both among coaches and sports science researchers. However, at the present stage, although there were many studies on resistance to drag, the studies were all focused on uphill running, pulling heavy weights, and pulling parachutes. Due to the difficulty in experimental control, studies on additional limb weight have been rarely reported. Bennett (2009) has shown the added mass and increased moment of inertia in the lower extremities for the sprint kinematics characteristics, the influence of the results found in the thighs and legs on the radius of gyration with the additional 10% link quality, sprint time was decreased. While no statistical difference, this prompted the body additional weight training methods to develop a sprinter's special forces and ultimately improve the performance. Moreover, further kinematic data showed that this training method has no significant adverse effect on the technical structure of movement and would not cause the injury of the late group due to the excessive stride length (Bennett, 2009). However, the sample size of this study was small, and the standard deviation was large, which were the defects of this study. The author only analyzed the effect of the training method on the lower limbs from the perspective of kinematics.

The above literature analyzed the impact of weight-bearing running on athletic performance from a kinematic perspective. However, how will the ground reaction force change under the loading condition, and how will the motion range of the ankle, knee, and hip joints of the lower extremity change, and how will it affect the kinematic characteristics and motion performance. More detailed dynamic analysis and explanation of training effect have not been reported in the literature.





The method of body mass added exercise training could be used to develop athletes' special strength and improve their performance, but its scientific basis was not clear. The study with added mass in the body to perform badminton footwork could reveal the kinematic characteristics and change of athletic performance, and explain the WR method of training effect, to further optimize the training methods into the application of badminton footwork training, thus preventing sports injury and improving performance.

1.3 Objectives of Study

Objective 1: This thesis aimed to explore the kinematics of the footwork training method in badminton with extra loading to the lower limb and analyze the changes in the joint angles and range of motion of the lower limb joints during the typical footwork in badminton. Further, investigate whether this training method will cause changes in the athletes' technical movements or even induce over-loading, thus exposed to injuries.

Objective 2: This thesis aimed to explore the changes of kinematics and kinetics of the hip, knee, and ankle joint while external loading parameters are changed and further reveal the mechanism of motor regulation of the lower limb weight-bearing footwork in badminton players.

Objective 3: This thesis aimed to integrate the kinematic and kinetic changes as presented in the 1st and 2nd objective, further investigate the acute biomechanical response for the development of badminton-specific footwork training.





Objective 4: This thesis aimed to summarise all theoretical information and practical knowledge developed from the biomechanical experiments of typical badminton lunges with wearable resistance loading. Thus, findings would assist the development of new training programs and schemes, thus providing reference, implication, and potential new directions of footwork training.

1.4 Conceptual Framework of Study

In this project, the additional (**3%, 6%, 10%**) BM (body mass) wearable resistance (WR) loads attached to the lower limb will be used as the intervention factors. The thigh is $2/3WR$, and the shank is $1/3WR$. The multi-area distribution is evenly placed in the front and back. The kinematics (marker trajectories) and kinetics (ground reaction force) of the lower limb will be collected while the players performed the typical (Left-forward backhand and Right-forward forehand) badminton lunging footwork, and the data are processed in the OpenSim musculoskeletal modeling software to calculate the experimental results (joint angles and moments). Lastly, the influence of different WR masses on the kinematics and kinetics of the lower extremity during the typical badminton footwork will be discussed. The main technical outline of this thesis is as follows (*Figure 1.1*).



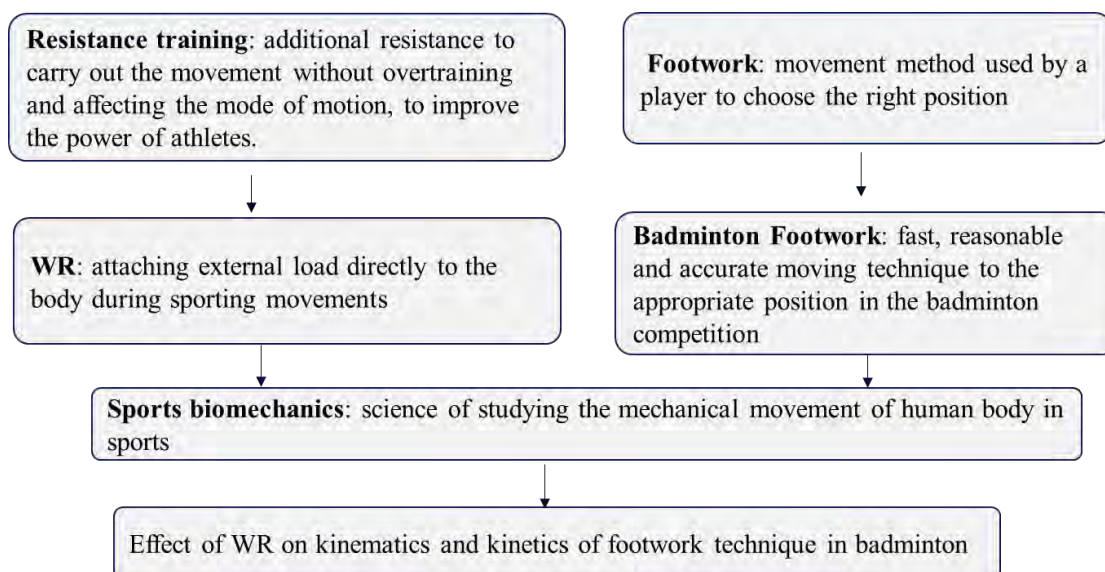


Figure 1.1. Technical outline of this thesis

1.5 Research Hypothesis

According to previous studies and relevant experimental results from the early stage, the hypothesis of this study are as follow:

Hypothesis 1: Spatial and temporal parameters of typical badminton footwork with loaded lower limbs with different WR loads will show significant difference. Specifically, the supporting (stance) time and lunge approaching velocity would be different between the **LF** and **RF** lunges. The attached WR (**3%BM**, **6%BM**, and **10%BM**) loadings to the lower limb would show different supporting time and approaching velocity compared to the unloaded (**0%BM**) condition.



Hypothesis 2: Kinematic (maximal and minimal joint angles, and ROM) parameters of the typical badminton footwork with attached WR loads would be different. The angles (maximal and minimal angle) and ranges of motion (ROM) of the hip, knee, and ankle joints may show significance between the **LF** and **RF** lunges. The hip, knee and ankle joints may present different motion patterns in response to the different **WR** conditions compared to the unloaded (**0%BM**) condition.

Hypothesis 3: Kinetic (maximal and minimal joint moments) parameters of the typical badminton footwork with attached WR loads would be significantly different compared to the unloaded (**0%BM**) condition. The hip (maximal) flexion moments may be different between the **LF** and **RF** lunges. The knee may present larger abduction moments but larger internal rotation moments in the **LF** lunges. Smaller dorsiflexion and plantarflexion moment may be found during the **RF** lunges compared to the **LF** lunges.

Hypothesis 4: Joint stiffness (change of joint moments divided by change of joint angles) of typical badminton footwork with different WR loads would show significance. The **LF** and **RF** lunges may show difference in the joint stiffness under the incremental WR loading conditions. The hip, knee and ankle joint stiffness may be different as acute response and adjustment to the WR loads in the directional lunges.

