博士論文

Risk factor assessment of badminton injuries

using epidemiological surveillance and medical check-up

and badminton skill teaching method for injury prevention

（疫学調査・メディカルチェックを用いた

バドミントンでの損傷危険因子評価および

外傷・障害予防に向けたバドミントン技術教授法）

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CONTENTS OF THE THESIS

List of abbreviations

Abbreviation	Term
ANOVA	analysis of variance
BMI	body mass index
CI	confidence interval
D	dominant
ER	external rotation
FMS	functional movement systems
FIFA 11+	Fédération Internationale de Football Association 11+
GIRD	glenohumeral internal rotation deficit
HBD	heel buttock distance
IR	internal rotation
ICC	intraclass correlation coefficient
IQR	interquartile range
ND	nondominant
OR	odds ratio
R	right
ROM	range of motion

Abbreviation	Term
SD	standard deviation
SEBT	star excursion balance test
SLR	straight leg raising
TROM	total range of motion
VAS	visual analog scale
yr	year
50m	50 meters run
1000m	1000 meters run

Chapter 1

Introduction

Badminton is a non-contact racket sport with more than 330 million people playing worldwide (BWF, 2020). It requires players to perform repetitive overhead motion, with shoulder rotation (Fahlström et al., 2006) and also requires players to perform lunge motions, side stepping, jumps, running and quick directional changes (Shariff et al., 2009; Kuntze et al., 2009) while retrieving a shuttlecock with stroking techniques that vary from relatively slow to quick and deceptive movements. Based on these characteristics of badminton, physical strength, coordination, body range of motion (ROM), agility and balance are required (Lo and Stark, 1991; Brahms, 2014). Overhead stroke, approximately 44.6%, is the most crucial tactical stroke (Grice, 2008) that is followed by lob (23.4%), net (18.1%) and others (13.9%) in men's singles match (Phomsoupha and Laffaye, 2015) and is approximately 57%, followed by lob (15.1%), net (15.1%) and others (12.8%) in women's singles match (Ming et al., 2008; Phomsoupha and Laffaye, 2015).

Similar to other overhead motion sports, badminton players perform trunk rotation to transfer the force generated by ground reaction. And to complete the unnatural and highly dynamic overhead motion stroke, force transfer from lower limbs to upper limbs is generated (Van der Hoeven and Kibler, 2006). Due to these characteristics of badminton, injuries and pain frequently occur. To understand injury risk factors and mechanisms and to prevent injuries, the epidemiological perspective with the four-step sequence has been useful and applied (Figure 1-1; Bahr and Krosshaug, 2005). Firstly, the magnitude of the injury problem must be identified and described in terms of the incidence and severity. Secondly, the risk factors and mechanisms of sport injuries must be identified. Thirdly, preventive methods that are likely to reduce the injury risk are introduced. Finally, the effectiveness of the prevention methods must be evaluated by repeating the first step (Van Mechelen et al., 1992).

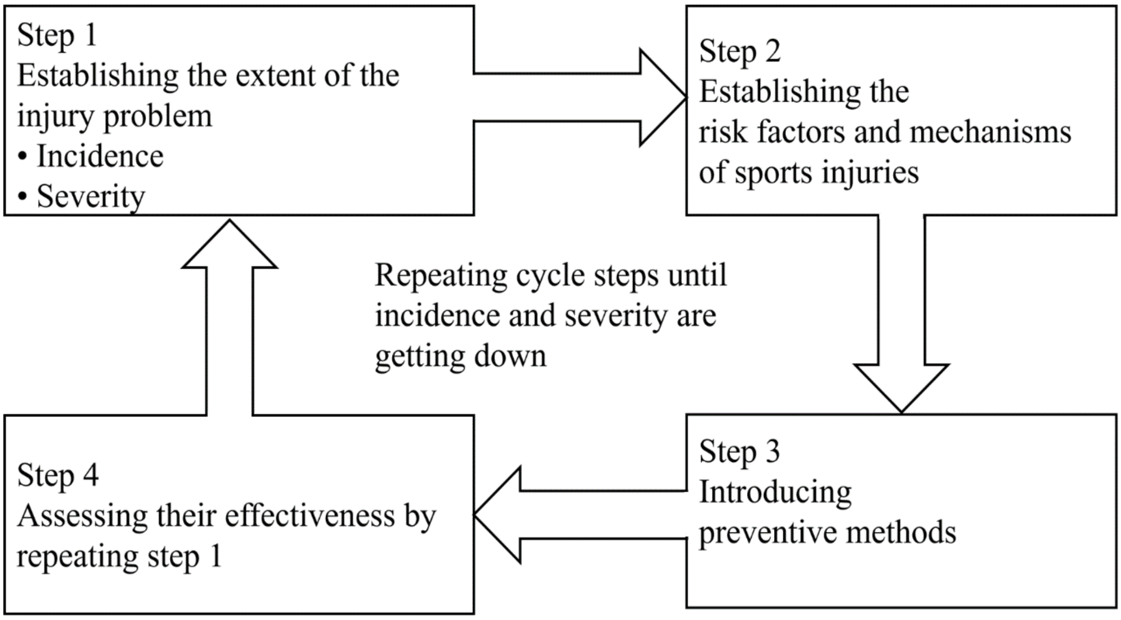


Figure 1-1. Four-step sequence of sports injury prevention (Van Mechelen W et al., Sports Med 1992).

In this thesis, shoulder injuries/pains and lumbar injuries/pains are the key points. In chapter 1, epidemiology and risk factors of badminton injuries, and biomechanics of forehand overhead stroke motion are reviewed. Then, based on the review, the purpose of this thesis will be presented using the epidemiological perspective with the four-step sequence.

1.1. Epidemiology of badminton-related injuries and pains

In badminton injuries, 74% of injuries are overuse injuries, and 26% are traumatic injuries including strain (12%), sprain (11%) and fracture (1.5%) (Jørgensen and Winge, 1987). Traumatic injuries often occur in lower extremity (63%), followed by upper extremity (18.1%), and back and waist (16.6%) (Shariff et al., 2009). Regarding injury sites, there are some controversies among literatures. In lower limbs, some study reported that ankle was the most common injury site (Hensley and Paup, 1979; Krøner et al., 1990) whereas other studies reported that knee was the most common injury site (Shariff et al., 2009). In upper limbs, shoulder (Jørgensen and Winge, 1987; Shariff et al., 2009) was reported the most common injury site in some researches whereas another study reported elbow (Hensley and Paup, 1979). In addition, trunk injuries were recognized as the second most common in badminton players aged 13-16 years (Goh et al., 2013) whereas other studies reported that the injury incidence of trunk was lower (Jørgensen and Winge, 1987; Krøner et al., 1990; Shariff et al., 2009). Regarding badminton-related pain, two previous studies with small sample sizes were found. One study revealed that among players aged 14-18 years, 27.6% complained about shoulder pain and 35.4% complained about lumbar pain (Petrinovic et al., 2016). Another study of overhead players which include badminton players revealed that foot pain was the most common (17.9%), knee pain ranked the second (14.7%) and shoulder/elbow pain came the third (9.5%) (Sekiguchi et al., 2017). Regarding badminton players, shoulder pain was caused by subacromial impingement, instability or scapulothoracic dyskinesia that approximately 27.6%-52.6% of badminton players experienced shoulder pain (Jørgensen and Winge, 1987; Aroma et al., 2015; Petrinovic et al., 2016). However, the results of badminton-related pain were unspecific.

1.2. Risk factors of badminton injuries using epidemiological surveillance and medical check-up

Previous studies of epidemiological surveillance revealed that increased age (Hoy et al., 1994; Miyake et al., 2016; Marchena-Rodriguez et al., 2020), female gender (Miyake et al., 2016; Marchena-Rodriguez et al., 2020), increased badminton hours weekly (Jørgensen and Winge, 1987), badminton match (Miyake et al., 2016) and low badminton level (Jørgensen and Winge, 1987) were risk factors of badminton injuries. However, studies on risk factors for badminton-related pain, especially for shoulder pain and lumbar pain using epidemiological surveillance have not been found.

As for studies on badminton injuries using medical check-up, certain tests, including visual analog scale (VAS), shoulder ROM and shoulder ROM strength were used to study risk factors caused shoulder injury and pain. Previous studies revealed that the intensities of shoulder pain assessed by VAS were mean at 60 ± 7 mm in tournament level badminton players and at 56 ± 23 mm in amateur badminton players. The shoulder pain was related to sleeping disturbances, changes in badminton play habits and it also affected work activities and daily living (Fahlström et al., 2006, Fahlström and Söderman, 2007).

With respect to shoulder ROM of badminton players, total range of motion (TROM), that is internal rotation (IR) + external rotation (ER), on the dominant side was reduced more than the nondominant side (Couppe et al., 2014; Jaime et al., 2019). Decreased IR and increased ER on the dominant shoulder were common findings, but no significant differences were observed between players with shoulder pain and those without (Fahlström et al., 2006; Fernandez-Fernandez et al., 2019). Meanwhile, significant increased ER absolute strength on the nondominant side was found in female players (Jaime et al., 2019) while no significant differences of rotational strength were found between dominant and nondominant side in male players (Couppe et al., 2014; Fernandez-Fernandez et al., 2019). However, studies on risk factors of badminton injuries using medical check-up are scarce and no intervention studies on reduction of injury associated with badminton have been found.

1.3. Biomechanics of badminton forehand overhead stroke

Badminton forehand overhead stroke is recognized as the fundamental (Huang et al., 2002) and the most typical skill (Tsai et al., 2005). Conventionally, forehand overhead stroke is divided into four phases, that is, preparation, acceleration, hit, and follow-through (Figure 1-2; Lo and Stark, 1991).

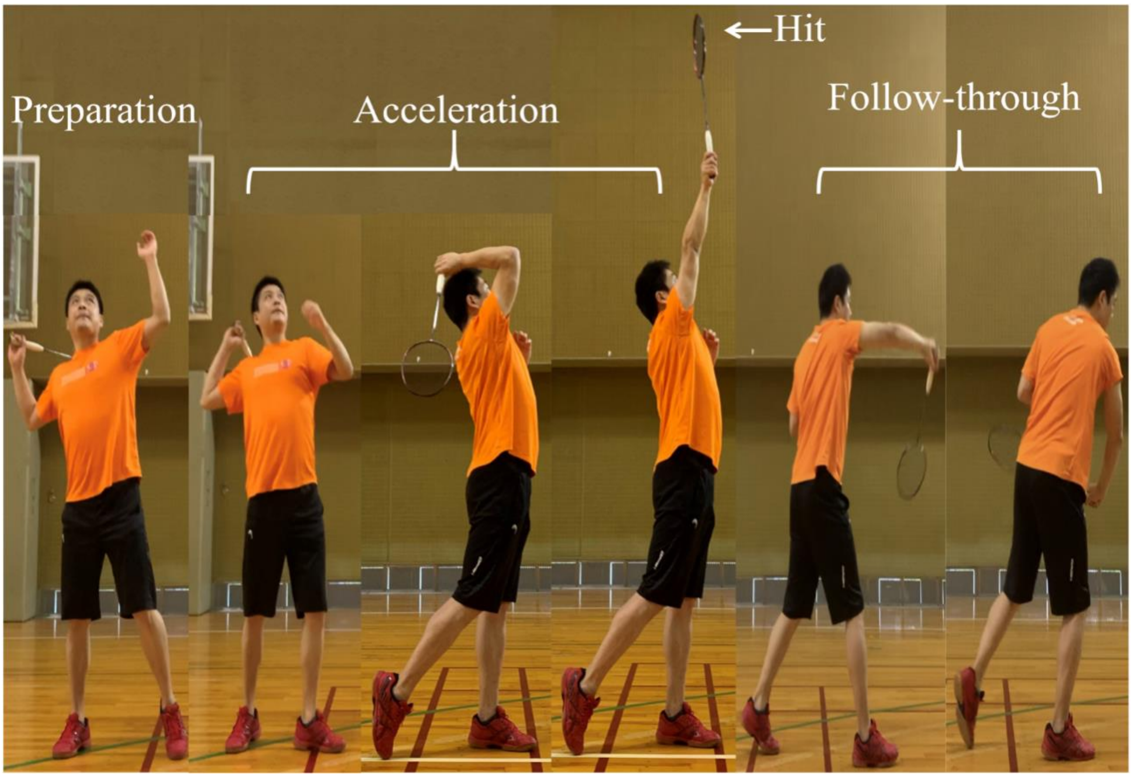


Figure 1-2. Four phases of badminton forehand overhead stroke motion.

The duration time of the four phases, from the start of the preparation phase to the end of the follow-through phase approximates one second. The phase of the preparation takes approximately three quarters of one second to perform the motions as following: (1) moving the center of gravity followed by the dominant side leg step in a posterior and slightly lateral direction, (2) the shoulder is extended and adducted and the wrist is extended leading to the racket-head to point upward, (3) pointing the nondominant hand toward the shuttlecock to sustain the balance posture. Acceleration is a highly dynamic phase consisting of a backswing and a forward swing. Two factors of the acceleration phase dominate the effects of hit: (1) adequate performance of the backswing forward swing which need players perform weight shift, trunk rotation, racket-head backswing, shoulder adduction and forearm rotation smoothly and simultaneously, (2) the length of the kinematic chain at the moment of hitting the shuttlecock. From preparation to hit, upper limb muscles, such as biceps brachii, triceps brachii, extensor carpi radialis and flexor carpi ulnaris, were activated. At a constant time before the phase of hit, the peak electromyographic amplitude appears in the triceps brachii, extensor carpi radialis, flexor carpi ulnaris and trapezius (Sakurai and Ohtsuki, 2000). After the hit, players perform the follow-through phase to dissipate excess momentum by crossing the racket to the contralateral side while swing the rear foot to the front foot (Grice, 2008; Brahms, 2014; Zhang et al., 2016).

Previous studies have revealed that skilled players used more forearm supination, more trunk rotation and more shoulder rotation than novices (Tang et al., 1995; Zhang et al., 2016; Matsunaga and Kaneoka, 2018). Moreover, compared with novices, skilled players showed a more constant time from peak electromyographic amplitude to hit. Immediately after hit, the electromyographic activity of flexor carpi radialis and triceps brachii decreased in skillful players while novices showed continued electromyographic activity after hit (Sakurai and Ohtsuki, 2000). A case report of an elite junior badminton player revealed that repetitive forehand overhead strokes from acceleration to follow-through were likely to cause a stress fracture to the humeral epiphysis (Boyd and Batt, 1997). However, as far as we have searched, there were no studies of laboratory-based motion capture systems on the associations between shoulder and lumbar injuries with forehand overhead stroke techniques.

Improper (poor or inexperienced) overhead motions producing abnormal biomechanics that not only negatively affect overhead motion performance, but also lead to injuries (Olsen et al., 2006; Jayanthi and Esser, 2013). Proper forehand overhead stroke techniques and coaching approaches are important for coaches and badminton players, especially for child and novice players to learn, correct and improve forehand overhead stroke techniques, decrease the joint loading and possibly prevent upper limb and lumbar injuries.

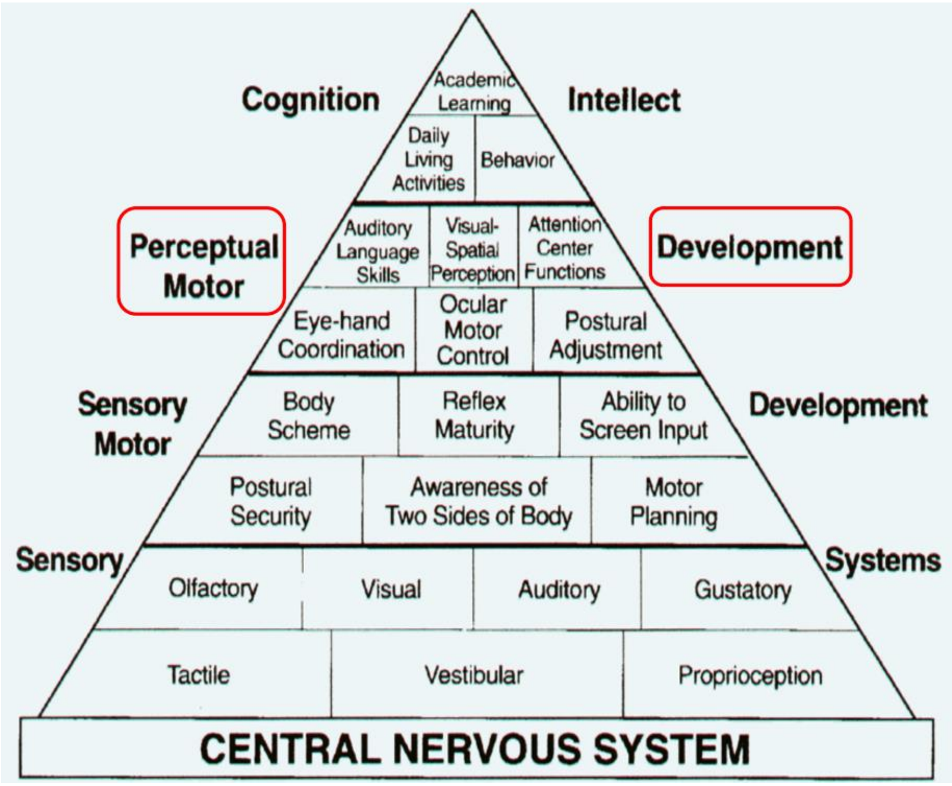


Figure 1-3. Pyramid of motor development and learning (Williams and Shellenberger, 1996).

Recognition and motor abilities of childhood are immature. According to the motor development and learning pyramid (Figure 1-3), the period of perceptual motor development (red line) is recognized as context-specific motor skills and skillful period (7 years- adulthood). The period of context-specific motor skills concerns the refinement and elaboration of motor skills and regularly entails the complicated combination of movements, as well as the transformation of qualitative cognitive. And the skillful period involves a child/adolescent in an environment of motor abilities whereby they gain very specific refinement of motor skills to achieve mastery (Favazza and Siperstein, 2016). Hence, to learn and develop badminton skills better, motor abilities as well as proper motor skills should be highlighted before academic learning period. Nevertheless, no studies on forehand overhead stroke motion acquisition and correcting have been found.

1.4. Purpose and contents of this thesis

The observations from the previous studies above, epidemiology and risk factors of badminton injuries and biomechanics of forehand overhead stroke have been studied, there were few studies that have used medical check-up to investigate risk factors of badminton injury. We have not found teaching studies of badminton motor skills for child players and novices. We have not found injury prevention studies on injury rates or pain complaints as well. Additionally, epidemiology of injury and pain related to badminton in school-aged badminton players is not well understood.

Therefore, the purposes of this thesis are to detect risk factors of badminton injuries based on epidemiological surveillance and medical check-up, to perform badminton forehand overhead stroke skill teaching to improve motor skill acquisition and to improve physical fitness using neuromuscular training so that badminton injury prevention can be enhanced. Statements of the specifical studies are as follows:

(1) Study 1 (Chapter 2): Identifying problems causing injuries is the first step to prevent sports injuries. In this study, we investigated epidemiology of badminton pains and injuries in elementary school-aged badminton players (7-12 years old) and university badminton players (18-22 years old). Then, we identified risk factors of badminton injuries based on the epidemiological surveillance.

Hypothesis: (1) Incidence of badminton injury and pain show an upward trend with increasing age. (2) Training hours of per week is a risk factor for badminton injuries.

(2) Study 2 (Chapter 3): As the association of badminton injuries and biomechanics of forehand overhead stroke is identified, it is essential to explore teaching and learning approaches for coaches, players, especially for child players whose recognition, motor abilities, and badminton techniques are immature. Thus, in this study a teaching method for forehand overhead stroke using task analysis (complex tasks are broken into subtasks) was performed.

Hypothesis: The teaching method using task analysis is effective in learning forehand overhead stroke motion for novice high school students.

(3) Study 3 (Chapter 4): Physical dysfunction is likely to cause badminton injuries. In this study, medical check-up was utilized to attempt to detect risk factors of badminton injuries. Firstly, we compared physical fitness between the elementary school-aged badminton players and university badminton players so that we can provide accurate references for badminton players. We also investigated the magnitude of badminton pain using visual analog scale (VAS) which is a medical check-up method of evaluating body pain. Then, we identified the risk factors (physical dysfunction) for shoulder pain and lumbar pain.

Hypothesis: GIRD (Glenohumeral internal rotation deficit), insufficient shoulder ER gain, weak balance ability and decreased trunk rotation are risk factors for shoulder pain in university badminton players.

(4) Study 4 (Chapter 5): To detect the physical dysfunction using medical check-up, Study 3 can help us identify badminton players who may be at a risk of injury. In order to improve physical fitness and to prevent badminton injuries, a neuromuscular training program consisting of core stability training, hamstrings strength training and dynamic balance was performed in the university badminton players.

Hypothesis: The injury incidence of the intervention group significantly decreases compared with the control group over the controlled trial period of 6 months, and there are significant differences on physical fitness parameters between the intervention group and the control group.

Then, in Chapter 6, the results at epidemiology and risk factors of badminton injuries, badminton teaching method, and neuromuscular training program obtained are integrated from the four studies. The epidemiological perspective with four-step sequence for badminton injury prevention is discussed. Finally, the clinical implications and future directions are presented.

This study was reviewed and approved by Ethical Committee of the Graduate school of Arts and Sciences, the University of Tokyo, Japan (Notification Number 602-2 July 26, 2018). All of the study design complied with the declaration of Helsinki.

Chapter 2, Study 1

Survey of epidemiology and risk factors of badminton injuries in school age players

This study has been published as:

Xiao Zhou, Kazuhiro Imai*, Xiao-Xuan Liu, Eiji Watanabe: Epidemiology of pain and injury in elementary school-aged badminton players. Gazz Med Ital - Arch Sci Med, *in press*.

2.1. Introduction

Badminton is a racket sport played by more than 330 million people over the world (BWF, 2020). Due to the various movements in badminton, *i.e.*, instant start and stop footwork, repetitive shoulder external/internal rotation and trunk rotation (Fahlström et al., 2006; Shariff et al., 2009; Kuntze et al., 2009), injuries and pains are frequent. Several epidemiological studies on injury related to badminton have been published. Majority of the studies focused on adolescents, adults and professional badminton players that revealed the incidence of suffering from at least one badminton injuries ranges from 54.8% to 82% (Hensley and Paup, 1979; Jørgensen and Winge, 1987). Knee, ankle, shoulder, elbow and lumbar are common sites of badminton injuries (Hensley and Paup, 1979; Jørgensen and Winge, 1987; Krøner et al., 1990; Høy et al., 1994; Shariff et al., 2009).

Badminton forehand overhead stroke referred to as a kinetic chain as an overhead motion sport, which allows energy generation by ground reaction and force transfer from lower limbs and trunk muscles to upper limbs (Van and Kibler, 2006; Zhang et al., 2016). Any deficit in the kinetic chain may cause pain and/or injuries (Jayanthi and Esser, 2013; Sekiguchi et al., 2017). As mentioned above, shoulder, lumbar, knee injuries and pains are frequently occurred in badminton players. Epidemiological studies on badminton players reported incidences of shoulder injuries at about 1.4%-8.7% (Jørgensen and Winge, 1987; Krøner et al., 1990), lumbar/spine injuries at about 1.8%-13.7% (Jørgensen and Winge, 1987; Krøner et al., 1990; Yung et al., 2007), and knee injuries at about 10.9%-16.2% (Jørgensen and Winge, 1987; Krøner et al., 1990). Incidences of shoulder pain which means an alarm of shoulder injuries are about 27.0%-52.6% (Jørgensen and Winge, 1987; Lo et al., 1990; Petrinović et al., 2016). Shoulder pain would cause abnormal overhead motion and affect activities of daily living such as sleeping disturbance (Fahlström et al., 2006; Wasser et al., 2017). However, more than one-third of badminton players with shoulder pain continued to play, which might lead to shoulder injuries (Fahlström et al., 2006). As for trunk and knee pain, a previous study of overhead players which included 95 badminton players reported that among all pains associated with badminton, trunk pain is 6.3% and knee pain is 14.7%. (Sekuguchi et al., 2017).

In addition, some studies reported injury rate using number of injuries per 1000 athlete-hours of exposures, which is the average number of injury occurrences for one player in one thousand hours of play. The number of badminton players varies from 0.9 to 5.1 injuries per 1000 athlete-hours of exposures (Jørgensen and Winge, 1987; Yung et al., 2007; Goh et al., 2013; Miyake et al., 2016). Even though badminton has relative lower injury incidence than other popular sports such as soccer and basketball (Cumps et al., 2007; Pfirrmann et al., 2016), it is crucial to assuring long-term, pain/injury free participation, especially for youth players. Therefore, to identify risk factors may lead to implement early interventions.

Literatures reported female gender (Miyake et al., 2016), increased age (Høy et al., 1994; Miyake et al., 2016), increased badminton hours per week (Jørgensen and Winge, 1987), badminton match (Miyake et al., 2016) and low badminton level (Jørgensen and Winge, 1987) were risk factors for badminton injuries. Knee movement was regarded as a risk factor for knee pain (Huang et al., 2014; Fu et al., 2017). However, as far as we have searched, there are currently no studies on risk factors of shoulder pain and lumbar pain among badminton players. Studies on other overhead motion sports, *e.g.*, baseball, reported increased age (Lyman et al., 2001; Sekiguchi et al., 2018), lower height (Lyman et al., 2001), hard training intensity (Sekiguchi et al., 2018) and longer training hours weekly (Matsuura et al., 2017) were risk factors of shoulder pain. Additionally, lumbar pain and knee pain were demonstrated significantly correlated with shoulder pain in youth baseball players (Sekiguchi et al., 2018). A study of overhead motion players which included badminton players stated a significant correlation between shoulder pain and back or lower limb pain, however, it was unspecific, and the number of badminton players was small (Sekiguchi et al., 2017).

Younger players may suffer from different injuries from those of adolescent and adult players, therefore before developing prevention programs, epidemiological data on incidence in school age players should be well investigated. However, majority of previous population-based epidemiological studies in badminton players grouped elementary school-aged (7-12 years old) and adolescent (13-22 years old) players together, and epidemiological data concerning elementary school-aged players are scarce. Moreover, evaluation of the entire body is crucial to examine injured players (Sekiguchi et al., 2018) and prevent injury. Nevertheless, risk factors for shoulder pain, lumbar pain and knee pain, and their associations are not well understood.

Therefore, to assure safe participation for badminton players, the purposes of this study were (1) to investigate the distribution of pains and injuries, identify injury incidence in elementary school-aged badminton players and university badminton players; (2) to identify risk factors for shoulder pain, and the association between shoulder pain, lumbar pain and knee pain among elementary school-aged badminton players so that injury prevention and intervention can be implemented as early as possible.

2.2. Materials and Methods

2.2.1. Participants

Total of 663 participants in this study consisted of elementary school-aged badminton players (aged 7-12 years) and university badminton players (aged 18-22 years). Including 663 participants, 611 elementary school-aged badminton players, participating in the national tournament belong to the Japan Schoolchildren Badminton Federation. 52 university badminton players participating in the national tournament belong to Senshu University and Waseda University.

2.2.2. Data collection

During March-August 2019, data was collected by a self-reported questionnaire from 663 badminton players. Informed consent forms written by all the participants have been obtained. For the minors including elementary school-aged players, informed consent forms written by the guardians have been also obtained. The questionnaire asked for information including gender, age, badminton experience, training hours of per day, training days of per week, warm-up, cool down, and pain or injury histories related to badminton. Pains and injuries were specifically recorded regarding anatomical sites. The anatomical sites were presented using a picture showing body parts including face, neck, shoulder, elbow, hand, lumbar, groin, thigh, knee, Achilles tendon, ankle, and foot. All the pains and injuries were specifically reported regarding type of pain/injury (pain, acute and traumatic injury, chronic and overuse injury), the age that occurred, cause and mechanism of pain/injury, and current pain/injury status. Generally, all the elementary school-aged badminton players wrote the questionnaire by themselves, however, guardians were allowed to help them respond to the questionnaire.

2.2.3. Definition of injury and pain

An injury was defined as any physical complaint sustained during badminton match or training play causing one or more of the three judgement criteria as follows: (1) have to stop the current badminton training or match immediately, (2) cannot presence in subsequent badminton training or matches, and (3) require medical care with time loss. Injuries were categorized as traumatic injuries which has acute onset, and overuse injuries defined by gradual-onset and chronic physical complaint without traumatic injuries. A pain was defined as any physical painful complaint or discomfort with sustained badminton capacity (Rössler R et al., 2016).

2.2.4. Statistical analysis

To achieve the first goal, elementary school-aged badminton players were assigned to three groups, broken down by age. Distribution of pains and injuries associated with badminton, and injury rate were described and compared in elementary school-aged and university badminton players. To achieve the second goal, distributions of pains and injuries in shoulder, lumbar and knee were described. Then, medians with interquartile range (IQR) were adopted to present continuous variables which were categorized according to the distribution, and categorical variables were shown in numbers and percentage. The variables including gender, age, badminton experience, training hours of per day, training days of per week, total hours of per week, whether doing warm-up and cool down or not were considered potential confounding factors.

Normality of basic parameters distribution, *i.e.*, age, duration of badminton experience, duration of training, training days, training hours per week, warm-up time and cool-down time was examined using Shapiro-Wilk test. Mann-Whitney U-test was adopted for data analysis in university badminton players. Kruskal-Wallis one-way analysis of variance (ANOVA) followed by Dunn's test was adopted for statistical analysis of groups (7-8 year-old group, 9-10 year-old group and 11-12 year-old group). Comparisons of the injury incidences between groups (7-8 year-old group, 9-10 year-old group, 11-12 year-old group and 18-22 year-old group) were analyzed using χ^2 test, and the injury rate was calculated as per 1000 athlete-hours of exposures, with 95% confidence interval (CI) using Poisson distribution. An hour of exposures is defined as 1 hour of participation in badminton by one athlete. The injury rate of per 1000 athlete-hours of exposures in the badminton period is calculated as follows:

Injury rate per 1000 athlete-hours of exposures = [∑(No. of injuries)/∑{(No. of participants) × (hours of training)}] × 1,000.

Significant differences in values between groups for injury rate per 1000 athlete-hours of exposures were assumed if the 95% CI did not overlap.

Then, we operated crude analysis and multivariate logistic regression analysis which included all the variables in the model to examine the association of shoulder pain, lumbar pain and knee pain. Next, adjusted odds ratio (OR) and 95% CI were analyzed using multivariate logistic regression analysis to examine the association of all the variables with shoulder pain, lumbar pain and knee pain. Furthermore, the participants were stratified into two groups by the risk factor of shoulder pain. The association of shoulder pain, lumbar pain and knee pain in two groups were examined using multivariate logistic regression analysis, respectively. Odds ratio (OR) with 95% CI was performed for the results of the multivariate logistic regression analysis model. Differences were considered statistically significant when p value was less than 0.05.

Variables were divided into categories as follows: gender (male or female), age (7-8, 9-10 or 11-12 years), badminton experience (< 1, 1 to < 3 or ≥ 3 years), training hours per day (≤ 2.5, or > 2.5 hours), training days per week (≤ 3, 4-5, or 6-7 days), total hours per week (≤ 11, or > 11 hours), warm-up (yes or no) and cool-down (yes or no).

2.3. Results

2.3.1. Characteristics of badminton players

In this study, 51 out of 52 university badminton players including 25 male and 26 female players, and 510 out of 611 elementary school-aged badminton players, including 217 male and 293 female players completed the survey. The mean ± standard deviation (SD) ages of university badminton players were 19.8 ± 1.2 years old, ranging from 18 to 22 years old. The mean ± SD ages of elementary school-aged badminton players were 10.1 ± 1.2 years old, ranging from 7 to 12 years old. 49.6% (253 players) of 510 elementary school-aged badminton players and 88.2% (45 players) of 51 university badminton players experienced at least one badminton injury. Data on characteristics of university badminton players are presented in Table 2-1. There were no significant differences of age, badminton experience, training hours of per day, training days of per week and training hours of per week between male and female players. Data on characteristics of elementary school-aged badminton players are shown in Table 2-2. Regardless of gender, no significant differences in training days of per week, training hours of per week and cool-down time were observed between the three groups. For male players analyzed by Kruskal-Wallis ANOVA, significant differences were observed in age ($p < 0.001$) and badminton experience ($p < 0.001$) among the three groups. With Post-hoc test using Dunn's test, significant differences were found in badminton experience between 7-8 year-old group and 9-10 year-old group ($p < 0.01$), 7-8 year-old group and 11-12 year-old group ($p < 0.001$), respectively. Training days of per week showed an upward tendency with increasing age ($p = 0.075$).

For female players analyzed by Kruskal-Wallis ANOVA, significant differences were observed in age ($p < 0.001$) and badminton experience ($p < 0.001$) among the three groups. With Post-hoc test using Dunn's test, significant differences were found in badminton experience between 7-8 year-old group and 9-10 year-old group ($p < 0.01$), 7-8 year-old group and 11-12 year-old group ($p < 0.001$), 9-10 year-old group and 11-12 year-old group ($p < 0.001$), respectively. Warm-up time of 11-12 year-old group was significantly longer than 7-8 year-old group ($p < 0.05$). Training hours of per week showed an upward tendency with increasing age ($p = 0.086$).

Table 2-1. Characteristics of university badminton players broken down by gender.

Variables	Male (n = 25)	Female (n = 26)
Age, year	19.9 ± 1.1	19.6 ± 1.3
Experience, year	10.6 ± 3.0	11.7 ± 1.9
Training hours/day	3.2 ± 0.4	3.4 ± 0.6
Days/week	5.2 ± 0.8	5.2 ± 0.4
Hours/week	16.6 ± 3.1	17.8 ± 2.3

Values are mean ± SD.

Table 2-2. Characteristics of surveyed elementary school-aged badminton players in different age groups.

Variables	Male			Female		
	7/8 year-old (n = 35)	9/10 year-old (n = 93)	11/12 year-old (n = 89)	7/8 year-old (n = 31)	9/10 year-old (n = 118)	11/12 year-old (n = 144)
Age, year	7.6 ± 0.5	9.6 ± 0.5	11.2 ± 0.4	7.9 ± 0.3	9. 6 ± 0.5	11.2 ± 0.4
Experience, year	2.2 ± 1.0*	2.8 ± 1.3*	3.2 ± 1.4*	2.1 ± 0.8†	2.7 ± 1.2†	3.3 ± 1.4†
Training hours/day	2.8 ± 1.2	2.8 ± 0.8	2.7 ± 0.9	2. 5 ± 0.7	2. 8 ± 0.8	2.7 ± 0.8
Days/week	4.3 ± 1.3	4.4 ± 1.2	4.7 ± 1.1	4.8 ± 1.4	4.4 ± 1.3	4.6 ± 1.2
Hours/week	11.8 ± 4.6	12.5 ± 5.0	13.1 ± 5.8	11.9 ± 5.0	12.3 ± 4.8	12.6 ± 5.8

Values are mean ± SD.

*p value < 0.05, between groups in male badminton players.

†p value < 0.05, between groups in female badminton players.

2.3.2. Distribution of badminton injuries

In total, 1313 pains and injuries (7-12 year-old players: 648 pain, 210 traumatic injuries and 186 overuse injuries; 18-22 year-old players: 193 pain, 42 traumatic injuries and 34 overuse injuries) were reported. Incidence of pain was higher than that of injury in all groups. Regarding elementary school-aged badminton players, pain as well as injuries increased with age, especially overuse injuries sharply increased with age. (Figure 2-1). The distribution of pains and injuries according to anatomical site among elementary school-aged badminton players is shown in Figure 2-2 (a). The most common pains and injuries were localized in knee, 16.1%, followed by foot (15.9%), ankle (13.8%), shoulder (6.5%), lumbar (6.4%) and Achilles tendon (6.1%). The distribution of pains and injuries in anatomical site among university badminton players is shown in Figure 2-2 (b). The most common pain and injuries were localized in lumbar (15.2%), followed by knee (13.8%), ankle (12.6%), shoulder (12.6%) and foot (12.3%)

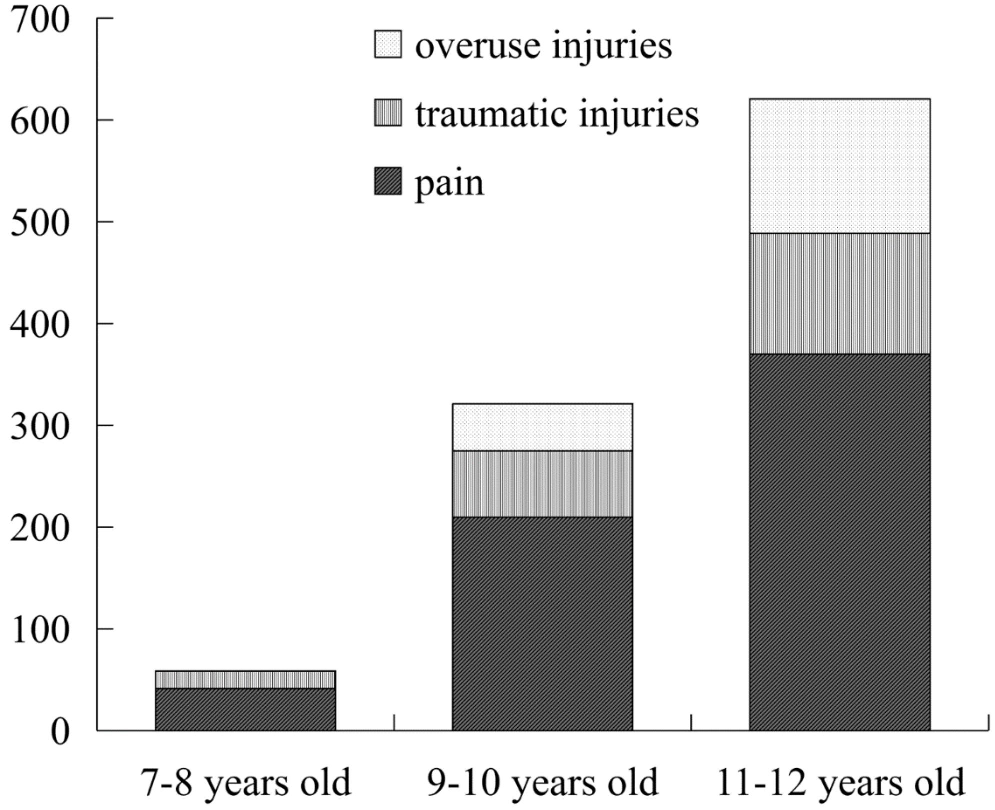


Figure 2-1. Incidence of pain and injuries in elementary school-aged badminton players.

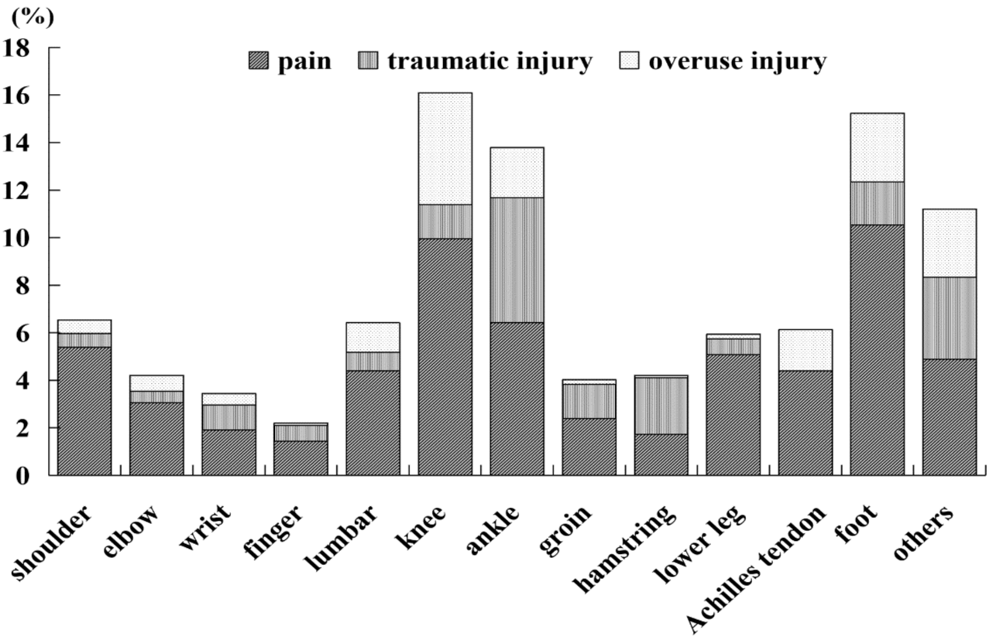


Figure 2-2 (a)

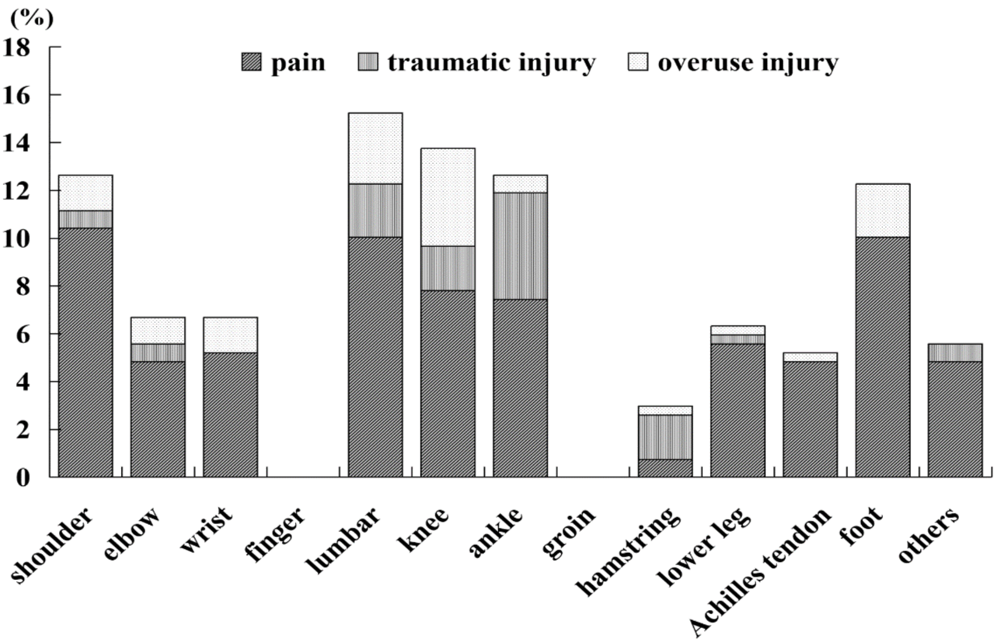


Figure 2-2 (b)

Figure 2-2. Distribution of pain and injuries in anatomical sites. (a): Distribution of anatomical site pain and injuries in elementary school-aged badminton players. (b): Distribution of anatomical site pain and injuries in university badminton players.

Regarding injury itself, data on injury anatomical site of different age groups are shown in Table 2-3. In 7-12 year-old elementary school-aged badminton players, injuries most frequently occurred in ankle (19.4%), followed by knee (16.2%), foot (12.4%), hamstring (6.6%) and lumbar (5.3%). In 18-22 year-old university badminton players, injuries most frequently occurred in knee (21.3%). Ankle injuries (18.7%) as well as lumbar injuries (18.7%) came the second. Among all four groups, injuries most frequently occurred in lower limbs, such as ankle and knee.

Table 2-3. Distribution of injuries in different age groups.

Body region	7-12 years, 18-22 years N (%)	7-8 years N (%)	9-10 years N (%)	11-12 years N (%)	18-22 years N (%)
Shoulder	18 (3.8)	1 (5.6)	5 (4.3)	6 (2.3)	6 (8.0)
Elbow	17 (3.6)	1 (5.6)	2 (1.7)	9 (3.4)	5 (6.7)
Wrist	20 (4.2)	0 (0.0)	4 (3.5)	12 (4.6)	4 (5.3)
Finger	8 (1.8)	0 (0.0)	3 (2.6)	5 (1.9)	0 (0.0)
Lumbar	35 (7.4)	1 (5.6)	6 (5.2)	14 (5.3)	14 (18.7)
Knee	80 (16.9)	4 (22.2)	21 (18.1)	39 (14.9)	16 (21.3)
Ankle	91 (19.3)	5 (27.8)	18 (15.5)	54 (20.6)	14 (18.7)
Groin	17 (3.6)	0 (0.0)	4 (3.5)	13 (5.0)	0 (0.0)
Hamstring	32 (6.8)	1 (5.6)	5 (4.3)	20 (7.6)	6 (8.0)
Achilles tendon	19 (4.0)	0 (0.0)	4 (3.5)	14 (5.3)	1 (1.3)
Foot	55 (11.7)	1 (5.6)	19 (16.4)	29 (11.1)	6 (8.0)
Others	80 (16.9)	4 (22.0)	25 (21.4)	47 (18.0)	4 (4.0)
Total	472 (100.0)	18 (100.0)	116 (100.0)	262 (100.0)	76 (100.0)

2.3.3. Injury rate of badminton injuries

The overall injury rate per 1000 athlete-hours of exposures was 1.63 (95% CI: 1.49-1.77). Injury rate showed an upward trend with age (Figure 2-3). Injury rates per 1000 athlete-hours of exposures for the four groups were 0.58 in 7-8 year-old group (95% CI: 0.32-0.84), 1.11 in 9-10 year-old group (95% CI: 0.91-1.31), 2.19 in 11-12 year-old group (95% CI: 1.93-2.46), 2.17 in 18-22 year-old group (95% CI: 1.69-2.66), respectively. Injury incidence of 11-12 year-old group and 18-22 year-old group were significantly higher compared with 9-10 year-old group ($p < 0.001$). No significant differences on injury incidence between 11-12 year-old group and 18-22 year-old group. In addition, injury incidence of 9-10 year-old group was significantly higher compared with 7-8 year-old group ($p < 0.01$).

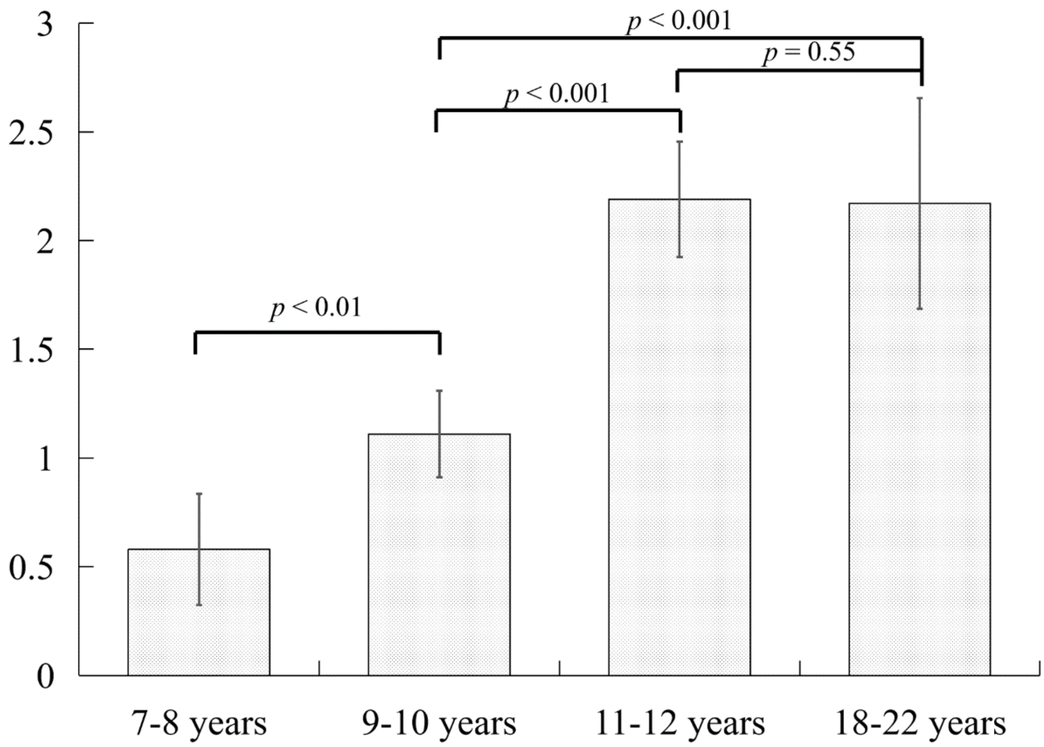


Figure 2-3. Injury rate per 1000 athlete-hours of exposure. The error bars represent 95% confidence intervals. The χ^2 test revealed significant differences in injury incidences, between age groups.

According to duration of badminton experience of elementary school-aged badminton players, each group was further divided into three categories, that is, 1-2 years badminton experience category, 3-4 years category and 5-8 years category. And according to duration of badminton experience of university badminton players, the group was divided into two categories, that is, 3-11 years category and 12-15 years category. As shown in Table 2-4, in each group of elementary school-aged badminton players, players with 1-2 years badminton experience category had the highest injury rate per 1000 athlete-hours of exposures. The injury rates of different badminton experience category in each group of elementary school-aged badminton players had a downward trend with increasing duration of experience whereas the injury rates in either group of university badminton players had an upward trend with increasing duration of experience.

Table 2-4. Injury rates broken down by badminton experience in different age groups.

Variable	NO. of Injuries	Athlete-hours of exposures	Injury rate per 1000 athlete-hours of exposures	95% CI
7-8 year-old				
1-2 years	15	25150	0.60	[0.29-0.90]
3-4 years	3	6120	0.49	[0.00-1.04]
5-8 years	-	-	-	-
9-10 year-old				
1-2 years	67	57690	1.16	[0.88-1.44]
3-4 years	42	39650	1.06	[0.74-1.38]
5-8 years	7	7280	0.96	[0.25-1.67]
11-12 year-old				
1-2 years	124	50950	2.43	[2.01-2.86]
3-4 years	102	46870	2.18	[1.75-2.60]
5-8 years	36	21630	1.66	[1.12-2.21]
18-22 year-old				
3-11 years	35	16960	2.06	[1.38-2.75]
12-15 years	41	18127	2.26	[1.57-2.95]

2.3.4. Association of shoulder pain, lumbar pain and knee pain among elementary school-aged badminton players

Out of 611 elementary school-aged badminton players, 460 players including 194 boys and 266 girls had no experience of shoulder injuries, lumbar injuries and knee injuries (Table 2-5). Among the 460 players, 41 cases of shoulder pain, 32 cases of lumbar pain and 61 cases of knee pain were reported. Table 2-6 and Table 2-7 show the results of crude and multivariate logistic regression analysis model for association of shoulder pain, lumbar pain and knee pain. Shoulder pain was significantly associated with knee pain (OR: 4.10, 95% CI: 2.01-8.38, $p < 0.001$; adjusted OR: 4.32, 95% CI: 2.03-9.28, $p < 0.001$). Knee pain was significantly associated with lumbar pain (OR: 3.36, 95% CI: 1.51-7.50, $p < 0.01$; adjusted OR: 3.38, 95% CI: 1.48-7.74, $p < 0.01$), and lumbar pain was significantly associated with shoulder pain (OR: 8.26, 95% CI: 3.68-18.54, $p < 0.001$; adjusted OR: 10.35, 95% CI: 4.25-25.23, $p < 0.001$).

Table 2-5. Baseline characteristics of elementary school age badminton players.

Variables	Median (IQR)	N (%)	Pain sites Shoulder (n = 41)	Lumbar (n = 32)	Knee (n = 61)
Gender					
male		194 (42.2)	20 (48.8)	14 (43.8)	29 (47.5)
female		266 (57.8)	21 (51.2)	18 (56.3)	32 (52.5)
Age, year	10.0 (9.0, 11.0)				
7-8		76 (16.5)	10 (24.4)	8 (25.0)	9 (14.8)
9-10		190 (41.3)	12 (29.3)	11 (34.4)	28 (45.9)
11-12		194 (42.2)	19 (46.3)	13 (40.6)	24 (39.3)
Experience, year	2.3 (1.3, 3.5)				
< 1		81 (17.6)	7 (17.1)	5 (15.6)	12 (19.7)
1 to < 3		210 (45.7)	24 (58.5)	12 (37.5)	27 (44.3)
≥ 3		169 (36.7)	10 (24.4)	15 (46.9)	22 (36.1)
Hours, per day	2.5 (2.0, 3.0)				
≤ 2.5		232 (50.4)	15 (36.6)	16 (50.0)	29 (47.5)
> 2.5		228 (49.6)	26 (63.4)	16 (50.0)	32 (52.5)
Days, per week	4 (3.0, 5.0)				
≤ 3		128 (27.8)	10 (24.4)	5 (15.6)	12 (19.7)
4-5		247 (53.7)	21 (51.2)	21 (65.6)	36 (59.0)
6-7		85 (18.5)	10 (24.4)	6 (18.8)	13 (21.3)
Total hours, weekly	11.3 (8.0, 15.0)				
≤ 11		219 (47.6)	17 (41.5)	15 (46.9)	28 (45.9)
> 11		241 (52.4)	24 (58.5)	17 (53.1)	33 (54.1)
Warm-up					
Yes		449 (97.6)	41(100.0)	31 (96.9)	60 (98.4)
No		11 (2.4)	0 (0.0)	1 (3.1)	1 (1.6)
Cool down					
Yes		300 (65.2)	29 (70.7)	10 (31.3)	36 (59.0)
No		160 (34.8)	12 (29.3)	22 (68.7)	25 (41.0)

Table 2-6. Association between knee pain and shoulder pain among elementary school age badminton players.

Pain sites	Shoulder pain Absence (n = 419)	Presence (n = 41)	*p*-value
Knee pain (n = 61)			
N (%)	47 (11.2)	14 (34.1)	
OR (95% CI)[a]	1.00	4.10 (2.01-8.38)	< 0.001
Adjusted OR (95% CI)[b]	1.00	4.32 (2.03-9.28)	< 0.001

[a]Crude model, [b]Adjusted for gender (male or female), age (7-8, 9-10 or 11-12 years), badminton experience (< 1, 1 to < 3 or ≥ 3 years), hours per day (≤ 2.5, or > 2.5 hours), days per week (≤ 3, 4-5, or 6-7 days), total hours per week (≤ 11, or > 11 hours), warming up (yes or no) and cool down (yes or no), OR: odds ratio, CI: confidence intervals.

Table 2-7. Lumbar pain associated with knee pain and shoulder pain among elementary school age badminton players.

Pain sites	Lumbar pain (n = 32)		
	Absence (n = 428)	Presence (n = 32)	*p*-value
Knee pain (n = 61)			
N (%)	51 (12.2)	10 (31.3)	
OR (95% CI)[a]	1.00	3.36 (1.51-7.50)	< 0.01
Adjusted OR (95% CI)[b]	1.00	3.38 (1.48-7.74)	< 0.01
Shoulder pain (n = 41)			
N (%)	29 (6.9)	12 (37.5)	
OR (95% CI)[a]	1.00	8.26 (3.68-18.54)	< 0.001
Adjusted OR (95% CI)[b]	1.00	10.35 (4.25-25.23)	< 0.001

[a]Crude model, [b]Adjusted for gender (male or female), age (7-8, 9-10 or 11-12 years), badminton experience (< 1, 1 to < 3 or ≥ 3 years), hours per day (≤ 2.5, or > 2.5 hours), days per week (≤ 3, 4-5, or 6-7 days), total hours per week (≤ 11, or > 11 hours), warming up (yes or no) and cool down (yes or no), OR: odds ratio, CI: confidence intervals.

2.3.5. Risk factors for shoulder pain

Table 2-8 shows adjusted OR and 95% CI for shoulder pain, lumbar pain and knee pain using multivariate logistic regression analysis of all the variables. There was a significant association between training hours per day and shoulder pain (hours, per day > 2.5 hours: adjusted OR: 2.58, 95% CI: 1.02-6.55, $p < 0.05$). Gender, age, badminton experience, days per week, total hours per week, warm-up and cool down were not significantly associated with shoulder pain. Likewise, no significant associations were observed between all the variables and lumbar pain as well as between all the variables and knee pain.

Table 2-8. Adjusted odds ratio for shoulder pain, lumbar pain and knee pain by multivariate analysis.

	Pain sites					
Variables	Shoulder (n = 41)	Adjusted OR (95% CI)[a]	Lumbar (n = 32)	Adjusted OR (95% CI)[a]	Knee (n = 61)	Adjusted OR (95% CI)[a]
Gender						
male	20 (48.8)	1.00	14 (43.8)	1.00	29 (47.5)	1.00
female	21 (51.2)	1.30 (0.67-2.52)	18 (56.3)	1.06 (0.51-2.20)	32 (52.5)	1.24 (0.72-2.14)
Age, year						
7-8	10 (24.4)	1.00	8 (25.0)	1.00	9 (14.8)	1.00
9-10	12 (29.3)	0.48 (0.19-1.22)	11 (34.4)	0.40 (0.14-1.11)	28 (45.9)	1.37 (0.59-3.17)
11-12	19 (46.3)	0.92 (0.38-2.27)	13 (40.6)	0.46 (0.16-1.30)	24 (39.3)	1.20 (0.49-2.89)
Experience, year						
< 1	7 (17.1)	1.00	5 (15.6)	1.00	12 (19.7)	1.00
1 to < 3	24 (58.5)	1.56 (0.61-4.02)	12 (37.5)	1.07 (0.34-3.35)	27 (44.3)	0.81 (0.37-1.76)
≥ 3	10 (24.4)	0.64 (0.21-1.92)	15 (46.9)	1.97 (0.61-6.34)	22 (36.1)	0.77 (0.34-1.74)
Hours, per day						
≤ 2.5	15 (36.6)	1.00	16 (50.0)	1.00	29 (47.5)	1.00
> 2.5	26 (63.4)	2.58 (1.02-6.55)*	16 (50.0)	1.37 (0.46-4.11)	32 (52.5)	1.69 (0.78-3.67)
Days, weekly						
≤ 3	10 (24.4)	1.00	5 (15.6)	1.00	12 (19.7)	1.00
4-5	21 (51.2)	1.79 (0.63-5.09)	21 (65.6)	3.13 (0.95-10.32)	36 (59.0)	2.30 (0.99-5.37)
6-7	10 (24.4)	3.45 (0.81-14.77)	6 (18.8)	3.01 (0.55-16.43)	13 (21.3)	3.36 (0.99-11.35)
Total hours, weekly						
≤ 11	17 (41.5)	1.00	15 (46.9)	1.00	28 (45.9)	1.00
> 11	24 (58.5)	0.48 (0.15-1.60)	17 (53.1)	0.53 (0.14-1.99)	33 (54.1)	0.49 (0.19-1.28)
Warm-up						
Yes	41 (100.0)	-	31 (96.9)	1.00	60 (98.4)	1.00
No	0 (0.0)	-	1 (3.1)	0.84 (0.10-7.15)	1 (1.6)	1.36 (0.17-11.17)
Cool down						
Yes	29 (70.7)	1.00	10 (31.3)	1.00	36 (59.0)	1.00
No	12 (29.3)	1.31 (0.63-2.70)	22 (68.7)	1.18 (0.54-2.62)	25 (41.0)	0.70 (0.40-1.23)

[a]Adjusted for gender (male or female), age (7-8, 9-10 or 11-12 years), badminton experience (< 1, 1 to < 3 or ≥ 3 years), hours per day (≤ 2.5, or > 2.5 hours), days per week (≤ 3, 4-5, or 6-7 days), total hours per week (≤ 11, or > 11 hours), warming up (yes or no) and cool down (yes or no), OR: odds ratio, CI: confidence intervals, *Significantly associated with shoulder/lumbar/knee pain, *p*-value < 0.05.

2.3.6. Further analysis of risk factors

In order to identify whether longer training hours caused the pain or not, we stratified participants into two groups using 2.5 hours per day (the risk factor of shoulder pain) as a cut-off point and compared the associations of lumbar pain, shoulder pain and knee pain in two groups. The results are presented in Table 2-9, Table 2-10 and Table 2-11. According to the results, a significant association was observed between shoulder pain and knee pain as well as between lumbar pain and knee pain upon exceeding 2.5 training hours per day. On the contrary, whether training hour per day $\leq$ 2.5 hours or >2.5 hours, lumbar pain was always significantly associated with shoulder pain ($\leq$ 2.5 hours: adjusted OR: 11.38, 95% CI: 2.80-46.26, $p < 0.01$; > 2.5 hours: adjusted OR: 11.55, 95% CI: 3.21-41.56, $p < 0.001$, respectively).

Table 2-9. Association between lumber pain and shoulder pain broken down by 2.5 hours per day.

	Shoulder pain (≤ 2.5 hours)			Shoulder pain (> 2.5 hours)		
Pain sites	Absence (n = 217)	Presence (n = 15)	*p*-value	Absence (n = 202)	Presence (n = 26)	*p*-value
Lumbar pain (n = 32)						
N (%)	11 (5.1)	5 (33.3)		9 (4.5)	7 (26.9)	
Adjusted OR (95% CI)[a]	1.00	11.38 (2.80-46.26)	< 0.01	1.00	11.55 (3.21-41.56)	< 0.001

[a]Adjusted for gender (male or female), age (7-8, 9-10 or 11-12 years), badminton experience (< 1, 1 to < 3 or ≥ 3 years), hours per day (≤ 2.5, or > 2.5 hours), days per week (≤ 3, 4-5, or 6-7 days), total hours per week (≤ 11, or > 11 hours), warm-up (yes or no) and cool-down (yes or no),

OR: odds ratio, CI: confidence intervals.

Table 2-10. Association between lumber pain and knee pain broken down by 2.5 hours per day.

	Knee pain (≤ 2.5 hours)			Knee pain (> 2.5 hours)		
Pain sites	Absence (n = 203)	Presence (n = 29)	*p*-value	Absence (n = 196)	Presence (n = 32)	*p*-value
Lumbar pain (n = 32)						
N (%)	11 (5.4)	5 (17.2)		11 (5.6)	5 (15.6)	
Adjusted OR (95% CI)[a]	1.00	3.01 (0.87-10.39)	> 0.05	1.00	3.50 (1.08-11.36)	< 0.05

[a]Adjusted for gender (male or female), age (7-8, 9-10 or 11-12 years), badminton experience (< 1, 1 to < 3 or ≥ 3 years), hours per day (≤ 2.5, or > 2.5 hours), days per week (≤ 3, 4-5, or 6-7 days), total hours per week (≤ 11, or > 11 hours), warm-up (yes or no) and cool-down (yes or no), OR: odds ratio, CI: confidence intervals.

Table 2-11. Association between shoulder pain and knee pain broken down by 2.5 hours per day.

Pain sites	Knee pain (≤ 2.5 hours)			Knee pain (> 2.5 hours)		
	Absence (n = 203)	Presence (n = 29)	*p*-value	Absence (n = 196)	Presence (n = 32)	*p*-value
Shoulder pain (n = 41)						
N (%)	11 (5.4)	4 (13.8)		16 (8.2)	10 (31.3)	
Adjusted OR (95% CI)[a]	1.00	3.27 (0.86-12.40)	> 0.05	1.00	5.23 (1.99-13.77)	< 0.05

[a]Adjusted for gender (male or female), age (7-8, 9-10 or 11-12 years), badminton experience (< 1, 1 to < 3 or ≥ 3 years), hours per day (≤ 2.5, or > 2.5 hours), days per week (≤ 3, 4-5, or 6-7 days), total hours per week (≤ 11, or > 11 hours), warm-up (yes or no) and cool-down (yes or no), OR: odds ratio, CI: confidence intervals.

2.4. Discussion

In this study, we conducted an epidemiological study to investigate and to compare pain and injury in elementary school-aged and university badminton players. In addition, we investigated risk factors for pain and association of pain sites in elementary school-aged badminton players. Among all the pain/injury reports, pain incidence was more than traumatic injury incidence and overuse injury incidence. The result of this study revealed that the incidence of badminton traumatic/overuse injury in age of 7-12 year-old players was 49.6%, which is less than injury incidence in adolescents and adults (Hensley and Paup, 1979; Jørgensen and Winge, 1987) whereas the result of university badminton players aged 18-22 years supports the previous studies. This study also revealed that injuries increased with age in elementary school-aged badminton players. Previous study in badminton players of middle school (13-15 year-old), high school (16-18 year-old), and university (19-22 year-old) reported that overuse injuries occurred approximately 3 times more than traumatic injuries (Miyake et al., 2016). In this study, the age of 7-12 year-old players, traumatic injuries occurred more than overuse injuries, which is different from the previous study of the age of 13-22 year-old. In addition, overuse injuries sharply increased with age in 7-12 year-old players. In the players at the age of 18-22 year-old, overuse injuries were slightly more than traumatic injuries. The results indicated that traumatic injuries are more common in elementary school-aged badminton players, and overuse injuries are more common in middle school, high school and university badminton players.

As for the anatomical sites, there are some controversies among previous studies. Previous studies reported that 33.3% to 82.9% badminton injuries occurred in lower limbs and 11.1% to 31.0% occurred in upper limbs (Krøner et al., 1990; Høy et al., 1994; Shariff et al., 2009). Some studies reported that the most frequent injury site was ankle (Hensley and Paup, 1979; Krøner et al., 1990) as others reported knee (Shariff et al., 2009). With respect to upper limbs, some studies reported shoulder (Jørgensen and Winge, 1987; Shariff et al., 2009) to be the most frequent injured site, whereas in another study, elbow (Hensley and Paup, 1979) was described to be the most frequent injured site. Lumbar/back injuries were reported as the second most frequent in youth competitive players age at 13-16 years old (Goh et al., 2013) whereas other studies reported the incidences of lumbar/back were lower (Jørgensen and Winge, 1987; Krøner et al., 1990; Shariff et al., 2009).

In this study, in the elementary school-aged badminton players, the most frequent injured site was ankle (77 cases; traumatic injuries 71.4%, overuse injuries 28.6%). Knee was the second most frequent site (64 cases) and 76.6% of knee injuries were overuse injuries. The foot came the third (49 cases), and 61.2% of foot injuries were overuse injuries. Additionally, 3.0% (12 cases) of injuries related to badminton were shoulder (50% traumatic injuries and 50% overuse injuries) and 5.3% (21 cases) were lumbar (38.1% traumatic injuries and 61.9% overuse injuries). Overuse injuries were more frequent in knee and foot, whereas traumatic injuries were more frequent in ankle. On the other hand, in the university badminton players, the most frequent injured site was knee (16 cases; traumatic injuries 21.2%, overuse injuries 68.8%). Lumbar (14 cases; traumatic injuries 42.9%, overuse injuries 57.1%) as well as ankle (14 cases;

traumatic injuries 85.7%, overuse injuries 14.3%) was the second most frequent injured site. Shoulder (6 cases; traumatic injuries 33.3%, overuse injuries 66.7%) and foot (6 cases; overuse injuries 100%) came the third. The previous study reported that 84.0% of knee injuries and 51.9% of foot injuries were overuse injuries, and 66.7% of ankle injuries were traumatic injuries (strains, sprains, and fractures) (Jørgensen and Winge, 1987), which in accordance with this study. Regarding Achilles tendon, overuse injuries were 19 cases, but no traumatic injuries in this study. Previous study of badminton players at the age of 7-57 years reported that the frequency of Achilles tendon tears was 5.3% (Krøner et al., 1990). Achilles tendon tear has a tendency to occur with increasing age, so there was no Achilles tendon tear case in the participants of the current study.

In comparison of the injuries in some other popular youth sports including soccer, tennis and volleyball, the injury incidence of badminton is much less (Backx et al., 1989). Regardless of overhead motion sports, these athletes rely greatly on their lower limbs to provide foundation for their overhead motions. Plus, to transfer body core mass and maintain balance, these sports involve in movements such as turning, pivoting, and landing which are likely to add extra load to the lower limbs. Knee is the most prevalent overuse injury site in the current study, and the same result was reported of youth football players (Leppänen et al., 2019) and youth basketball players (Leppänen et al., 2015). These sports require repetitive jumping and/or sudden stops and then add stress to the patellar tendon, which lead to knee pain and overuse injuries.

Badminton players with poor technique or fatigue exhibit greater ankle ROM and greater internal joint rotation in the horizontal plane as well as inversion joint moment in the frontal plane (Fu et al., 2017; Herbaut and Delannoy, 2020). It has a higher ankle injury during performing plant-and-cut action or lateral jump when the foot lands in stance (Kimura et al., 2010; Herbaut and Delannoy, 2020) that could explain the high traumatic injury incidence of ankle in players of the current study.

As for pain sites, previous studies reported foot pain was the most frequent (17.9%), followed by knee (14.7%), shoulder/elbow (9.5%) and back (6.3%) in badminton players aged 6-15 years (Sekiguchi et al., 2017). Another study revealed that 35.4% players complained about lumbar pain and 27.6% players complained about shoulder pain aged 14-18 years (Petrinović et al., 2016). In this study, the result of elementary school-aged badminton players showed that foot (17.0%) and knee (16.1%) were the most common sites of pain, followed by shoulder/elbow (13.6%) whereas in university badminton players, the most common site of pain was shoulder (10.4%), followed by lumbar (10.0%), foot (10.0%), knee (7.8%) and ankle (7.4%). The result of elementary school-aged badminton players is consistent with a previous study of 6-15 year-old players (Sekiguchi et al., 2017). However, ankle (10.3%), ranked fourth, is different from the previous study which reported back (6.3%) (Sekiguchi et al., 2017). Comparing to pain in other sports studies, the results of pain in lower limbs, especially in knee and foot, are close to the pain distributions in similar-age volleyball and handball players found in the past studies (Sekiguchi et al., 2017). In this study, 9.0% of elementary school-aged badminton players complained about lumbar pain which was lower than previous studies of aged 14-18 years. 52.9% of university badminton players complained about lumbar pain which was much higher than elementary school-aged and 14-18 year-old badminton players (Petrinović et al., 2016).

In our research, for the same age group of elementary school-aged badminton players, we found a decreased trend of developing injuries as the duration of training experiences went up. We believe this result is associated with more experienced players' better badminton skills and physical fitness. Moreover, as the training loads for most players are moderate, we believe that most of the players have not yet reached the threshold after which training begins to increase the risk of injuries. Increasing duration of experience may indicate better skill mastery and better physical fitness to prevent badminton injuries and may imply a survival effect where players without injuries are more likely to continue playing. Therefore, monitoring training loads and carefully schedule training regimes according to player's skill level can minimize the effect of training-related injuries.

Regarding risk factors for pain, some studies of overhead players revealed that age (Lyman et al., 2002; Sekiguchi et al., 2018), gender (Mohseni-Bandpei et al., 2012), training hours per week (Matsuura et al., 2017), training days per week (Mohseni-Bandpei et al., 2012), history of shoulder pain (Matsuura et al., 2017) and training intensity (Sekiguchi et al., 2018) were risk factors for shoulder pain. Conversely, other studies showed that training hours per week as well as training days per week were not related to shoulder pain (Sekiguchi et al., 2018). As for lumbar pain, a study of baseball players aged 6-15 years revealed that increasing age was a risk factor for lumbar pain (Yabe et al., 2019). No previous studies on risk factors for knee pain based on epidemiological study were found.

In this study, neither training hours per week nor age showed significant association with shoulder pain. We demonstrated training hours > 2.5 hours per day being significantly associated with shoulder pain. Thus, although most motor practices could improve motor learning (Imai and Nakajima, 2008), we suggest players limit training hours to less than 2.5 hours per day. In addition, we have not found such risk factors for lumbar pain and knee pain.

With respect to the association between shoulder pain, lumbar pain and knee pain, there were some studies in baseball, soccer, wrestling and basketball. Some studies of baseball players revealed that significant associations were observed between shoulder pain and lumbar pain, shoulder pain and knee pain, and lumbar pain and knee pain (Matsuura et al., 2017; Sekiguchi et al., 2018; Yabe et al., 2019). A previous study of soccer players (Sogi et al., 2018) also revealed that lumbar pain was significantly associated with knee pain. Another study among top wrestlers revealed that pain in spine was associated with pain in shoulder and knee (Jonasson et al., 2011). A previous study of basketball also revealed that there was a significant association between upper extremity pain and lumbar pain in elementary and middle school age basketball players (Hagiwara et al., 2020). Regarding badminton, a previous study on overhead motion sports including 95 badminton players revealed that shoulder pain was significantly associated with back pain (Matsuura et al., 2017). In this study, in elementary school-aged badminton players with more training hours, shoulder pain was significantly associated with lumbar pain and knee pain, and lumbar pain was significantly associated with knee pain. The findings of our studies agree with previous studies mentioned above.

Body core mass shifting, balance, joint coordination (*i.e.*, shoulder adduction/abduction, trunk rotation) (Zhou et al., 2019) and footwork (lunge, jump, crossover stepping) (Kuntze et al., 2009; Kimura et al., 2010) are required during badminton play. As for forehand overhead stroke motion, trunk is a major segment of the overhead motion kinetic chain in transferring energy from lower limbs to upper limbs. Trunk contributes to more than 50% of total energy whereas shoulder does 13% of the work (Kibler 1995; Zhang et al., 2016). Also, in order to generate force, transfer body core mass and maintain balance, it is essential for knee to perform a large movement frequently. During hitting a shuttlecock, several events occur simultaneously including body core mass shifting and trunk rotation (Grice, 2008). Therefore, repetitively inadequate motions not only negatively affect badminton performance, but also cause pains and injuries (Zhou et al., 2019). The findings of previous studies supported the observations of this study that shoulder pain is associated with lumbar pain and knee pain, and lumbar pain is associated with knee pain in elementary school-aged badminton players.

However, as training time increases, pain tends to occur and lead to non-related shoulder pain, lumbar pain and knee pain as a consequence. Additionally, players who are more sensitive to pain may also be more likely to feel pain in multiple sites, but these pains may not be related as well. In other words, we cannot determine the associations between pains of two different sites unless we exclude the effects of training time and pain threshold. To do so, we divided the participants into two groups by training hours. When training hours per day was taken into consideration, in training hours per day ≤ 2.5 hours group, significant associations were found between lumbar pain and shoulder pain whereas no significant associations were found between lumbar pain and knee pain, shoulder pain and knee pain. In training hours per day > 2.5 hours group, significant associations were found between shoulder pain, lumbar pain and knee pain, respectively. In other words, lumbar pain correlated with shoulder pain regardless of training time while shoulder pain correlated with knee pain and lumbar pain only when training time > 2.5 hours per day. The results are not all in line with previous studies where knee pain is associated with lumbar pain and shoulder pain (Jonasson et al., 2011; Matsuura et al., 2017; Sekiguchi et al., 2018; Sogi et al., 2018; Yabe et al., 2019; Hagiwara et al., 2020).

Lumbar pain, which might weaken the ability of the lumbar function as an energy transmitter, can cause improper trunk movements. This will result in greater maximal shoulder external rotation angle that accordingly alter shoulder joint load (Oyama et al., 2014). In other words, lumbar pain creates an intermittent load that has to be compensated for by shoulder movement which causes shoulder pain. Our result demonstrated that lumbar pain is associated with shoulder pain regardless of training time which supports the statement. To help preventing shoulder pain, training time per day and lumbar pain should be taken into consideration by coaches and elementary school-aged badminton players. Also, coaches, physicians and physiotherapists should also pay attention to potential injury risks in knee as well as trunk and shoulder when players' training time > 2.5 hours per day.

Past researchers have found that both over and under trained players have higher risks of developing injuries (Orchard, 2012). With respect to injury rate of badminton players aged 13-16 years, 0.90 and 1.13 per 1000 athlete-hours of exposures have been revealed in past studies (Goh et al., 2013; Miyake et al., 2016). In other studies of 7-12 year-old players, soccer showed 0.61 injuries per 1000 hours of exposures (Rössler et al., 2016) and mini-basketball showed 3.83 per 1000 athlete-hours (Kuzuhara et al., 2016). In this study, injury rate per 1000 athlete-hours of exposures in elementary school-aged badminton players was 1.55 and 2.17 in university badminton players, which were higher than previous badminton study aged 13-16 years. Moreover, an upward risk tendency with age and peaked injury incidence were found among 11-12 year-old in elementary school-aged badminton players, which might be explained by badminton exposure time and growth spurt. In addition, injury incidence rate of elementary school-aged badminton players had a downward trend with increasing duration of badminton experience, which was in line with a previous study of soccer (Kristen et al., 2005).

Beginner players are more prone to get injured because they do not have good physical competence to respond to sport's intensive physical demand, meanwhile, their skills are still in the adaptational window which may also lead to more injuries as a consequence of incorrect techniques. In baseball, youth pitchers exhibit many risky behaviors which are associated with shoulder tiredness and shoulder pain. Therefore, the American Sports Medicine Institute made pitching guidelines (*e.g.*, pitch count limits and required rest recommendations) based on decades of research for baseball players aged under 22 years to prevent shoulder injury (American Sports Medicine Institute. Guidelines for Youth and Adolescent Pitchers, 2020). Furthermore, it also appeals to each baseball organization for establishing the rules to ensure that players must follow the guidelines while training. Badminton is a popular overhead motion racket sport played by more than 330 million people (BWF, 2020). However, no such playing guidelines have been made for youth badminton players. In this study some risk factors were identified, and we believe other risk factors will be detected and age-appropriate playing guidelines for badminton players will be designed in the future. Functional movement screen (FMS) is a screening test developed to estimate movement competence. The lower the FMS score, the less competent a player's physical quality is. Many previous studies have shown that players with lower FMS score have higher possibility of suffering from injuries (Bardenett et al., 2015; Garrison et al., 2015; Pfeifer et al., 2019).

In our samples, badminton players aged 7-12 year-old and 18-22 year-old showed a high percentage of pain and injury and mostly involved lower limbs. Injury prevention programs should be implemented from this age period of 7-12 year-old. For example, balance exercises are applied to prevent ankle injury (Mcguine et al., 2006), and stretching are adopted to ease shoulder pain (Cools et al., 2015).

Some limitations of this study need to be acknowledged. Firstly, the study is retrospective and cross-sectional study instead of prospective study. Secondly, we did not investigate the intensities of pain, injury severity (minor, moderate, severe) or time to return to badminton play. Lastly, the extrinsic (*e.g.*, environmental, racket, shuttlecock and seasonal variation) and intrinsic factors such as physical fitness and badminton motor skills were not investigated in this study. Physical fitness, including shoulder ROM (*e.g.*, GIRD, ER gain) (Johnson et al., 2018; Hellem et al., 2019), general joint laxity (Jansson et al., 2005; Imai 2018), hamstrings tightness (Endo and Sakamoto, 2014), core stability (Pogetti et al., 2018) and trunk rotation (Elliott, 1988; Aguinaldo et al., 2007; Keeley et al., 2008) have been revealed in association with body pain or injuries. Improper motion skills were regarded as mechanism of body pains or injuries associated with overhead motion sports (Elliott, 1988; Aguinaldo et al., 2007; Zhang et al., 2016; Asker et al., 2018; Zhou et al., 2019).

Numerous sports studies on total athlete-hours of exposures have been published, but few studies on weekly training hours. In this study, we found 78.3% of all the 253 injured players with weekly time ≥ 10 hours. In addition, incidence of injured players of time ≥ 10 hours per week was higher than that of time < 10 hours per week. Overtraining might be a risk factor of injury, but the current data are small samples. In future, age-appropriate guidelines on weekly training time should be studied in large sample size.

The recent review article showed that the epidemiology of badminton injuries had a population difference and investigating the epidemiology of injuries in each given population is essential to understand the magnitude of injuries and identify the priority anatomical regions to implement specific badminton injury prevention strategies (Senadheera, 2019). This study focused on elementary school-aged badminton players. Junior high school and high school will be targeted in the future. Figure 2-4 show some differences in lunge motion between an elementary school-aged badminton player and a university badminton player of our studies. Inappropriate badminton motor skill may cause badminton pains and injuries. In future studies, we will attempt to use “task analysis” (Zhou et al., 2019) to identify the association between badminton motor skill and badminton pains and injuries.

(a) (b)

Figure 2-4. Lunge motion of the participants

(a): Lunge motion of an elementary school-aged badminton player. (b): Lunge motion of a university badminton players

2.5. Conclusions

The present study provides an insight into injury incidence and characteristics of injuries in school-aged badminton players. Among 7-10 year-old badminton players, traumatic injuries occurred more than overuse injuries, but overuse injuries sharply increased with age. Around half of the elementary school-aged badminton players suffer from at least one badminton injuries, mostly involving lower limbs. Overuse injuries were more common in knee and foot, while trauma was more common in ankle. Injury incidence rate had an upward trend with increasing age in elementary school-aged badminton players, but injury incidence rate between 11-12 year-old players and 18-22 year-old players had no significant difference. On the other hand, injury incidence rate had a downward trend with increasing duration of experience, which indicates that inexperienced techniques might be a risk factor of injuries for elementary school-aged badminton players. This study also identified risk factors for shoulder pain and associations of pain at different anatomical sites in elementary school-aged badminton players. Training time per day is a risk factor for shoulder pain which should be limited to $\leq$ 2.5 hours per day. Lumbar pain, shoulder pain and knee pain were correlated with each other, respectively. Moreover, lumbar pain was significantly correlated with shoulder pain independent of training time. These findings have the potential to help target the most at-risk region and enhance badminton injury prevention programs in elementary school-aged and university badminton players.

Chapter 3, Study 2

The effect of teaching method using task analysis for badminton skill learning

This study has been published as:

Xiao Zhou, Kazuhiro Imai*, Yuanchun Ren. Teaching Method Using Task Analysis to Boost Motor Skill and Badminton Forehand Overhead Clear Skill Learning. Int J Sports Sci Med 3(2): 47-53, 2019.

3.1. Introduction

Forehand overhead stroke is crucial foundational, tactical and typical skill in badminton play (Lo and Stark, 1991; Grice, 2008; Hassan, 2017). The motion similar to a throwing motion is referred to as kinematic chain. It is difficult to maintain appropriate biomechanics of the kinematic chain to deliver energy smoothly while performing the skill (Grice, 2008; Hassan, 2017). By the shuttlecock trajectory, types of the forehand overhead stroke were mainly classified as smash, clear and drop (Hassan, 2017). In badminton match of women's singles, overhead stroke is 57.0%, including 24.7% clear, 23.7% drop and 8.6% smash (Ming et al., 2008; Phomsoupha and Laffaye, 2015), and in those of men's singles, overhead stroke is 44.6%, including 17.0% clear, 13.8% drop and 13.8% smash (Phomsoupha and Laffaye, 2015). Conventionally, the phases of the forehand overhead stroke are categorized as preparation, acceleration, hit and follow-through. The forehand overhead stroke motion of smash, clear and drop alike when proper phases are performed. Some movements, such as body core mass shift, trunk rotation, and upper limb rotation occur almost simultaneously during performing forehand overhead stroke (Grice, 2008). An inadequate overhead motion causes abnormal biomechanics of kinetic chain that has been demonstrated not only negative effects on motion performance (Sakurai and Ohtsuki, 2000; Wang et al., 2009; Zhang et al., 2016), but also greater risk of injuries (Fleisig et al., 1999). In study 1 (Chapter 2), inexperienced techniques were identified to be one of the risk factors for badminton injuries. Many cases showed badminton-related injuries were happened while falling or stumbling to retrieving a shuttlecock (Kroner et al., 1990). Upper limb injuries related to badminton localized to shoulder frequently (Shariff et al., 2009) that almost caused by performing smash and clear (Whittam, 2013).

Past studies of badminton using biomechanics revealed that the fundamental body movements of forehand overhead stroke motion consisted of ROM of shoulder, elbow, wrist and trunk in skilled badminton players (Tsai et al., 2000; Zhang et al., 2016). Additionally, body position of badminton players (relative to the moving shuttlecock) and the angle of racket of contacting the shuttlecock at the moment also affected performance of forehand overhead stroke (Li et al., 2017). With regard to methods of teaching and training in badminton, previous studies utilized feedback (Tzetzis and Votsis, 2006), pedagogical model of game (Nathan, 2016) and compounded tactical and skill teaching to boost badminton performance ([1]French et al.,1996; [2]French et al.,1996). Some studies demonstrated that stretching (Jang et al., 2018) and core stability exercises (Hassan, 2017) were effective in improving dynamic balance to boost badminton motion skill performance.

Task analysis is the procedure to break complicated tasks down into such subtasks that the subtasks are comprehensible and manageable easily (Srinivasan and Parthasarathi, 2013). Motor abilities of subtasks which are potential, and fundamental components of motor skill performance are estimated based on task analysis. Identifying motor abilities is related to the successful performance of subtasks. For instant, several components, constituting of the tennis serve motor skill, must be properly executed for serving a tennis ball successfully. The first step of task analysis is to identify the components of tennis serve, that is, handshake grip, maintain balance of stance position, ball throw, backward swing, forward swing, ball hit and follow through. Then potential motor abilities for the subtasks are identified as multi-limb coordination, rate control, speed of arm movement, aiming, control precision, *etc* (Magill and Anderson, 2013). To correct improper phases of the tennis serve motor skill, the subtasks as well as exercises are utilized to eliminate deficits in motor abilities of tennis players. Teaching method using task analysis is effective to learn foundational motor skills especially for novices (Siegel, 1972). However, there was not any badminton teaching study of task analysis on badminton motor skills teaching and badminton exercises. The purpose of this study was to conduct a randomized controlled trial of badminton forehand overhead clear teaching experiment to examine the effectiveness of a teaching method using task analysis.

3.2. Materials and methods

3.2.1. Participants

From six physical education classes, 60 high school male students aged 13-17 years were randomly recruited. All of them were novices who had no experience of taking professional badminton training. The participants were randomly divided into two groups (30 students in each group) as control group and task analysis group.

3.2.2. Profiles of teaching experiment

Before the teaching trial, a questionnaire was used to collect the demographics (age, weight and height) of the participants. A physical fitness test consisting of 50 meters run (50m), 1000 meters run (1000m), pull-ups and standing broad jump was performed. To examine whether there were significant differences in badminton skills of the participants in the control group and task analysis group or not, the tests of forehand long serve motor skill and forehand overhead clear motor skill were performed. The lessons of the control group were designed using conventional teaching method while those of the task analysis group were designed using task analysis.

The criteria of evaluating forehand overhead long serve motor skill and forehand overhead clear stroke motor skill were modified from a book named "Badminton steps to success" (Grice, 2008). To evaluate the badminton skills, the evaluation was designed into two categories as shuttlecock landing performance score and phase performance score. The shuttlecock landing performance score was made to estimate the accuracy of serve and clear, and the phase performance score was made to estimate forehand long serve and forehand overhead stroke motor skills. To perform shuttlecock landing performance score, badminton court was broken down into several zones with landing scores ranging 1-7 point (Figure 3-1), depending on where the shuttlecock landed. In addition, motor abilities of forehand overhead stroke motor skill were evaluated. The motor abilities for three phases of the forehand overhead stroke motor skill, *i.e.*, preparation, acceleration and follow through phases were evaluated using multi-limb coordination. The hit phase was evaluated using eye-hand coordination and visual tracking. Considered immature muscles strength and weak motor ability of the participants aged 13-17 years, the width of the six zones were set at the same 66cm while the longest one was set at 76 cm.

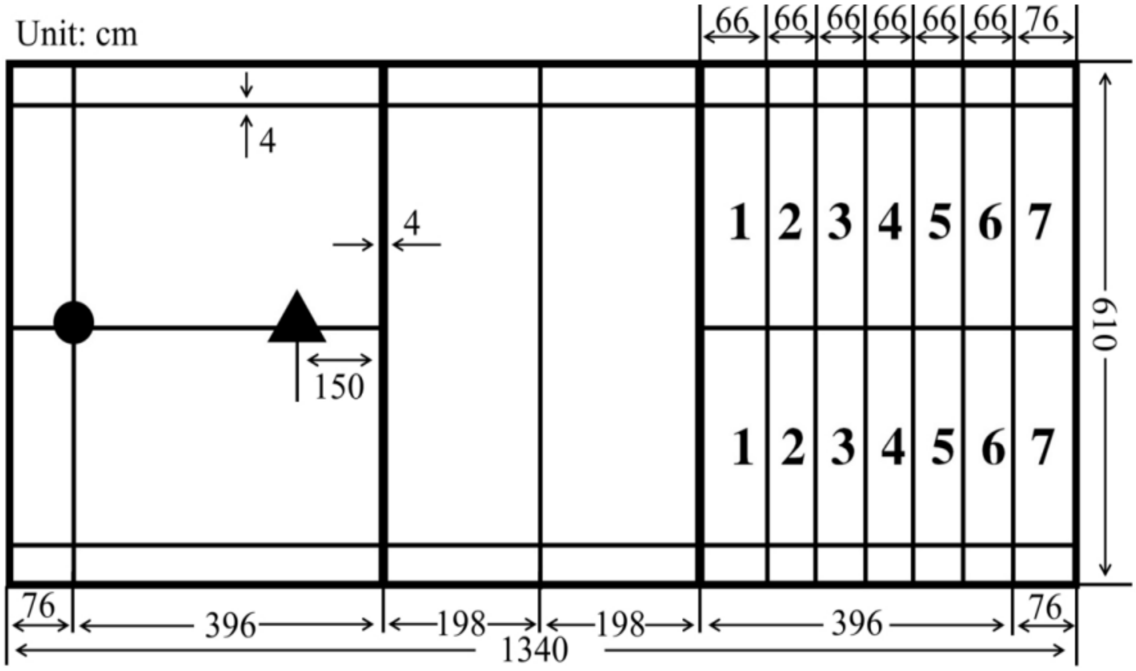


Figure 3-1 Badminton court of the badminton skills test. (1) ▲: the spot where the participants performed a forehand long serve. (2) ●: the spot where participants performed a forehand overhead clear.

Badminton skills tests were performed in the same court before and after the teaching experiment, respectively. The average temperature of the court was 23 ± 2°C, and the relative humidity 41 ± 2%. A racket with a tension of 21lb and a shuttlecock with an international speed metric of 3/77 were selected. Ten trials for forehand overhead clear were performed before and after the teaching experiment, respectively. Ten trials for forehand long serve were performed before the teaching experiment. The minimum score was set at 10 and the maximum score was set at 70 for each participant in both the forehand long serve and forehand overhead stroke tests. The physical fitness and badminton skill tests were performed to identify whether there were significant differences or not between the control group and the task analysis group before the experiment. Due to no teaching lessons for the forehand long serve, we did not perform the test of the forehand long serve motor skill after the teaching experiment. To examine the effectiveness of the teaching methods on forehand overhead stroke motor skill, we performed the test of the forehand overhead clear motor skill acquisition before and after teaching experiment.

3.2.3. Criteria and procedure of teaching experiment

To evaluate the forehand long serve motor skill performance, the criteria, consisting of ten steps were designed as follows:

- handshake grip
- put body core mass on rear foot
- swing back rack arm
- wrist cock
- move body core mass
- trunk rotation
- forearm rotation
- contact the shuttlecock at leg level
- move racket in front of and over the contralateral shoulder
- recover in ready position

To evaluate the forehand overhead clear motor skill performance, the criteria, consisting of ten steps were designed as follows:

- handshake grip
- hold racket arm up
- maintain balance on both feet
- trunk rotation in the direction of the shuttlecock
- forearm rotation
- hit the shuttlecock as high as possible
- swing toward the net
- move racket to the body contralateral side
- place posterior foot forward
- recover in ready position

Phase performance scores of each step were ranged 1-7. Each step consisted of the forehand long serve motor skill performance and forehand overhead clear motor skill performance described above. Each step was scored as follows: 1 = incorrect, 2 = very improper, 3 = improper, 4 = medium, 5 = development, 6 = proper, 7 = very proper. Three qualified and experienced badminton coaches (mean experience of badminton play: 10.5 years; mean hours per week of badminton teaching: 5.3 hours) were chosen. Two of them were chosen randomly and estimated the phases performance of the forehand long serve motor skill and forehand overhead clear motor skill and scored for the above 10 steps both of pre-and post-experiment. The mean scores were defined as phase performance scores which were calculated by scores of the two coaches. Due to the requirement of the reproducible serve for forehand overhead clear test, the serve was performed by the third coach. Before the teaching experiment the two coaches analyzed and revealed deficits in motor skill abilities of each participant by the criteria of forehand long serve motor skill and forehand overhead clear motor skill during the badminton tests. For instance, when a participant failed to coordinate trunk and upper limbs rotation during acceleration phase of forehand overhead clear, the coach recorded the participant as a shortage of multi-limb coordination.

The conventional teaching programs executed in the control group were as follows (Figure 3-2):

・the participants were organized to learn and practice separate phases of forehand overhead clear motor skill

・the participants were organized to learn and practice the whole forehand overhead clear motor skill

・the participants were organized to practice forehand overhead clear motor skill

The coach gave feedback and corrected improper and wrong phases of the participants during the teaching lesson.

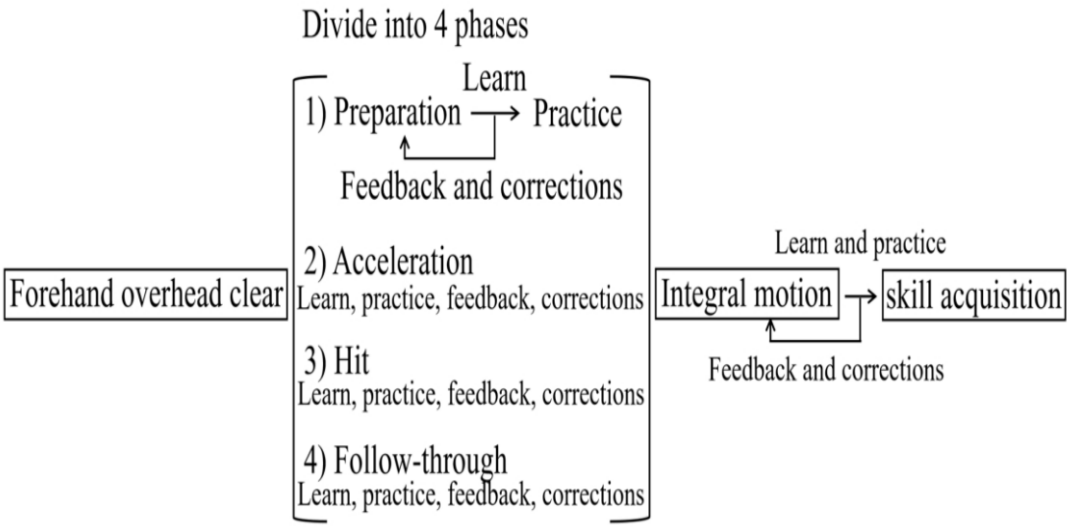


Figure 3-2. Conventional teaching method procedure for control group.

Teaching method using task analysis was executed in task analysis group. Before the teaching experiment, the motor abilities of each phase of forehand overhead stroke were analyzed and evaluated by the coach. Results on the performance of each participant were analyzed for detecting their deficits in motor abilities. The task analysis teaching programs (Figure 3-3) were as follows: the coach organized the participants to learn and practice separate phase and the whole skill of forehand overhead clear, and also used specific methods to eliminate deficit motor abilities during the teaching experiment. For instance, burpee and rope-skipping were used to the participant with weak multi-limb coordination ability. Hit a static (*i.e.*, hanging shuttlecock) or a dynamic shuttlecock (*i.e.*, throwing shuttlecock) was used to develop eye-hand coordination and visual tracking abilities. By task analysis, forehand overhead stroke motor skill was divided into 4 phases, that is preparation, acceleration, hit and follow through, and 3 subtasks, that is multi-limb coordination, eye-hand coordination and visual tracking abilities.

The teaching experiment in two groups was executed by the coach who did not participate in the evaluation of the experiment test. The teaching experiment took 9 weeks. Two lessons (45 minutes per lesson) were scheduled for a week.

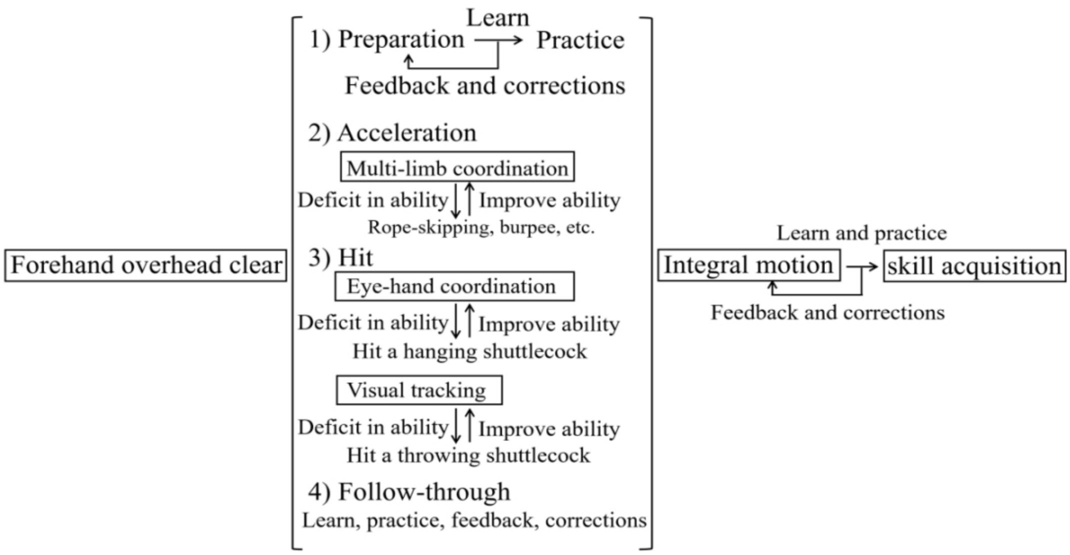


Figure 3-3. Task analysis teaching method procedure for task analysis group.

3.2.4. Statistical analysis

Shapiro-Wilk test was adopted to examine normality of collected data, that is age, weight and height, 50m, 1000m, pull-ups and standing broad jump and scores of forehand long serve motor skill and forehand overhead clear motor skill performance. The distributions of age, weight, height, 50m, 1000m, pull-ups and standing broad jump were non-normal distribution whereas the distributions of forehand long serve score and forehand overhead clear score were normal. Data of non-normal distribution between control group and task analysis group was analyzed using Mann-Whitney U test before the experiment. Regarding the effects of two different teaching methods, the interaction between time and teaching methods was analyzed using a two-way analysis of variance (ANOVA) with repeated measures. Then, follow-up analyses were done to examine any differences in two groups between the testing time of pre-and post-experiment by Post-hoc simple effects analysis. For each statistical analysis, p-value $<$ 0.05 was considered to be significant.

3.3. Results

Table 3-1 and Table 3-2 show basic parameters and physical fitness of all the participants. No significant differences in age, height, and weight were observed between both groups. Likewise, no significant differences of 50m, 1000m, pull-ups and standing broad jump were found between the control group and task analysis group.

Table 3-1: Basic parameters of the participant in the control group and task analysis group.

	Control group (n = 30)	Task analysis group (n = 30)	*p* value
Age (year)	14.7 ± 0.9	14.6 ± 1.2	>0.05
Height (cm)	173.8 ± 4.3	171.5 ± 5.8	>0.05
Weight (kg)	58.2 ± 7.3	58.1 ± 8.6	>0.05

Values are mean ± SD.

Table 3-2: Physical fitness of the participants in the control group and task analysis group.

	Control group (n = 30)	Task analysis group (n = 30)	*p* value
50m (s)	8.0 ± 0.9	7.6 ± 0.6	>0.05
1000m (min)	4.1 ± 0.3	4.2 ± 0.2	>0.05
Pull-ups (time)	5.7 ± 3.4	4.5 ± 3.5	>0.05
Standing broad jump (cm)	220.2 ± 21.0	228.5 ± 22.3	>0.05

Values are mean ± SD.

Table 3-3 shows results of phase performance of forehand long serve motor skill and forehand overhead clear motor skill. Before the teaching experiment as pre-experiment test, no significant differences of phase performance scores of forehand long serve motor skill and forehand overhead clear motor skill were found between the control group and the task analysis group. Likewise, no significant differences of shuttlecock landing performance scores of forehand long serve skill and forehand overhead clear skill were found between the control group and the task analysis group before the teaching experiment.

Table 3-3. Performance of Forehand long serve motor skill and forehand overhead clear motor skill in pre-experiment test.

		Control group (n = 30)	Task analysis group (n = 30)	*p* value
Forehand long serve	Phase performance	21.2 ± 2.5	20.8 ± 1.8	>0.05
	Shuttlecock landing performance	22.6 ± 2.5	24.7 ± 2.8	>0.05
Forehand overhead clear	Phase performance	25.2 ± 1.4	25.7 ± 1.3	>0.05
	Shuttlecock landing performance	23.1 ± 2.9	22.2 ± 2.4	>0.05

Values are mean ± SD.

Figure 3-4 and Figure 3-5 present the results of the effectiveness of conventional teaching method and task analysis teaching method examined using the two-way ANOVA analysis. As for motor skill learning estimated by the phase performance, mean scores of all the participants significantly enhanced from 25.5 (control group: 25.7, task analysis group: 25.2) before the teaching experiment to 44.0 (control group: 36.2, task analysis group: 51.8) through the teaching experiment. In addition, significant interaction effects ($F_{1,58} = 322.23$, $p < 0.01$, partial $\eta^2 = 0.85$) and significant time main effects ($F_{1,58} = 1701.84$, $p < 0.01$, partial $\eta^2 = 0.97$) were observed. Figure 3-4 shows that compared with the control group, the participants in the task analysis group significantly improved ($F_{1,58} = 336.09$, $p < 0.01$, partial $\eta^2 = 0.85$) during the teaching experiment by Post-hoc simple effects analysis.

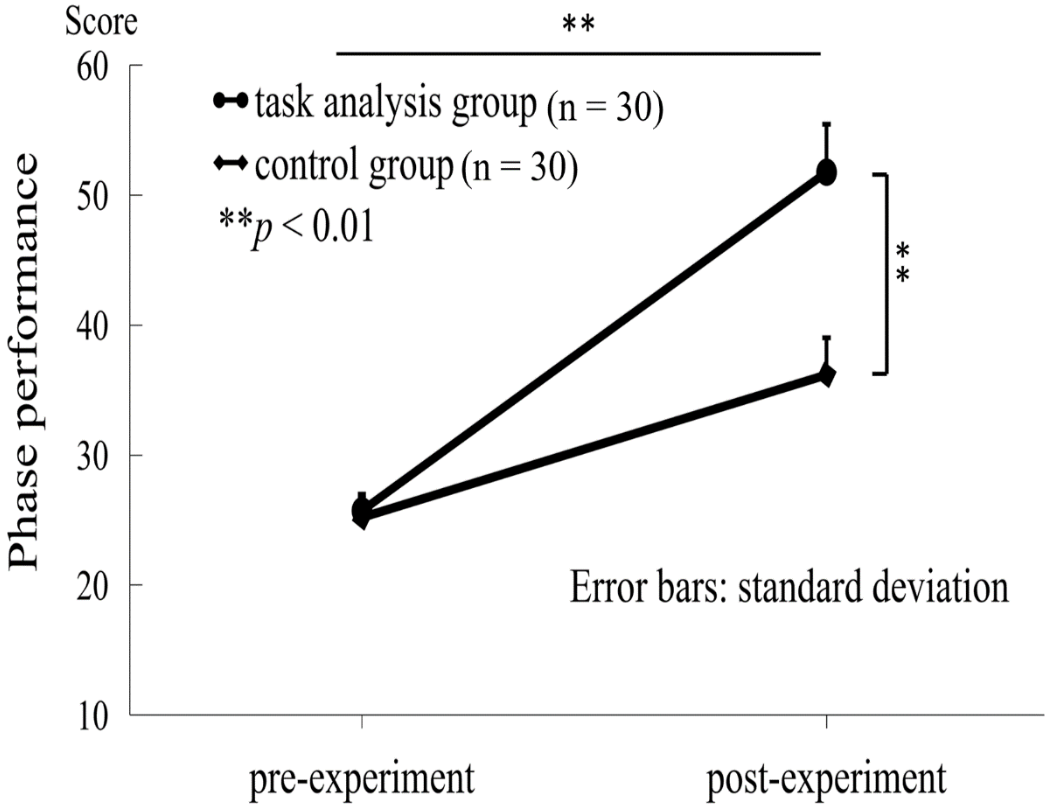


Figure 3-4. Phase performance of forehand overhead clear during the experiment. Significant differences in phase performance were found between two groups using the two-way ANOVA analysis ($^{**}p$ values < 0.01).

Results of the two-way ANOVA on shuttlecock landing performance scores are shown in Figure 3-5. The results showed that mean scores of all the participants significantly enhanced from 22.7 (control group: 23.1, task analysis group: 22.1) before teaching experiment to 52.4 (task analysis group: 54.0, control group: 50.8) at the end of the teaching experiment. Meanwhile, significant interaction effects ($F_{1,58} = 7.11$, $p < 0.01$, partial $\eta^2 = 0.11$) and significant time main effects ($F_{1,58} = 1392.09$, $p < 0.01$, partial $\eta^2 = 0.96$) were detected. Moreover, the participants in the task analysis group significantly improved ($F_{1,58} = 4.73$, $p < 0.05$, partial $\eta^2 = 0.08$) than those in the control group during the teaching experiment by Post-hoc simple effects analysis (Figure 3-5).

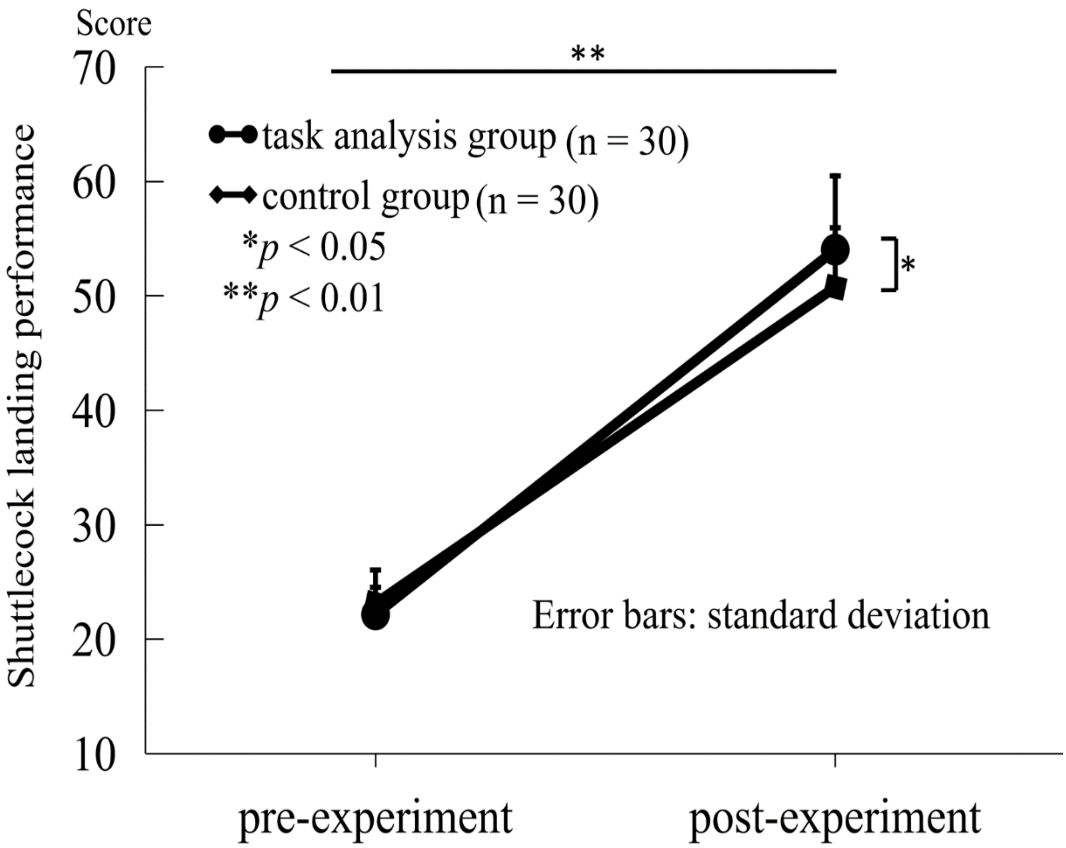


Figure 3-5. Forehand overhead clear shuttlecock landing performance during the experiment. Significant differences in shuttlecock landing performance were found between two groups using the two-way ANOVA analysis ($^{*}p$ values < 0.05, $^{**}p$ values < 0.01).

3.4. Discussion

Shuttlecock landing performance scores connect with participant's badminton overhead clear skills, that is the accuracy of badminton forehand overhead clear, and phase performance scores connect with participant's badminton forehand overhead stroke motor skills. The conventional teaching method as well as task analysis teaching method was effective in boosting scores of shuttlecock landing performance (forehand overhead clear skills) and phase performance (motor skills). Moreover, task analysis teaching method was more effective in boosting forehand overhead clear skills and motor skills, especially motor skills, compared with conventional teaching method.

The enhances of spatial and temporal accuracy of movements through practice are referred to motor skill learning (Willingham, 1988). Practice and feedback which are the primary components of motor skill learning behavioral approach (Masaki and Sommer, 2012; Magill and Anderson, 2013; Yanagihara, 2014) could help a human boost motor skill accuracy and consistency whereby. Meanwhile, motor skill learning is also affected by cognition (Sulllivan et al., 2008; Masaki and Sommer, 2012). Moreover, various practices affect the central nervous system and brain plasticity (Imai and Nakajima, 2008) that could generate the maximum effects to improve motor skills learning (Wulf, 1991). Vision tracking practice is effective in acquiring and developing perception skills, especially for novices (Vu Huynh and Bedford, 2011; Bijanrajaeian and Mousavi, 2014). Motor abilities are categorized as two broad types: physical proficiency abilities and perceptual motor abilities. In the two categories, some small motor abilities, such as rate control, eye-hand coordination, multi-limb coordination, static strength, and visual tracking have been identified (Magill and Anderson, 2013).

Among preparation, acceleration, hit and follow through phases, acceleration phase and hit phase are more difficult to learn and master for novices. A study of baseball, a type of overhead motion sports, stated that pitchers coordinated multi-limb simultaneously during acceleration phase of pitching, *i.e.* transfer body core mass, rotate trunk, shoulder abduction, and shoulder horizontal adduction (Fortenbaugh et al., 2009). In badminton forehand overhead stroke performance, upper limb rotation and contralateral arm downward movement occur at the same moment to generate the maximum energy to racket during acceleration phase (Grice, 2008). As for the phase of hit, badminton players must track a coming shuttlecock and then decide the moment of hitting it. Multi-limb coordination is the crucial motor ability for acceleration phase performance, and visual tracking is the crucial motor ability for hit phase performance. The motor ability of coordinating the eye movement with hand movement is eye-hand coordination (Magill and Anderson, 2013). In the current study, using task analysis, forehand overhead stroke motor skill was divided into 4 phases, that is preparation, acceleration, hit and follow through, and 3 corresponding subtasks, that is multi-limb coordination, eye-hand coordination and visual tracking abilities. Additionally, shortages of motor skill abilities of the participants were identified and boosted.

Feedback and correcting practice conducted by the coach enhanced the badminton skill performance of the control group and task analysis group in this study, which supports previous studies of badminton (Singh et al., 2011). For novices, from separate phase to integral motion is the general process of motor skill learning, but the main difference between the task analysis teaching group and control group is that task analysis teaching method target weak motor skill abilities of the participants. After the teaching experiment, the participants in task analysis group presented better effectiveness, especially forehand overhead stroke motor skill learning. We speculated that in task analysis group, motor skill abilities (*i.e.*, multi-limb coordination, eye-hand coordination and visual tracking) of the participants enhanced more efficiently compared with the control group.

Improper phases of motor skills not only affect motion performance negatively, but also increase the risk of injuries. In overhead motion sports, such as baseball and tennis, improper overhead phases resulted in abnormal biomechanics which alter shoulder joint load, ultimately caused shoulder injuries, such as shoulder labral tear or rotator cuff impingement (Olsen et al., 2006; Jayanthi and Esser, 2013). Another previous study revealed some movements of badminton forehand overhead stroke motion using biomechanics. For instant, the phase of follow through after hitting a shuttlecock occurs as elbow flection reached the maximum joint angle approximately 120º, and then decreased to approximately 80º to complete the phase (Zhang et al., 2016). Meanwhile, it is crucial for overhead motion players to perform the follow through phase to dissipate excess strength. In the current study, we found that compared with the task analysis group, the angle of elbow of the participants in the control group was greater with upper limbs deviation. Upper limbs deviation cause shoulder adduction limitation and elbow hyperextension that may cause upper limb injuries. Thus, proper mechanics acquisition of motor skill is crucial for overhead motion players to minimize the likelihood of injury. Previous studies of racquet sports on the association between improper phases and pain/injury demonstrated that improper phases generated additional load to body segments and increase the likelihood of injuries (Jayanthi and Esser, 2013). Nevertheless, we have not detected studies of injury prevention on the association of injury rates or pain complaints and badminton motor skill phases correction.

Some limitations are acknowledged in the current study. Firstly, we have not investigated the reproducibility of badminton forehand overhead clear motor skill. In future studies, reproducibility should be investigated and revealed. Secondly, evaluation measures of shuttlecock landing are unsuitable for estimating performance accuracy. Using the trajectory of the shuttlecock (Vial et al., 2019) instead of shuttlecock landing performance score may better estimate badminton forehand overhead clear skills of performers more accurately. Thirdly, eye-hand coordination and visual tracking were estimated by experienced coaches in the current study. Objective data assessment may be strengthened using real time eye tracking system. Finally, although we have found that the participants in the control group presented greater elbow angle (a shortage of upper limbs control) while performing the follow-through phase (Figure 3-6), accurate information of shoulder and elbow kinematics should be collected by biomechanics in further studies.

(a) (b)

Figure 3-6. Follow-through phases of the participants in two groups.

(a): Follow-through phase of a participant in control group. (b): Follow-through phase of a participant in task analysis group.

3.5. Conclusion

This study presented that teaching method using task analysis could help novices promote badminton forehand overhead clear learning. This teaching method using task analysis is effective in learning badminton motor skills, correcting improper phases, and enhancing motor skills. Furthermore, it is crucial for players to boost badminton motor skills efficiently that a teaching method using task analysis should be utilized to improve the effects of badminton learning. Teaching method using task analysis might be a promising approach to correct inexperienced techniques and to prevent badminton injuries.

Chapter 4, Study 3

Survey of risk factors of badminton injury using medical check-up

This study has been published as

Zhou X, Imai K*, Liu, X. Survey of Epidemiology and Mechanisms of Badminton Injury Using Medical Check-Up and Questionnaire of School Age Badminton Players. International Scholarly and Scientific Research & Innovation, 14(6), 146-151, 2020.

Zhou X, Imai K*, Xiaoxuan Liu: Weak hamstrings tightness, weak balance ability and asymmetric trunk rotation caused shoulder pain in male university badminton players: Proceedings of ISER International Conference: 1-6, 2020.

Zhou X, Imai K*, Liu X, Watanabe E. Physical dysfunction caused shoulder pain in university male badminton players. International Journal of Advances in Science, Engineering and Technology, *in press*.

4.1. Introduction

As a type of overhead sports, badminton forehand overhead motion is similar to throwing motion which is referred to as a kinetic chain (Scarborough et al., 2020). Decreasing the trunk energy production by 20% can lead to increased load on the shoulder joint by up to 34% (Lintner et al., 2008). Therefore, a breakage in any of the kinetic chain may cause injuries or pain (Jayanthi and Esser, 2013; Sekiguchi et al., 2017). Shoulder, lumbar injuries and pains are well-known problems in badminton players (Jørgensen and Winge, 1987; Krøner et al., 1990). Over half of players reported shoulder pain and 20% of the players continued to play with ongoing pain (Fahlström et al., 2006; Arora et al., 2015; Phomsoupha and Laffaye, 2020). Pain is an alarm of injury that often be neglected. Study 1 (Chapter 2) revealed that shoulder pain and lumbar pain were frequent in elementary school-aged badminton players and university badminton players. Training time more than 2.5 hours a day was detected to be a risk factor of shoulder pain. Moreover, lumbar pain was related to shoulder pain in badminton players as well as in baseball players (Sekiguchi et al., 2018) and basketball players (Hagiwara et al., 2020).

Some studies of baseball players reported that there was a correlation between trunk range of motion (ROM) and shoulder pain (Sekiguchi et al., 2020) and shoulder injury (Aragon et al., 2012; Endo and Sakamoto 2014). Glenohumeral internal rotation deficit (GIRD) and insufficient shoulder external rotation (ER) on dominant side increased risk for shoulder injury (Burkhart et al., 2003; Wilk et al., 2015). A previous study of handball players revealed that decreased shoulder ER strength was a risk factor for shoulder injury (Achenbach et al., 2019). As for lumbar pain, previous studies reported that asymmetry of hip rotation ROM (Van Dillen et al., 2008), tight hamstrings flexibility (Mistry et al., 2014), trunk rotation strength and endurance (Lindsay and Horton, 2006) were risk factors for lumbar pain. A systematic review reported that a restriction in lumbar lateral flexion as well as hamstrings ROM was associated with an increased risk of developing lumbar pain (Sadler et al., 2017).

Regarding badminton studies using medical check-up, some studies have studied shoulder ROM and shoulder rotation strength in badminton players (Couppe et al., 2014; Fernandez-Fernandez et al., 2019). However, research on physical fitness to detect risk factors for shoulder pain is limited.

Improving physical fitness, *i.e.*, muscle strength (Cools et al., 2015), muscle flexibility (Sakata et al., 2019), trunk stability (Cope et al., 2019) and balance ability (Garrison et al., 2013) can prevent shoulder injury in overhead sports players. Improved understanding of what deficits in physical fitness may facilitate badminton injury screening and injury prevention.

On the other hand, numerous studies on the association of throwing motion techniques and shoulder pains and injuries in baseball pitchers have been found (Keeley et al., 2008; Fortenbaugh et al., 2009; Oyama et al., 2014; Oyama et al., 2017). Although previous badminton studies adopted biomechanics to examine forehand overhead stroke motion (Zhang et al., 2016; Tsai et al., 2000), no studies on the association of forehand overhead stroke motion techniques and shoulder pains and injuries were found. Additionally, in study 1, elementary school-aged badminton players had an upward injury rate with increasing age, which indicates improper badminton phases might cause injuries. Therefore, accurate physical fitness reference parameters in child badminton players, which can help enhance injury prevention should be also studied.

This study aimed to identify risk factors for shoulder pain and lumbar pain in national level university badminton players using medical check-up and forehand overhead stroke test. Firstly, we compared physical fitness between elementary school-aged badminton players and university badminton players; then we targeted shoulder pain and lumbar pain in university badminton players so that risk factors can be detected. Based on literature, we hypothesized that GIRD, increased shoulder external rotation, weak balance ability and decreased trunk rotation are risk factors for shoulder pain, and weak balance ability, decreased trunk rotation and greater SLR degree are risk factors for lumbar pain in university badminton players.

4.2. Materials and methods

4.2.1. Participants

From March 2019 to August 2019, 52 university badminton players (26 male and 26 female) and 22 elementary school-aged badminton players (10 male and 12 female) have been investigated. One male university badminton player with shoulder surgery experience was excluded. All of the participants participated in the national tournament. The dominant side of all the participants was right side.

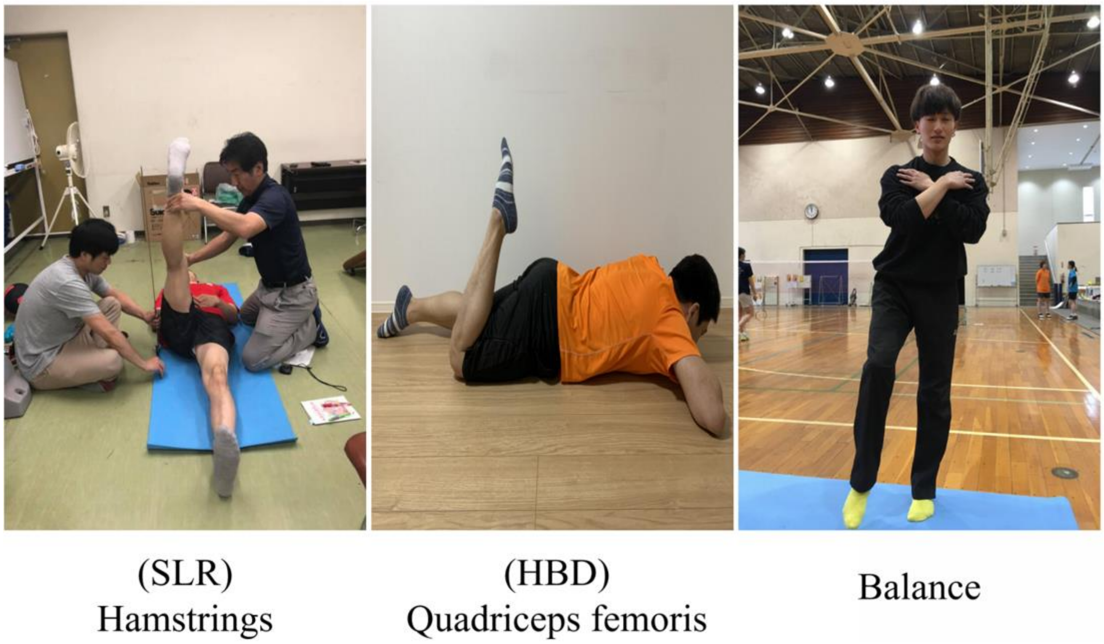
4.2.2. Measurements of medical check-up

In order to detect risk factors of shoulder pain and lumbar pain, a questionnaire and medical check-up were used. The questionnaire included basic parameters (gender, age, weight, height, body mass index: BMI, dominant side), duration of badminton experience, training minutes of per day, training days of per week, training minutes per week and anamnesis of past injury and shoulder pain. Visual analog scale (VAS) was utilized to examine intensities of pain sites, including shoulder, lumbar, elbow, hand, thigh, knee, leg, Achilles tendon, ankle, plantar and toe. Participants were also asked to answer this question "Do you have any shoulder pain now?".

A physical fitness test of medical check-up was operated to evaluate hand grip strength, heel buttock distance (HBD), straight leg raising (SLR) angle, balance ability, range of motion (ROM) of both shoulders and trunk. A digital hand dynamometer (N-FORCE, Wakayama, Japan) was used to measure hand grip strength. Measuring capacity of the digital hand dynamometer is 0-90.0 kg with sensitivity of 0.1 kg. ROM was measured by a digital goniometer SA-5468 (Suncosmo, Tokyo, Japan). Measuring range of the digital goniometer is 0-360.0 degree (°) and has a sensitivity of 0.1° with resolution of 0.05°.

An orthopedic surgeon with more than 20 years of experience, and a sports medicine doctoral student performed the physical fitness test of medical check-up. Firstly, the participant stood without shoes on a yoga mat and hand grip strengths on both sides were measured with the digital hand dynamometer. Next, muscle tightness of lower limbs was evaluated by HBD and SLR (Fig. 4-1). To evaluate muscle tightness of quadriceps femoris, the participant lied prone on the yoga mat. When the participant kept the pelvis flat, the examiner flexed the participant's knee slowly until the heel approached the buttock. The distance between the heel and the buttock was measured and recorded as HBD. Then, with the participant in supine position on the yoga mat, the examiner slowly raised the participant's leg with knee extended. The examiner kept raising the participant's leg until the participant could not continue because of pain or tightness in the posterior leg (hamstrings). The examiner measured the angle of start-stop point using the goniometer and recorded it as SLR.

The time of balance on one leg (balance ability) was measured by single leg stance. When the test started, participants crossed arms on chest with eyes closed, then stood with one leg as long as they could while lifted another thigh with flexion of 90°. The test was stopped if any of the followings happened: (1) open eyes, (2) move the stance leg, (3) the lifted leg touch the stance leg or the yoga mat. Participants were allowed at most 3 trials on each leg and the longest times of each leg were selected.



(a) (b) (c)

Figure 4-1. Diagrammatic representation of the physical fitness test measurements. (a): Straight leg raising (SLR) for hamstring muscles flexibility evaluation. (b): Heel buttock distance for quadriceps femoris tightness evaluation. (c): Single leg stance for static balance ability evaluation.

In shoulder ROM assessment, IR and ER on both of dominant side and nondominant side were measured. The participant was in supine position on a standard examining table, with straight leg, 90 degree of shoulder abduction, 90 degree of elbow flection and forearm in neutral position. The examiner stabilized the scapula and pushed the forearm anteriorly (IR) and posteriorly (ER) while rotating the humerus to produce maximum passive IR and ER. The angles of IR and ER (Figure. 4-2a) were measured by the second examiner at the point of tightness in which no more glenohumeral motion would occur without movement of the scapular. As compared to the contralateral side, the loss of IR of the glenohumeral joint of dominant side was defined as GIRD (Achenbach et al., 2019), increased ER of the glenohumeral joint of dominant side was defined as ER gain. The TROM was calculated by adding IR and ER for each side individually and the loss of TROM of dominant side as compared to the contralateral side was defined as TROM loss.

Finally, trunk ROM of flection, extension, and rotation were measured. The participant stood in an upright position with knees extended, progressively bent forward/backward the trunk with chin up and chest out as far as possible. The angle between the vertical line and trunk bending forward stop-point was measured and recorded as trunk flection (Figure. 4-2b). The angle between the vertical line and trunk bending backward stop-point was measured and recorded as trunk extension (Figure. 4-2c). The participant was asked to sit on the yoga mat with crossed legs, keep the trunk in an erect upright posture, and cross arms in front of chest. The participant was then instructed to rotate to the right (Figure. 4-2d) and left as far as possible. The examiner measured the angle of start-stop point using the goniometer and recorded as trunk right/left rotation.

(a) (b) (c) (d)

Figure 4-2. Range of motion measurements. (a): Shoulder external rotation evaluation. (b): Trunk flection evaluation. (c): Trunk extension evaluation. (d): Right trunk rotation evaluation.

After medical check-up, a forehand overhead clear test was performed. The participant stood between the long service line for double and back boundary line. Three trials for forehand overhead clear were performed by the participants using maximal strength. A badminton racket with a higher tension of 28 lb was used by university badminton players while a one with a lower tension of 21 lb was used by elementary school-aged badminton players. The shuttlecocks with an international speed metric of 3/77 were selected. After forehand overhead clear test, all the participants were asked immediately “Do you have any shoulder pain during the forehand overhead stroke?”. If “yes”, the participants were also asked “Which phases of forehand overhead stroke motor skill (preparation, acceleration, hit and follow-through) caused your shoulder pain?”.

4.2.3. Statistical analysis

Firstly, a Student t-test, *i.e.*, independent t-test and pair t-test, and non-parameter methods *i.e.*, Mann-Whitney U-test and Wilcoxon’s rank-sum test were utilized for data analysis of comparisons of the university and elementary school-aged badminton players. Categorial variables, analyzed by χ^2 test were presented as numbers and percentages. Secondly, binary logistic regression analyses were executed to investigate the association of hand grip strength, HBD, SLR, balance, shoulder and trunk ROM with the presence of present shoulder pain. The odds ratios (ORs) and 95% confidence intervals (CIs) of the association between physical fitness parameters and present shoulder pain were calculated. Then, the variables with p value < 0.2 were screened for identifying potential risk factors of present shoulder pain using multivariable logistic regression analysis. Lastly, a Student t-test and non-parameter methods were utilized for data analysis of lumbar pain. For statistical analysis, *p* value less than 0.05 was considered to be significant.

4.3. Results

4.3.1. Comparisons in university and elementary school-aged badminton players

Data on basic parameter of university and elementary school-aged players are shown in Table 4-1. Significant differences in age, height, weight, BMI, duration of badminton experience, days per week, training minutes per day and total training minutes per week were found between university and elementary school-aged players.

Table 4-1. Basic parameter of university players and elementary school-aged players.

Demographics	University players (n = 51)	Elementary school-aged players (n = 22)	*p*-value
Age, year (yr)	19.8 ± 1.2	9.2 ± 1.7	< 0.001
Height, cm	165.3 ± 7.4	143.4 ± 10.8	< 0.001
Weight, kg	60.2 ± 7.2	32.4 ± 7.6	< 0.001
BMI, kg/m^2	21.9 ± 1.6	15.5 ± 1.8	< 0.001
Badminton experience, yr	11.2 ± 2.6	2.5 ± 0.8	< 0.001
Days, per week	5.2 ± 0.6	3.9 ± 1.1	< 0.001
Min, per day	198.6 ± 29.6	147.3 ± 29.1	< 0.001
Total min, per week	1032.0 ± 165.7	568.6 ± 187.6	< 0.001

Values are mean ± SD.

Results of VAS of pain sites in university players and elementary school-aged players are shown in Table 4-2. Among all the university players, 34 players (66.7%) experienced shoulder pain and 42 players (82.4%) experienced lumbar pain while among all the elementary school-aged players, 10 players (45.5%) experienced shoulder pain and 4 players (18.2%) experienced lumbar pain. The university players experienced moderate pain in shoulder, lumbar, elbow, hand, thigh, knee, leg, Achilles tendon, ankle, plantar and toe, respectively. The VAS of ankle pain intensity on dominant side ranked the first (63.9 mm), followed by planta (62.6 mm). The elementary school-aged players experienced moderate pain in shoulder (43.9 mm), lumbar (49.0 mm) and thigh (41.0 mm) while the intensities of other pain sites were slight.

Table 4-2. Pain intensities of body sites in university players and elementary school-aged players.

Sites	VAS (mm) of University players	VAS (mm) of Elementary school-aged players
Shoulder	54.6 ± 23.7	43.9 ± 17.0
Lumbar	59.2 ± 23.8	49.0 ± 32.6
Elbow	53.2 ± 26.5	21.3 ± 9.1
Hand	48.7 ± 24.5	28.7 ± 14.1
Thigh		
D	50.6 ± 25.7	41.0 ± 27.8
ND	50.1 ± 24.7	39.6 ± 30.1
Knee		
D	59.0 ± 26.0	21.7 ± 2.4
ND	54.7 ± 29.9	26.9 ± 8.9
Leg		
D	49.4 ± 23.2	26.4 ± 15.8
ND	48.4 ± 24.8	27.3 ± 16.8
Achilles tendon		
D	52.4 ± 25.4	16.1 ± 5.9
ND	54.0 ± 27.9	15.0 ± 7.2
Ankle		
D	63.9 ± 27.7	30.4 ± 15.4
ND	59.2 ± 26.4	30.3 ± 14.7
Planta		
D	62.6 ± 23.9	24.9 ± 6.9
ND	60.9 ± 25.2	24.6 ± 6.5
Toe		
D	55.7 ± 30.7	30.4 ± 14.0
ND	52.4 ± 32.3	34.0 ± 11.5

Values are mean ± SD.

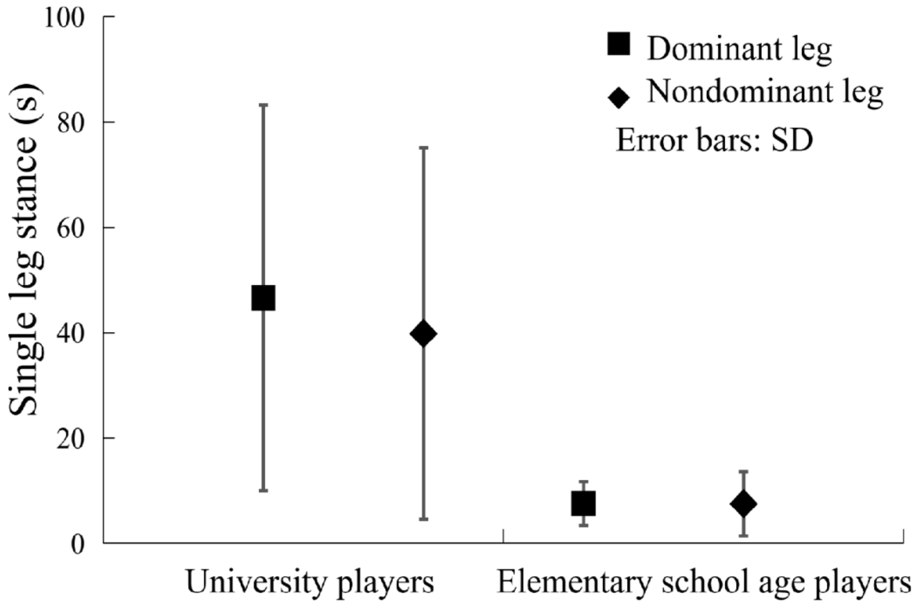
Comparisons of physical fitness between university players and elementary school-aged players are shown in Table 4-3, Figure 4-3, and Table 4-4. Compared with university players, elementary school-aged players showed significantly weaker hand grip strength on both sides, significantly smaller hand grip strength loss, and significantly smaller HBD on dominant side. There were significant differences in hand grip strength between dominant side and nondominant side in university players ($p < 0.001$) as well as in elementary school-aged players ($p < 0.01$) (Table 4-3). Likewise, elementary school-aged players showed significantly weaker balance on both sides (dominant side: 46.6s *vs* 7.6s, $p < 0.001$; nondominant side: 39.8s *vs* 7.5s, $p < 0.001$) and significantly greater SLR degrees on both sides (dominant side: 85.0º *vs* 101.7º, $p < 0.01$; nondominant side: 84.0º *vs* 99.4º, $p < 0.01$) than university players. In both of university players group and elementary school-aged players group, there were no significant differences in balance and SLR degrees between dominant side and nondominant side (Figure 4-3).

Table 4-3. Comparisons of various factors of physical fitness between university and elementary school-aged players.

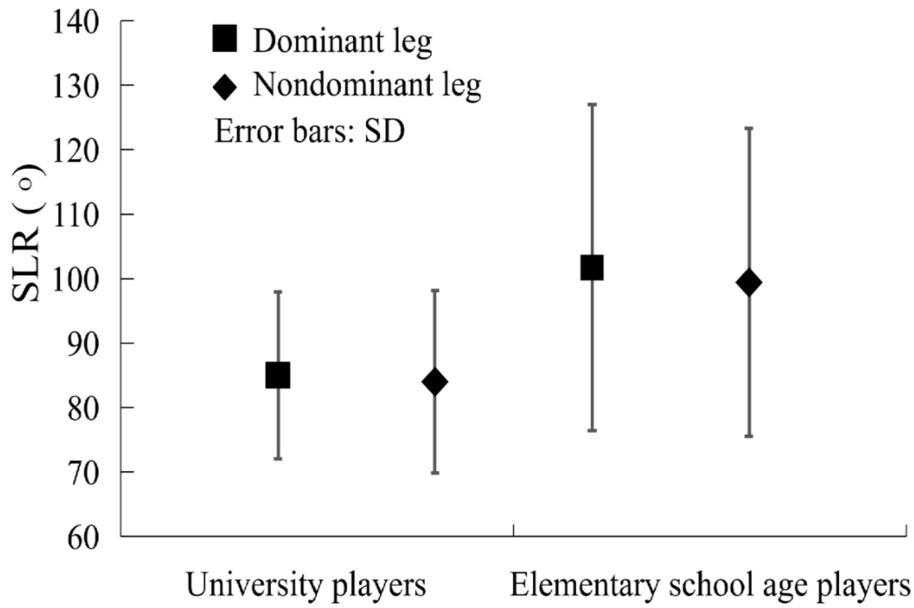
Variables	University players (n = 51)	Elementary school-aged players (n = 22)	*p*-value
Hand grip strength, kg			
D	37.8 ± 9.6††	14.1 ± 4.7†	< 0.001
ND	31.9 ± 8.4	12.9 ± 3.9	< 0.001
Hand grip strength loss, kg	6.4 ± 3.8	1.3 ± 1.7	< 0.001
HBD, cm			
D	1.6 ± 3.4	0.0 ± 0.0	< 0.01
ND	1.7 ± 3.8	0.4 ± 2.0	0.69

Values are mean ± SD.

†*p* value < 0.01, ††*p* value < 0.001, between dominant and nondominant sides.



(a)



(b)

Figure 4-3. Comparisons of single leg stance and SLR between university and elementary school-aged players. (a): Single leg stance time between university and elementary school-aged players. (b): SLR degrees between university and elementary school-aged players.

Results of ROM are shown in Table 4-4. Elementary school-aged players had significantly greater IR on both sides (dominant side: 96.7° *vs* 77.5°, $p < 0.001$; nondominant side: 104.7° *vs* 88.3°, $p < 0.001$), ER on dominant side (126.3° *vs* 116.5°, $p < 0.05$), TROM on both sides (dominant side: 223.0° *vs* 194.1°, $p < 0.001$; nondominant side: 222.9° *vs* 199.9°, $p < 0.001$), trunk extension (44.8° *vs* 37.3°, $p < 0.01$) and trunk rotation on both sides (dominant side: 78.6° *vs* 71.7°, $p < 0.05$; nondominant side: 79.5° *vs* 71.3°, $p < 0.001$) compared with university players. In university players, nondominant IR ($p < 0.001$) and TROM ($p < 0.05$) were significantly greater than dominant side whereas ER ($p < 0.001$) on dominant side was significantly greater than nondominant side. In elementary school-aged players, nondominant IR ($p < 0.001$) was significantly greater than dominant side whereas dominant ER ($p < 0.001$) was significantly greater than nondominant side. No significant differences were found on TROM between dominant side and nondominant side ($p > 0.05$).

Table 4-4. Comparisons of ROM between the university players and elementary school-aged players.

Variables	University players (n = 51)	Elementary school-aged players (n = 22)	*p*-value
IR, °			
D	77.5 ± 15.1	96.7 ± 9.8	< 0.001
ND	88.3 ± 13.2††	104.7 ± 10.5††	< 0.001
ER, °			
D	116.5 ± 9.5††	126.3 ± 16.9††	< 0.05
ND	111.5 ± 9.8	118.2 ± 15.1	0.07
TROM, °			
D	194.1 ± 19.3	223.0 ± 23.9	< 0.001
ND	199.9 ± 16.9†	222.9 ± 22.4	< 0.001
TROM loss, °	5.8 ± 12.5	-0.1 ± 10.4	0.06
GIRD, °	10.8 ± 11.3	8.0 ± 6.7	0.29
ER gain, °	5.0 ± 8.3	8.1 ± 7.2	0.13
Trunk flexion, °	93.0 ± 14.6	97.3 ± 18.7	0.29
Trunk extension, °	37.3 ± 8.0	44.8 ± 9.8	< 0.01
Trunk rotation, °			
D	71.7 ± 10.7	78.6 ± 9.1	< 0.05
ND	71.3 ± 7.9	79.5 ± 8.7	<0.001

Values are mean ± SD.

††*p* value < 0.001, †*p* value<0.05 between both sides.

Profile of all badminton players are shown in Table 4-5. After the forehand overhead stroke test, 16 university players reported present shoulder pain while 1 elementary school-aged players reported present shoulder pain. In university players with present shoulder pain, 43.8% of them (7/16) identified as being singles players while 56.2% identified as being doubles players (9/16). Data show present shoulder pain across the different types of badminton players. In those 16 players with present shoulder pain, 81.3% of the players (13/16) were offensive players, which were more than control and defensive players. With respect to the phases of forehand overhead stroke caused present shoulder pain, "hit" was 56.3%, which was higher than "acceleration" (31.3%) and "follow-through" (12.4%).

Table 4-5. Profile of the university players and elementary school-aged players with and without present shoulder pain.

Variables	University players		Elementary school-aged players	
	Present pain (n =16)	No pain (n = 35)	Present pain (n =1)	No pain (n =21)
Discipline				
Singles	7 (43.8%)	16	1	21
Doubles	9 (56.2%)	19	-	-
Footwork type				
Jump	8 (50.0%)	13	1	9
Lunge	8 (50.0%)	22	-	12
Player type				
Offensive	13 (81.3%)	11	-	-
Control	2 (12.5%)	14	-	-
Defensive	1 (6.2%)	10	-	-
Forehand overhead stroke phase				
Acceleration	5 (31.3%)	-	-	-
Hit	9 (56.3%)	-	-	-
Follow-through	2 (12.4%)	-	1	-

4.3.2. Risk factors for shoulder pain in university players

51 university players became the study's subject and were divided into two groups due to present shoulder pain. 16 players with present shoulder pain (8 male and 8 female players) were assigned into pain group while 35 players without present shoulder pain (17 male and 18 female players) were assigned into pain free group. The basic parameters of the players are shown in Table 4-6. There was no significant association between the basic parameters and the presence of shoulder pain.

Table 4-6. Basic parameters of the participants with and without present shoulder pain.

Demographics	Pain free (n = 35)	Pain (n = 16)	*p*-value
Gender			0.93
Male	17 (48.6)	8 (50.0)	
Female	18 (51.4)	8 (50.0)	
Age, year (yr)	19.6 ± 1.1	20.1 ± 1.3	0.23
Height, cm	165.2 ± 7.1	165.7 ± 8.4	0.83
Weight, kg	60.1 ± 7.2	60.3 ± 7.6	0.90
BMI, kg/m^2	22.0 ± 1.6	21.9 ± 1.5	0.93
Badminton experience, yr	11.0 ± 2.4	11.4 ± 2.9	0.60
Days, per week	5.2 ± 0.5	5.2 ± 0.7	0.82
Min, per day	199.4 ± 29.4	196.9 ± 30.9	0.78
Total min, per week	1039.1 ± 161.8	1016.3 ± 178. 3	0.65

Values are mean ± SD.

ORs and 95% CIs of analysis using binary logistic regression on the association between physical fitness tests and the presence of present shoulder pain are listed in Table 4-7 and Table 4-8. Participants with present shoulder pain showed significantly increased SLR degree of dominant leg compared with those without present shoulder pain (90.7° *vs* 82.4°, OR: 1.06, 95% CI: 1.00-1.11, $p < 0.05$). The other variables of physical fitness showed no significant association with present shoulder pain.

Table 4-7. Binary logistic regression analyses of variable factors of physical fitness associated with present shoulder pain.

Variables	Pain free (n = 35)	Pain (n = 16)	OR (95% CI)	*p*-value
Hand grip strength, kg				
D	36.8 ± 9.9	40.0 ± 8.7	1.04 (0.97-1.10)	0.27
ND	31.1 ± 8.4	33.9 ± 8.5	1.04 (0.97-1.12)	0.27
HBD, cm				
D	1.4 ± 3.0	2.3 ± 4.2	1.08 (0.91-1.27)	0.39
ND	1.3 ± 3.0	2.6 ± 5.1	1.09 (0.93-1.26)	0.28
SLR, º				
D	82.4 ± 11.6	90.7 ± 14.3	1.06 (1.00-1.11)	0.04
ND	81.4 ± 11.6	89.6 ± 17.7	1.04 (0.997-1.09)	0.067
Balance, s				
D	43.3 ± 30.1	53.9 ± 48.3	1.01 (0.99-1.02)	0.34
ND	45.9 ± 37.3	26.5 ± 26.7	0.98 (0.96-1.00)	0.085

Values are mean ± SD.

Table 4-8. Binary logistic regression analyses of ROM associated with present shoulder pain.

ROM	Pain free (n = 35)	Pain (n = 16)	OR (95% CI)	*p*-value
IR, º				
D	75.8 ± 12.5	81.3 ± 19.5	1.03 (0.98-1.07)	0.23
ND	88.2 ± 13.2	88.6 ± 13.8	1.00 (0.96-1.05)	0.92
ER, º				
D	116.1 ± 7.9	117.5 ± 12.5	1.02 (0.95-1.08)	0.64
ND	110.7 ± 8.2	113.4 ± 12.5	1.03 (0.97-1.10)	0.36
TROM, º				
D	191.9 ± 15.7	198.7 ± 25.5	1.02 (0.99-1.05)	0.25
ND	198.9 ± 15.0	202.0 ± 21.0	1.01 (0.98-1.05)	0.54
TROM loss, º	7.0 ± 12.4	3.2 ± 12.9	0.98 (0.93-1.03)	0.33
GIRD, º	12.4 ± 11.7	7.3 ± 9.8	0.96 (0.91-1.01)	0.14
ER gain, º	5.4 ± 8.2	4.0 ± 8.6	0.98 (0.91-1.05)	0.58
Trunk flexion, º	92.2 ± 14.4	94.6 ± 15.3	1.01 (0.97-1.05)	0.59
Trunk extension, º	36.2 ± 5.9	39.6 ± 11.3	1.06 (0.98-1.14)	0.17
Trunk rotation, º				
D	73.5 ± 10.6	67.9 ± 10.3	0.95 (0.90-1.00)	0.09
ND	72.1 ± 8.3	69.6 ± 7.0	0.96 (0.89-1.04)	0.31

Values are mean ± SD.

Finally, variables with p-value < 0.2, including SLR of both of sides, balance of nondominant leg, GIRD, trunk extension and dominant trunk rotation were screened, and then analyzed using multivariable logistic regression analysis. In the model, dominant (right) trunk rotation (Adjusted OR: 0.91, 95% CI: 0.84-0.99) and balance of nondominant leg (Adjusted OR: 0.97, 95% CI: 0.94-1.00) were significantly associated with the presence of present shoulder pain (Figure 4-4).

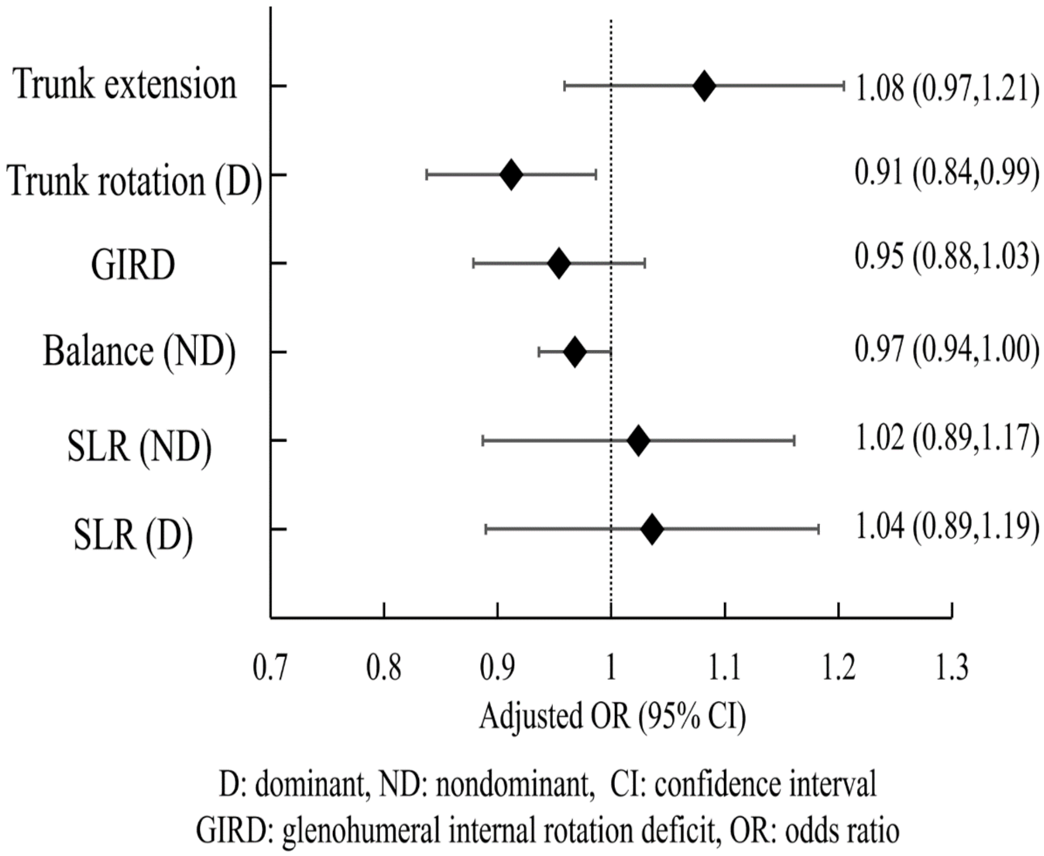


Figure 4-4. Multivariable logistic regression analysis of factors associated with incidence of present shoulder pain.

4.3.3. Risk factors for lumbar pain in university players

University badminton players with any injury experiences were excluded and the rest of 38 university players were assigned into two groups based on lumbar pain status broken down by gender. 32 players with lumbar pain experiences (15 male and 17 female players) were assigned into pain group while 6 players without lumbar pain experience (3 male and 3 female players) were assigned into pain free group. The basic parameters of the players are shown in Table 4-9. Regardless of gender, there were no significant differences between the basic parameters (age, height, weight, BMI, badminton experience, days per week, minutes per day and total minutes per week) and the presence of lumbar pain.

Table 4-9. Characteristics of the male and female participants with and without lumbar pain.

Demographics	Male		Female	
	Pain (n = 15)	Pain free (n = 3)	Pain (n = 17)	Pain free (n = 3)
Age, year (yr)	20.3 ± 1.0	19.7 ± 0.6	19.9 ± 1.0	20.0 ± 1.7
Height, cm	171.3 ± 4.8	166.3 ± 4.0	158.4 ± 3.9	161.3 ± 5.5
Weight, kg	65.5 ± 7.5	63.7 ± 4.9	55.1 ± 4.4	54.3 ± 1.5
BMI, kg/m^2	22.3 ± 2.1	23.0 ± 1.0	21.9 ± 1.5	20.9 ± 1.1
Badminton experience, yr	11.3 ± 2.9	10.0 ± 1.0	11.9 ± 1.9	12.7 ± 1.5
Days, per week	5.4 ± 0.7	5.0 ± 1.0	5.2 ± 0.4	5.7 ± 0.6
Min, per day	186.0 ± 23.2	200.0 ± 34.6	209.4 ± 35.3	200.0 ± 34.6
Total min, per week	1010.0 ± 159.4	1000.0 ± 249.8	1085.9 ± 136.3	1120.0 ± 69.3

Values are mean ± SD.

Comparisons of physical fitness between lumbar pain group and lumbar pain free group broken down by gender are shown is Table 4-10, Figure 4-5, and Table 4-11. Table 4-10 showed that no significant differences were found on hand grip strength, hand grip strength loss, HBD, balance and balance loss between the players with lumbar pain and those without lumbar pain in both of male and female groups. In male group, players with lumbar pain as well as players without lumbar pain had significantly greater hand grip strength of dominant side compared with nondominant side ($p < 0.05$). However, there were no significant differences of HBD and balance between both sides. In female group, players with lumbar pain had significantly greater hand grip strength on dominant side compared with nondominant side ($p < 0.05$) whereas no significant differences were found in pain free group. No significant differences of HBD and balance between both sides were found.

Table 4-10. Comparisons of physical fitness parameters in the participants with and without lumbar pain broken down by gender.

	Male				Female			
	Pain (n = 15)		Pain free (n = 3)		Pain (n = 17)		Pain free (n = 3)	
	D	ND	D	ND	D	ND	D	ND
Hand grip strength, kg	50.1 ± 6.4[a]	39.6 ± 5.7	40.4 ± 8.7[a]	34.8 ± 7.7	29.0 ± 3.5[a]	23.8 ± 3.0	26.2 ± 7.8	22.5 ± 0.1
Hand grip strength loss, kg	10.6 ± 4.9		5.6 ± 1.1		5.2 ± 3.5		3.7 ± 7.9	
HBD, cm	2.9 ± 4.4	3.2 ± 5.1	3.8 ± 4.4	3.1 ± 4.1	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 3.4	1.4 ± 3.0
Balance, s	42.2 ± 40.6	36.8 ± 38.5	18.4 ± 13.8	34.0 ± 37.7	40.7 ± 34.6	45.5 ± 41.3	28.9 ± 22.5	22.9 ± 13.1
Balance loss, s	19.8 ± 25.2		15.6 ± 2.0		23.6 ± 32.9		6.8 ± 8.6	

Values are mean ± SD.

[a]p value < 0.05, between dominant and nondominant sides.

With respect to SLR, comparison of pain and pain free groups broken down by gender are shown in Figure 4-5. Both of male and female groups showed that SLR degree on dominant side was significantly greater than nondominant side in pain group (male group: dominant side *vs* nondominant side: 82.1° ± 9.1° *vs* 79.3° ± 10.4°, $p < 0.05$; female group: dominant side *vs* nondominant side: 94.7° ± 13.9° *vs* 91.8° ± 12.9°, $p < 0.05$) whereas no such differences were found in pain free group. In male group, SLR degrees on both sides in pain group were significantly greater than pain free group (dominant side: pain group *vs* pain free group: 82.1° ± 9.1° *vs* 69.9° ± 1.0°, $p < 0.05$; nondominant side: pain group *vs* pain free group: 79.3° ± 10.4° *vs* 64.1° ± 3.0°, $p < 0.05$) whereas no significant differences on both sides between pain group and pain free group were found in female group (Figure 4-5).

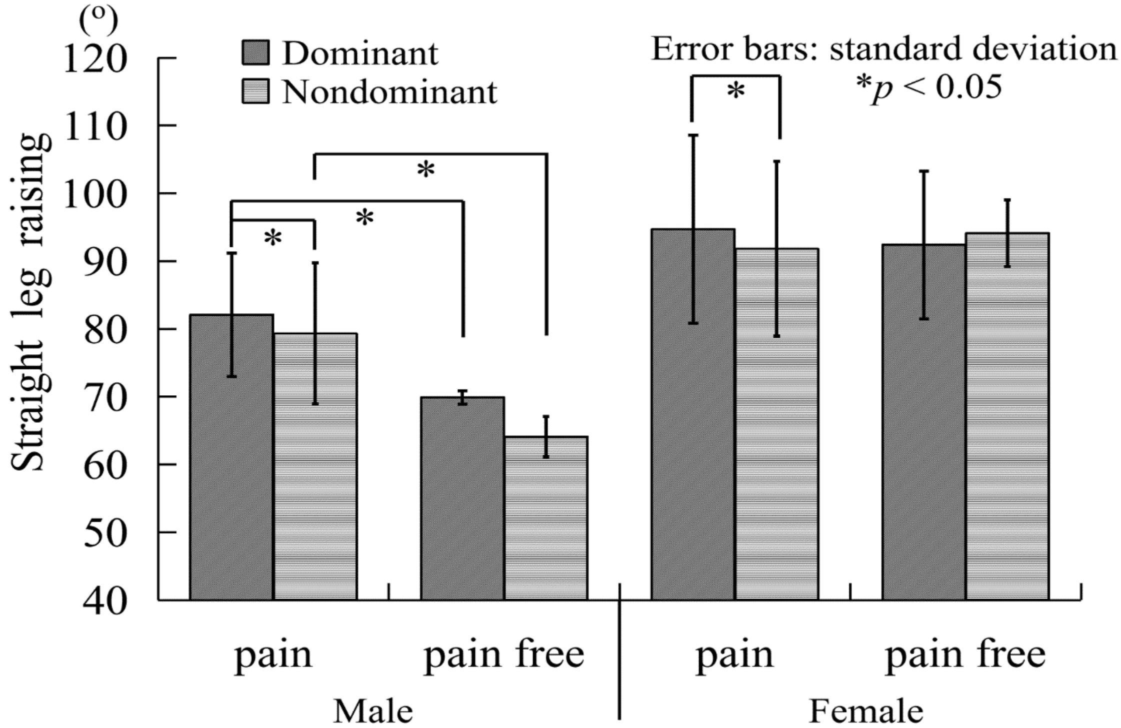


Figure 4-5. Comparisons of SLR degrees in the participants with and without lumbar pain broken down by gender.

Results of ROM are shown in Table 4-11. In male players, pain group had significantly greater nondominant IR than pain free group (73.0° *vs* 59.7°, $p < 0.05$) while no significant differences were observed on other variables between pain group and pain free group. In pain group, IR and TROM on dominant side were significantly smaller than nondominant side (IR: 64.0° *vs* 73.0°, $p < 0.05$; TROM: 173.0° *vs* 176.4°, $p < 0.05$) while ER on dominant side was significantly greater than nondominant side (ER: 109.0° *vs* 103.4°, $p < 0.05$). There were no significant differences on other variables between both sides. In pain free group, IR on dominant side were significantly smaller than nondominant side while no significant differences were found on other variables between dominant side and nondominant side. As for female players, pain group had significantly greater nondominant TROM than pain free group (196.0° *vs* 184.0°, $p < 0.05$) while no significant differences were observed on other variables between pain group and pain free group. In pain group, IR and TROM on dominant side were significantly smaller than nondominant side (IR: 71.0° *vs* 87.4°, $p < 0.05$; TROM: 184.2° *vs* 196.0°, $p < 0.05$) while no significant differences were observed on other variables between both sides. In pain free group, no significant differences on all the variables were found between dominant side and nondominant side.

Table 4-11. Comparisons of ROM in the participants with and without lumbar pain broken down by gender.

	Male				Female			
	Pain (n = 15)		Pain free (n = 3)		Pain (n = 17)		Pain free (n = 3)	
	D	ND	D	ND	D	ND	D	ND
IR (º)	64.0 ± 14.6[a]	73.0 ± 10.4[*]	51.7 ± 4.1[a]	59.7 ± 3.5	71.0 ± 7.4[a]	87.4 ± 6.5	76.8 ± 14.4	81.9 ± 9.1
ER (º)	109.0 ± 9.9[a]	103.4 ± 8.8	105.2 ± 25.7	102.6 ± 15.2	113.2 ± 9.8	108.6 ± 8.5	109.3 ± 10.4	102.1 ± 9.3
TROM (º)	173.0 ± 17.3[a]	176.4 ± 13.8	156.8 ± 28.8	162.3 ± 18.4	184.2 ± 13.9[a]	196.0 ± 11.2[*]	186.1 ± 15.1	184.0 ± 1.2
GIRD (º)	9.0 ± 7.8		8.0 ± 0.8		16.4 ± 9.3		5.1 ± 22.7	
ER gain (º)	5.6 ± 4.3		2.6 ± 11.2		4.6 ± 10.7		7.3 ± 11.2	
TROM loss (º)	3.4 ± 7.2		5.4 ± 11.2		11.8 ± 14.2		-2.2 ± 14.8	
Trunk rotation (º)	71.1 ± 12.1	71.0 ± 8.9	64.4 ± 11.4	72.2 ± 5.8	72.9 ± 10.1	71.2 ± 8.3	74.8 ± 4.5	72.2 ± 3.9
Trunk flection (º)	81.6 ± 17.5		69.8 ± 8.2		98.8 ± 13.7		103.5 ± 2.9	
Trunk extension (º)	39.4 ± 7.9		37.0 ± 7.1		37.3 ± 8.0		35.7 ± 7.5	

Values are mean ± SD.

[a] p value < 0.05, between dominant and nondominant sides.

[*] p value < 0.05, between pain and pain free groups.

4.4. Discussion

This study set out to provide physical fitness reference parameters for badminton players and identify risk factors of shoulder pain and lumbar pain. In doing so, some important findings in this study were found as follows: (1) elementary school-aged players had softer muscle flexibility and joint laxity and weaker balance ability; (2) decreased dominant trunk rotation and decreased nondominant balance ability were associated with increased presence of shoulder pain in university players; and (3) extra hamstrings flexibility was a risk factor for lumbar pain in male university players.

4.4.1. Shoulder and trunk ROM

Regularly, healthy overhead sports players present with soft tissue and osseous tissue adaptations of the dominant glenohumeral joint due to the repetitive stress of overhead motion. These changes, including soft tissue tightness or laxity and humeral retroversion, are represented as changers in ROM, resulting in posterior shoulder tightness (GIRD) and anterior shoulder laxity (ER gain) and are often involved in shoulder injury (Hibberd et al., 2014; Reuther et al., 2018).

Numerous overhead sports studies have studied shoulder ROM. In badminton studies, players showed that IR on dominant side was significantly smaller than nondominant side (Couppe et al., 2014, Fernandez-Fernandez et al., 2019) while ER on dominant side was significantly greater than nondominant side (Fernandez-Fernandez et al., 2019). Some studies of baseball players revealed that GIRD > 15° significantly increased shoulder injury (Shanley et al., 2015) whereas others reported lower shoulder injury risk in baseball pitchers with GIRD > 20° (Tyler et al., 2014). A previous studies of tennis players revealed that GIRD was associated with increased shoulder injury risk (Moore-Reed et al., 2016). Regarding ER gain, a prospective study on baseball reported that insufficient shoulder ER on dominant side (ER gain < 5°) increased the risks to shoulder injury and pain (Wilk et al., 2015; Camp et al., 2017). Another study of handball reported that GIRD and ER gain were risk factors for female players (Achenbach et al., 2019). In contrast, other studies of baseball and softball (Shanley et al., 2011; Chalmers et al., 2015) revealed that ER gain was not a risk factor for shoulder injuries. TROM loss increased shoulder injuries (Wilk et al., 2011; Kibler et al., 2012; Picha et al., 2016) while other studies reported that no associations of TROM loss and shoulder injuries were found (Trakis et al., 2008).

Regarding research on shoulder symptoms in overhead motion sports players by trunk ROM evaluation, some studies of baseball players demonstrated that restricted hip IR (Sekiguchi et al., 2020), increased hip extension (Scher et al., 2010) and weak trunk control (Chaudhari et al., 2011) were associated with shoulder injuries and pain. A study of softball players reported that restricted forward trunk rotation flexibility was a risk factor for shoulder injuries (Aragon et al., 2012).

We have not found any studies on physical fitness reference parameters of badminton players when controlling for age, but some studies of other overhead motion players and healthy people reported that shoulder ROM and trunk ROM of child were greater than adolescents and adults. Previous studies of baseball players reported that child players aged 7-11 years had greater shoulder IR (Picha et al., 2016), ER (Shanley et al., 2015; Picha et al., 2016), TROM (Shanley et al., 2015; Picha et al., 2016) and hip ROM (Picha et al., 2016) than those of young baseball players aged 12-18 years. A previous study of baseball on humeral retrotorsion accounts for shoulder IR demonstrated that when excluding the contributions of humeral retrotorsion to shoulder IR, youth baseball players (aged 6-10 years) showed greater shoulder IR than junior high school players (aged 11-13 years), junior baseball players (aged 14-15 years) and varsity baseball players (aged 16-18 years) (Hibberd et al., 2014). Another study of softball players reported that youth softball players had greater IR, ER and hip ROM compared with collegiate softball players (Friesen et al., 2020). Also, a previous study revealed that children (3-9 year-old) showed greater shoulder IR, shoulder ER, hip IR and hip ER than adolescents (10-19 year-old), adults (20-59 year-old), and older adults (60 + years) (McKay et al., 2016).

Similar to the findings of the past studies, in this study, elementary school-aged players showed significantly greater shoulder ROM (IR, ER and TROM) and trunk rotation than university players which can be interpreted by the different maturation levels. GIRD and ER gain happened in both of elementary school-aged players and university players. However, no significant differences of GIRD and ER gain were found between elementary school-aged players and university players. Therefore, GIRD and ER gain seem to develop at a young age and persist through adulthood (Picha et al., 2016).

4.4.2. Balance ability

On the other hand, in regard to balance ability studies using single leg stance, previous studies of volleyball players revealed that decreased balance ability was negatively associated with the presence of shoulder pain and disability (Reeser, 2010). A study of lacrosse players reported that players with weak single leg stance are more likely to shoulder symptoms (Radwan et al., 2014). Additionally, previous studies on balance ability of children and adolescents using single leg stance revealed that balance ability increased with age (Condon and Cremin, 2014; Mani et al., 2019). Another study using Y balance test, which is a method of dynamic balance evaluation revealed that there were significant differences on balance performance between youth and senior rugby players (Johnston et al., 2019). In this study, there were differences in balance ability between dominant side and nondominant side. Previous studies revealed that dominant side preference is biased by effective asymmetry of performance favoring the dominant side that may increase capacity of cortical and subcortical structures of controlling the dominant body side in individuals, ultimately resulted in higher postural stability in dominant side (Vieira et al., 2014). This evidence could interpret the discrepancy of balance ability in our studies. Moreover, we found that decreased balance ability of nondominant side was a risk factor for shoulder pain in university players. And elementary school-aged players showed significantly weaker single leg stance time compared with university players. To prevent shoulder pain, elementary school-aged players as well as university players are supposed to improve the balance ability to prevent badminton shoulder injuries.

In summary, we hypothesized that GIRD, ER gain, weaker balance ability and decreased trunk rotation are risk factors for shoulder pain in university badminton players. The findings of this study showed significant associations of weaker balance ability and decreased dominant trunk rotation and the incidence of shoulder pain, which is in line with the previous studies of baseball and softball players (Aragon et al., 2012; Endo et al., 2014; Sekiguchi et al., 2020). No significant associations of GIRD and ER gain with the increased risks of shoulder pain were found.

Badminton forehand overhead stroke motion is similar to a full throwing motion which requires multi-limb coordination and balance ability to perform body core mass shift, trunk rotation and upper limb rotation simultaneously (Saito et al., 2014; Zhou et al., 2019). The mechanics of the overhead motion are complex, which generate tensile stress on the shoulder through dissipating excess momentum (Saito et al., 2014; Zhou et al., 2019). Trunk is a major segment of overhead motion kinetic chain in transferring energy from lower limbs to upper limbs (Kibler, 1995). Disrupted kinetic chain, *i.e.*, improper trunk rotation sequences could alter stress in shoulder joint and ultimately result in shoulder injury and pain (Aragon et al., 2012; Oyama et al., 2014).

On the other hand, balance ability is a crucial factor which is inextricably involved in motor development and foundational movement skills (Fisher et al., 2005) in overhead motion players. Balance is the process of maintaining the body's center of gravity. Balance control is fundamental to safely accomplish the execution of smooth and coordinated neuromuscular action that involves displacement of body segments or the entire body (Shumway-Cook and Woollacott, 2012; Brachman et al., 2017).

Disturbances in balance control can alter throwing mechanics and lead to upper limb injuries. (Garrison et al., 2013).

Decreased dominant trunk rotation and weaker balance ability result in abnormal kinetic chain. Improper coordination of the abnormal kinetic chain causes improper overhead techniques. The improper overhead techniques which are risk factors for injuries (Nicholls et al., 2003) alter the load in the shoulder joint (Aragon et al., 2012; Oyama et al., 2014) or result in upper limbs deviation. The improper overhead techniques lead to shoulder injury and pain. We found that among university players, 87.6% of all the phases with present shoulder pain were acceleration and hit phases which need multi-limb coordination and trunk rotation. These findings supported our hypothesis and our other findings that decreased dominant trunk rotation and weaker balance ability were associated with shoulder pain. Therefore, when shoulder pain occurs, players, coaches, physicians and physiotherapists should notice trunk rotation and balance ability so that prevention programs can be implemented to decrease risks to shoulder injuries as early as possible.

4.4.3. SLR

Generally, hamstrings stiffness increases with age (Mierau et al., 1989). A previous study with SLR test on lumbar pain in children (aged 6-13 years) and adolescents (aged 14-18 years) revealed that SLR degrees of childhood were greater than adolescents (Mierau et al., 1989). The finding of this study supported the previous study that SLR degrees of elementary school-aged players were significantly greater than university players. Previous studies also revealed that a strong association was detected between the history of lumbar pain and decreased SLR degrees in adolescents (Børgesen and Vang, 1974; Mierau et al., 1989; Zhu et al., 2006). A recent systematic review revealed that decreased hamstrings flexibility or increased hamstrings stiffness was a risk factor of developing lumbar pain (Sadler et al., 2017). However, a systematic review with meta-analysis on association of hamstrings flexibility and lumbar pain revealed that hamstrings flexibility and stiffness were not strongly associated with lumbar pain (Hori et al., 2019). Different classification methods (Sahrmann et al., 2001) of lumbar pain among previous studies may interpret the discrepancy.

The hamstring muscles cross and act upon pelvis joint and knee joint. When the trunk is flexed, semimembranosus muscle and semitendinosus muscle help in hip extension as well as knee bend and inward rotation. The upper part of the pelvis connected to the spine is an anchor for muscles which pass alongside the spine. These muscles help with body posture, core stability, and trunk movement (Palastanga and Soames, 2012). The extensibility of hamstring muscles also influences pelvic postures when maximal trunk flexion is performed (López-Minarro and Alacid, 2010). When the hamstring muscles become tighter than the lumbar extensor muscles, lumbar flection is increased during movements accompanying pelvis flection. Restriction in the relative hamstring muscles flexibility compared with the lumbar extensor muscles may be a feature of the individuals with lumbar pain whose pain is typically aggravated by lumbar movements (Hori et al., 2019). When the hamstring muscles become weaker than abdominal muscles that the anteroposterior tilt of pelvis could be changed which will lead to lumbar hyperlordosis. Based on these, we speculated that extra hamstrings flexibility will result in lumbar pain, especially for badminton players who need perform repetitive trunk movements. In addition, female and child players showed extra hamstrings flexibility due to physiological characteristics. However, as the muscles become unbalance, lumbar pain might be caused among them. These findings supported out results of this study that regardless of gender, university players with lumbar pain showed greater SLR degrees than those without lumbar pain.

According to the findings of our studies, injury prevention should focus on improving and maintaining physical fitness, such as increasing trunk rotation and balance ability by neuromuscular training programs. So far, in current prevention programs, no such studies on badminton injury prevention measures have been found. Such neuromuscular training programs have been reported to be effective in enhancing physical fitness and reducing shoulder injury in other sports players. 10-week plyometric trainings on balance improved the static balance ability of handball players (Karadenizli, 2016). A core-muscle-training program, including bench and side bench was shown to enhance trunk range of motion in basketball players (Sasaki et al., 2019). A prospective intervention study of baseball players showed that a prevention program, consisting of balance training, dynamic mobility and stretching can improve horizontal adduction deficits in dominant shoulder, hip IR, and the angle of thoracic kyphosis to decrease shoulder symptoms and enhance overhead motion performance (estimated by ball speed) (Sakata et al., 2019). In addition, Foam Rolling could improve core function and balance in recreational sport participants (Junker and Stöggl, 2019). Regarding hamstring muscles training, a Nordic hamstrings training method of FIFA 11+ program was demonstrated that improved hamstrings tightness and reduced incidence of hamstrings injuries in previous studies of football (Petersen et al., 2011; Attar et al., 2016), basketball (Sasaki et al., 2019) and baseball (Seagrave et al., 2014). Future studies are needed to investigate effectiveness of such neuromuscular training programs in reducing and preventing badminton injuries by enhancing and maintaining factors of physical fitness which were identified as risk factors for badminton injuries by this study.

However, this study has some limitations. Decreased shoulder ER strength is a risk factor for shoulder injury in handball players (Achenbach et al., 2019). Likewise, weakened posterior shoulder musculature, that is weak muscle strength, is a risk factor of throwing-related pain in baseball players (Trakis, 2008). In our studies, we did not measure shoulder rotation strength of badminton players. Although decreased trunk rotation was reported as a risk factor for shoulder pain, we cannot determine whether trunk ROM alteration resulted in or developed after the shoulder pain. Core stability and dynamic balance ability have been studied in a variety of overhead sports studies (Garrison et al., 2013; Butler et al., 2016; Pogetti et al., 2018; Resende et al., 2020). Future studies are needed to adopt such measures to confirm risk factors of badminton injuries. Although extra hamstrings flexibility has been demonstrated to be a risk factor for lumbar pain, the range of SLR degrees which will not be linked to lumbar pain has not been studied. Moreover, the range of SLR degrees of badminton players with different age and gender might be different, future studies of hamstrings flexibility in female and male badminton players broken down by age are needed. In addition, we found that 87.6% of all the phases caused present shoulder pain were acceleration phase and hit phase in university players. But the association of the sequence of trunk rotation on upper limb biomechanics linked to shoulder injuries and pain have not been studied in this study. In future studies, the biomechanical study to explore the factors of increasing joint load with forehand overhead stroke techniques which may cause badminton injuries should be needed.

4.5. Conclusion

The present study demonstrated that decreased trunk rotation and weak balance ability were risk factors for shoulder pain in university badminton players, and extra hamstrings flexibility was a risk factor for lumbar pain in male badminton players. Elementary school-aged badminton players showed more flexible hamstrings, weaker balance ability and greater ROM. In addition, both of elementary school-aged badminton players and university badminton players experienced pain in shoulder and lumbar. These findings can help players improve and maintain targeted physical fitness for injury free badminton participation.

Chapter 5, Study 4

The effects of neuromuscular training programs for injury prevention in badminton players

5.1. Introduction

Shoulder symptoms and lumbar symptoms are common in badminton players, especially in school-aged badminton players (Goh et al., 2013; Miyake et al., 2016; Zhou et al., 2020). Among all injuries and pains in badminton players aged 7-12 years, the incidence of shoulder injuries and pain is 6.5%. The incidence of lumbar injuries and pain is 6.4%. (Zhou et al., 2020). According to previous studies (Jørgensen and Winge, 1987; Shariff et al., 2009; Petrinović et al., 2016; Phomsoupha and Laffaye, 2020) and study 1 (Chapter 2), among all the injuries of aged 13 and above years badminton players, the incidence of shoulder injuries is 8.0%-19.0% and that of trunk (lumbar/spine/back) injuries is 11.0% - 25.4%.

Although risk factors for shoulder injuries and lumbar injuries have not been identified in published badminton studies of medical check-up, we found in study 3 (Chapter 4) that decreased trunk rotation and weak balance ability were risk factors for shoulder injuries and that extra hamstrings flexibility was a risk factor for lumbar injuries. Therefore, implementing effective methods is crucial to prevent injuries and pains associated with badminton in school-aged badminton players, and methods must focus on the risk factors for badminton injury. A previous study of badminton used core stability training to improve balance ability and overhead stroke performance (Hassan, 2017). Nevertheless, as far as we have researched, there was no study on the effects of badminton injury prevention programs for shoulder injuries and lumbar injuries. As for other overhead motion sports, numerous studies have used stretching, muscle training and core stability programs to prevent injuries (Niederbracht et al., 2008; Escamilla et al., 2017; Sasaki et al., 2019; Sakata et al., 2019; Oranchuk et al., 2020; Werin et al., 2020).

Considering the risk factors for badminton injuries, we conducted a prospective controlled study to evaluate the effects of a neuromuscular training program on the incidence of badminton-related pains and injuries of shoulder and lumbar among university badminton players. The neuromuscular training program was made to enhance the factors of physical fitness, that is core stability, balance ability and hamstrings flexibility which had been identified as risk factors for badminton injuries by study 3 (Chapter 4). We hypothesized that the neuromuscular training program has effects of decreasing the occurrence of shoulder and lumbar symptoms.

5.2. Materials and methods

5.2.1. Participants

Total of 14 badminton players (10 females, 4 males) participating in the national tournament were recruited. A prospective controlled trial was conducted from March 2020 to September 2020. Before the trial, a questionnaire was used to collect basic parameters of the participants (age, gender, height, weight, badminton experiences, training minutes per day, training days per week) and anamnesis (pains and injuries associated with badminton, injuries associated with or without other sports). After the trial, pains and injuries associated with badminton during the trial were recorded by the participants. A pain was defined as any physical painful complaint or discomfort with sustained badminton capacity. An injury was defined as any physical complaint sustained during badminton training or match play leading to one or more of the three judgement criteria as follows: (1) have to stop the current badminton training or match immediately, (2) cannot presence in subsequent badminton training or matches, and (3) require medical care with time loss (Rössler R et al., 2016).

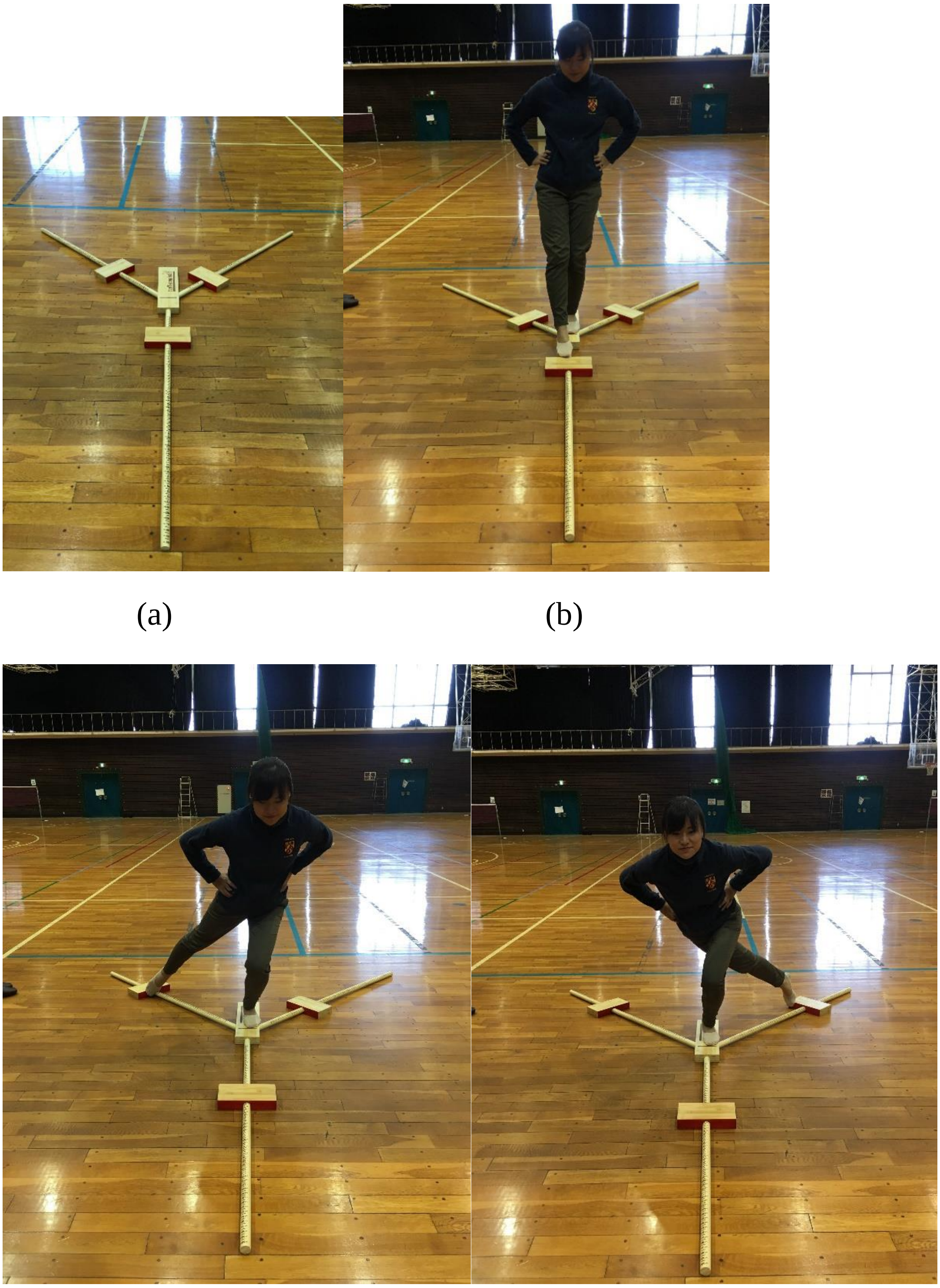
5.2.2. Physical fitness measurement

An orthopedic surgeon with more than 20 years of experience, and a sports medicine doctoral student performed the physical fitness test of medical check-up. Pre-and post-intervention training program, we used methods of medical check-up, including hand grip strength, SLR, single leg stance, trunk rotation, trunk flexion, trunk extension, Y-balance test and shoulder rotation to evaluate the physical fitness of the players. Medical check-up of pre-and post-intervention program were evaluated using the same methods of study 3. The tools used in study 3 (a digital hand dynamometer and a digital goniometer) were used to evaluate the physical fitness. An FMS Y-balance test kit was used for Y-balance test evaluation. (Figure 5-1 (a))

Y-balance test which has good intra-rater reliability ($ICC_{3,1}$: 0.85-0.91) and excellent inter-rater reliability ($ICC_{2,1}$: 0.99-1.00) (Phillip et al., 2009) was added to examine dynamic balance of the 14 players. The Y Balance Test Protocol was developed based on decades of research in motor skills performance improvement and injury prevention by Star Excursion Balance Test (SEBT). Unilateral reach in 3 directions of the SEBT, that is anterior, posteromedial and posterolateral. To operate the Y-balance test, the participant stood with one leg on the central footplate and the toes of the participant's foot at the starting line. The participant put the hands on the hips while maintaining single leg stance, and then was asked to reach with the contralateral leg in anterior (Figure 5-1 (b)), posteromedial (Figure 5-1 (c)) and posterolateral (Figure 5-1 (d)) directions. Three trials were completed in each direction. The same procedure was performed repeatedly using the contralateral leg as the stance leg. The maximal reach distance of each direction was measured by confirming the measure at the edge of the pole, at the point where the most distal part of the foot reached. Per Y-balance test, a trial was deemed as a failure if any one of the following happened: (1) unable to maintain unilateral stance, (2) touched down to the floor with reaching foot, (3) unable to return to the starting position, (4) kicked the pole or unable to maintain foot contact with the pole, (5) the hands left the hips.

The maximal distance each leg reached in each direction was selected and was averaged for composite reach score normalized to the participant's leg length (from the anterior superior iliac spine to the medical malleolus) presented by mean and SD, and composite score was also calculated. The equation of unilateral composite score was:

$$[(\text{Anterior} + \text{Posteromedial} + \text{Posterolateral}) / 3 \times \text{Right (Left) Limb Length}] \times 100$$



(a) (b)

(c) (d)

Figure 5-1. Y balance test protocol. (a): FMS Y-balance test kit. (b): Anterior reach Y-balance test. (c): Posteromedial reach Y-balance test. (d): Posterolateral reach Y-balance test.

5.2.3. Injury prevention training program

The neuromuscular training program consisted of five components, of which three (bench, side bench and Nordic hamstrings trainings) were designed from Fédération Internationale de Football Association 11+ (FIFA 11+) program, the fourth one (back bridge training) was designed from clinic practice of previous studies (Stevens et al., 2006; Imai et al., 2010) and the last one (balance training) was modified from SEBT. The neuromuscular training program is shown in Figure 5-2. It takes about 15 minutes to complete the program. The intervention group was instructed to add the neuromuscular training program to regular warm-up, and the control group was instructed to maintain regular warm-up. Before the trial, the orthopedic surgeon and the sports medicine doctoral student instructed and demonstrated to the participants how to perform the training program using appropriate postures.

Bench (a) Side Bench (b)

(A) Back bridge (c) (B)

Hamstrings (d) Balance (e)

Figure 5-2. The neuromuscular intervention training program. (a): Bench training. (b): Side bench training. (c): Nordic hamstrings training. (d): Back bridge training. (e): SEBT dynamic balance ability exercise.

Table 5-1. Neuromuscular training program.

Training program	Repetitions	Illustration
Bench	3 sets × 30 seconds	Figure 5-2 (a)
Sideways bench	3 sets × 30 seconds	Figure 5-2 (b)
Nordic hamstrings	5-7 times	Figure 5-2 (c)
Back bridge Level 1 (A) Level 2 (B)	3 sets × 30 seconds	Figure 5-2 (d)
SEBT exercise	3 times/direction × 8 directions	Figure 5-2 (e)

5.2.4. Statistical analysis

Comparisons of the prevalence of shoulder and lumbar pains and injuries between groups were analyzed using Fisher's exact test. Data of hand grip strength, SLR, single leg stance, trunk rotation and shoulder rotation between dominant side and nondominant side, pre-and post-intervention training program were analyzed using Wilcoxon's rank-sum test. And data of the intervention group and the control group were analyzed using Mann-Whitney U-test. The level of significance was set as below 0.05.

5.3. Results

Dominant sides of all the participants were right sides. We divided the participants into intervention group and control group with their willingness. The intervention group consisted of 10 participants while the control group consisted of 4 participants. Height of the participants in the intervention group was significantly greater than that of the control group (164.8 cm *vs* 156.3 cm, $p < 0.05$). No significant differences were found on age, weight, BMI, badminton experience, training days per week, training minutes per day and total training minutes per week between the two groups (Table 5-2).

Table 5-2. Baseline parameters of intervention and control groups.

	Intervention Group (n = 10)		Control Group (n = 4)		*p*-value
	Mean	SD	Mean	SD	
Age, year (yr)	19.6	0.7	19.0	0.0	> 0.05
Height, cm	164.8	8.1	156.3	3.3	< 0.05
Weight, kg	60.5	8.2	53.5	1.7	> 0.05
BMI	22.2	1.2	21.9	0.8	> 0.05
Badminton experience, yr	10.7	2.0	11.4	0.5	> 0.05
Days, per week	5.0	0.0	5.0	0.0	> 0.05
Minutes, per day	212.0	30.1	240.0	0.0	> 0.05
Total minutes, per week	1060.0	150.6	1200.0	0.0	> 0.05

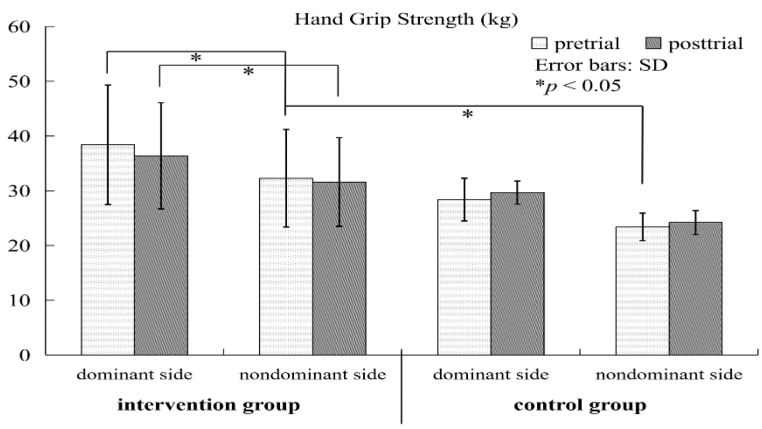
Before the training, 6 players (60.0%) reported shoulder pain/injury and 8 players (80.0%) reported lumbar pain/injury in the intervention group while 2 players (50.0%) reported shoulder pain/injury and 2 players (50.0%) reported lumbar pain/injury in the control group. Over the period of the 6-month prospective training, 1 player (10.0%) reported shoulder pain and 2 players (20.0%) reported lumbar pains while no players reported shoulder injury nor lumbar injury in the intervention group. In comparison, 2 players (50.0%) reported shoulder injuries and 1 player (25.0%) reported shoulder pain, and 2 players (50.0%) reported lumbar pains and 1 player (25.0%) reported lumbar injury in the control group (Table 5-3). The occurrence of shoulder and lumbar pain/injury after the trial was analyzed by Fisher's Exact test. Compared with the intervention group, the occurrence of shoulder pain/injury in the control group was significantly greater ($p < 0.05$). Moreover, the occurrence of lumbar pain/injury in the control group was greater than the intervention group without significant differences.

Table 5-3. Profiles of shoulder and lumbar pain/injury occurrence in university players.

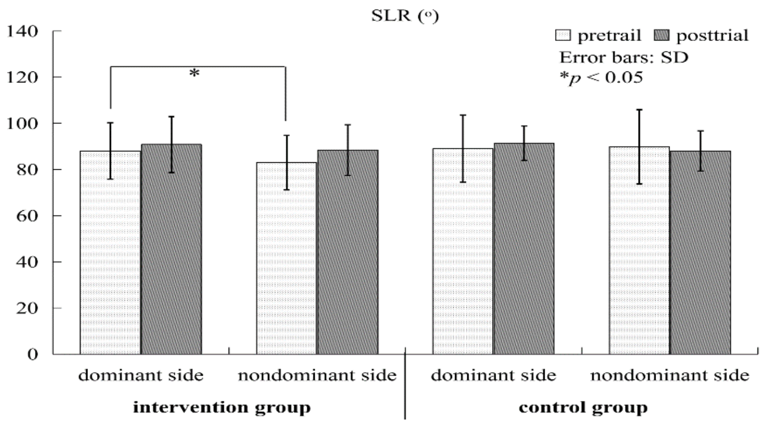
	Shoulder pain/injury		Lumbar pain/injury	
	before training n (%)	after 6 months n (%)	before training n (%)	after 6 months n (%)
Intervention Group (n = 10)	6 (60.0)	1 (10.0)	8 (80.0)	2 (20.0)
Control Group (n = 4)	2 (50.0)	3 (75.0)	2 (50.0)	3 (75.0)

With respect to the physical fitness, participants in the intervention group showed that hand grip strength on the dominant side was significantly greater than the nondominant side before the trial (38.4 ± 10.9 *vs* 32.3 ± 8.9 kg, $p < 0.05$) as well as after the trial (36.4 ± 9.7 *vs* 31.6 ± 8.1kg, $p < 0.05$). In the control group, there was no significant difference in hand grip strength between the dominant and nondominant sides before and after the trial. Comparison between the two groups, hand grip strength on the nondominant side in the intervention group was significantly greater than in the control group (32.3 ± 8.9 *vs* 23.4 ± 2.5 kg, $p < 0.05$) before the trial. No other significant differences in hand grip strength between the two groups were found before and after the trial (Figure 5-3 (a)).

The results of SLR are shown in Figure 5-3 (b). In the intervention group, SLR on the dominant side was significantly greater than the nondominant side before the trial (88.0º ± 12.2º *vs* 83.0º ± 11.8º, $p < 0.05$) whereas no significant differences were found between both sides after the trial. In the control group, there was no significant difference in SLR between the dominant and nondominant sides before and after the trial. Likewise, there was no significant difference in SLR between the intervention and control groups before and after the trial.



(a)



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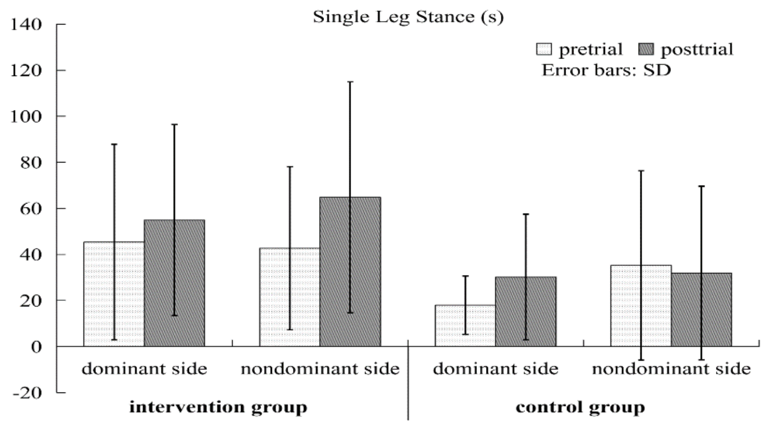

(c)

Figure 5-3. Variables of physical fitness in intervention and control groups pre- and post-trial. (a): Hand grip strength. (b): SLR. (c): Single leg stance.

Data on balance ability assessment with single leg stance are shown in Figure 5-3 (c). Irrespectively of groups, no significant differences in time to single leg stance were found between the dominant and nondominant sides before and after the trial. Likewise, there was no significant difference in single leg stance time between the intervention and control groups before and after the trial.

Data on balance ability assessment with Y balance test are shown in Table 5-4 and Figure 5-4. Comparison between the two groups, no significant differences in reach distances of anterior, posteromedial, posterolateral and composite scores on the right limb as well as on the left limb were found between the two groups before and after the trial (Table 5-4). Likewise, no significant differences in reach asymmetry of anterior, posteromedial and posterolateral were found between the two groups before and after the trial (Figure 5-4).

In the intervention group, reach distance in posterolateral and composite score on the right limb improved significantly after the trial (posterolateral/right: 118.5% ± 13.5% *vs* 113.0% ± 16.8%, $p < 0.05$; composite score/right: 104.1% ± 10.2% *vs* 100.5% ± 11.3%, $p < 0.05$) whereas no significant differences were found before and after the trial in the control group (Table 5-4 and Figure 5-4).

Table 5-4. Descriptive data of Y balance test in intervention and control groups pre- and post-trial.

		Intervention group (n = 10)		Control group (n = 4)	
		Pre-trial	Post-trial	Pre-trial	Post-trial
Anterior	Left	68.5 ± 7.8	73.1 ± 9.2	71.3 ± 7.1	73.8 ± 8.0
	Right	72.3 ± 9.0	74.8 ± 9.1	69.7 ± 4.2	73.5 ± 6.1
Posteromedial	Left	114.4 ± 8.6	119.4 ± 11.2	127.1 ± 23.2	128.3 ± 15.1
	Right	116.3 ± 14.5	119.2 ± 12.4	125.1 ± 15.2	128.8 ± 13.1
Posterolateral	Left	115.5 ± 13.5	116.2 ± 15.3	124.3 ± 20.8	127.4 ± 16.1
	Right	113.0 ± 16.8*	118.5 ± 13.5	121.0 ± 16.2	122.6 ± 14.0
Composite	Left	99.5 ± 7.8	102.9 ± 9.4	107.6 ± 16.9	109.9 ± 12.1
	Right	100.5 ± 11.3*	104.1 ± 10.2	105.3 ± 10.7	108.3 ± 8.2

Values are mean ± SD.

*p value < 0.05, between pre-trial and post-trial.

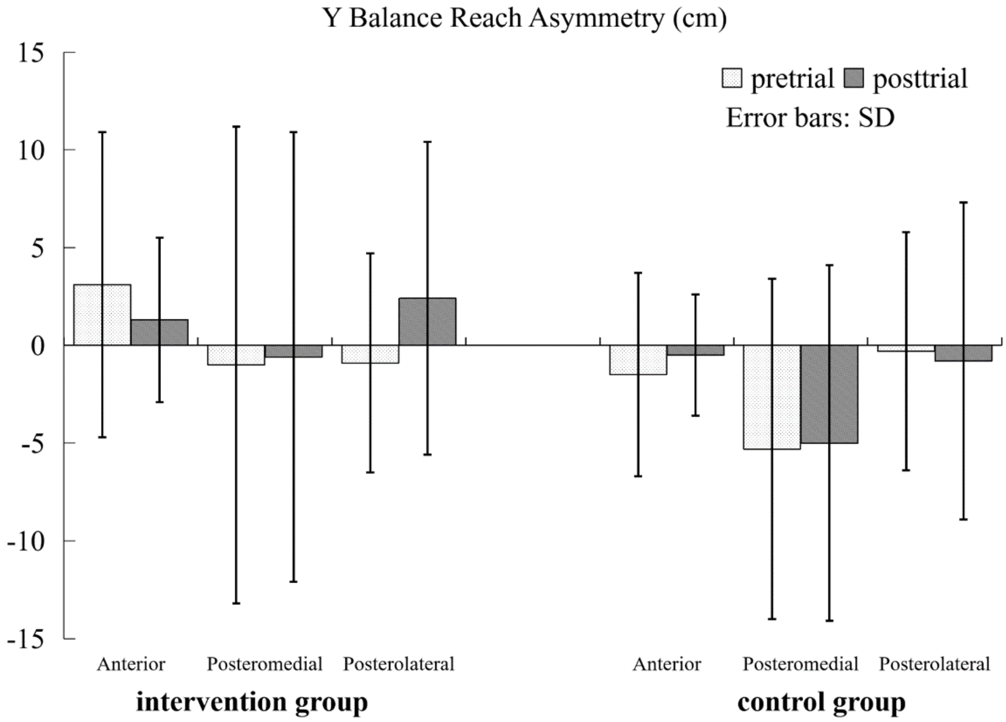

Figure 5-4. Reach asymmetry of Y balance test in intervention and control groups pre- and post-trial.

Table 5-5 and Figure 5-5 show results of shoulder ROM. In the intervention group, before the trial there were significant differences in IR (79.4º ± 11.5º *vs* 63.5º ± 8.2º, $p < 0.05$) and TROM (185.3º ± 13.9º *vs* 168.8º ± 18.2º, $p < 0.05$) between the dominant side and the nondominant side whereas significant differences in IR (83.1º ± 10.4º *vs* 61.9º ± 12.5º, $p < 0.05$) between both sides were found after the trial. In comparison of pre-trial *vs* post-trial, ER on the dominant side (117.5º ± 8.8º *vs* 105.3º ± 12.1º, $p < 0.05$) as well as on the nondominant side (112.4º ± 10.3º *vs* 105.9º ± 9.3º, $p < 0.05$) increased significantly post-trial. However, in the control group there were no significant differences in IR, ER and TROM pre- and post-trial. No significant differences in GIRD, ER gain and TROM loss were found between pre-trial and post-trial in the control group as well as in the intervention group.

Table 5-5. Descriptive data of shoulder ROM in the intervention and control groups pre- and post-trial.

Variables	Intervention group (n = 10)				Control group (n = 4)			
	Pre-trial		Post-trial		Pre-trial		Post-trial	
	D	ND	D	ND	D	ND	D	ND
IR (º)	63.5 ± 8.2*	79.4 ± 11.5	61.9 ± 12.5*	83.1 ± 10.4	69.1 ± 3.8	85.5 ± 8.4	57.4 ± 10.3	80.5 ± 10.9
ER (º)	105.3 ± 12.1	105.9 ± 9.3	117.5 ± 8.8†	112.4 ± 10.3†	109.7 ± 9.9	103.8 ± 4.0	110.6 ± 19.6	111.4 ± 8.6
TROM (º)	168.8 ± 18.2*	185.3 ± 13.9	179.4 ± 16.9	189.0 ± 14. 6	178.8 ± 8.3	189.3 ± 7.8	168.0 ± 13.8	184.3 ± 7.8

Values are mean ± SD.

*p value < 0.05, between dominant and nondominant sides.

†p value < 0.05, between pre-trial and post-trial.

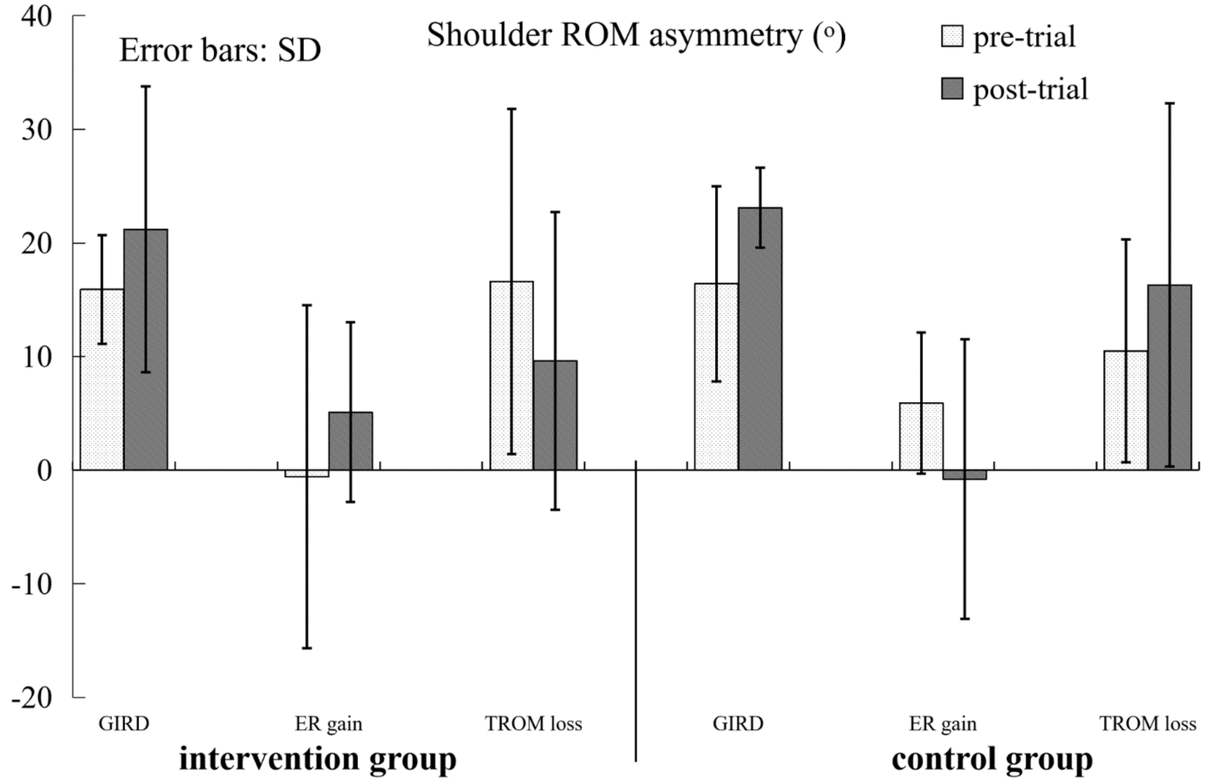

Figure 5-5. Asymmetry of shoulder ROM in intervention and control groups pre- and post-trial.

Table 5-6 and Figure 5-6 show results of trunk ROM. Regardless of two groups, no significant differences in trunk rotation, trunk flection and trunk extension on the dominant and nondominant sides were found pre- and post-trial. As for changes (pre-trial *minus* post-trial) in trunk ROM, in the intervention group changes in trunk flection ($-2.2^{o} \pm 10.0^{o}$ *vs* $-7.2^{o} \pm 12.7^{o}$, $p < 0.05$) and trunk extension ($1.2^{o} \pm 4.3^{o}$ *vs* $-9.8^{o} \pm 7.6^{o}$, $p < 0.01$) were significantly lower than in the control group.

Table 5-6. Descriptive data of trunk ROM in intervention and control groups pre- and post-trial.

	Intervention group (n = 10)				Control group (n = 4)			
	Pre-trial		Post-trial		Pre-trial		Post-trial	
	D	ND	D	ND	D	ND	D	ND
Trunk rotation (º)	75.0 ± 11.8	73.5 ± 6.9	71.5 ± 11.7	75.9 ± 7.9	63.8 ± 5.7	69.0 ± 8.6	70.5 ± 5.1	72.5 ± 8.1
Trunk flection (º)	97.0 ± 16.9		99.2 ± 15.2		86.5 ± 12.2		93.7 ± 13.0	
Trunk extension (º)	44.4 ± 5.7		43.1 ± 7.6		31.8 ± 11.7		41.6 ± 4.2	

Values are mean ± SD.

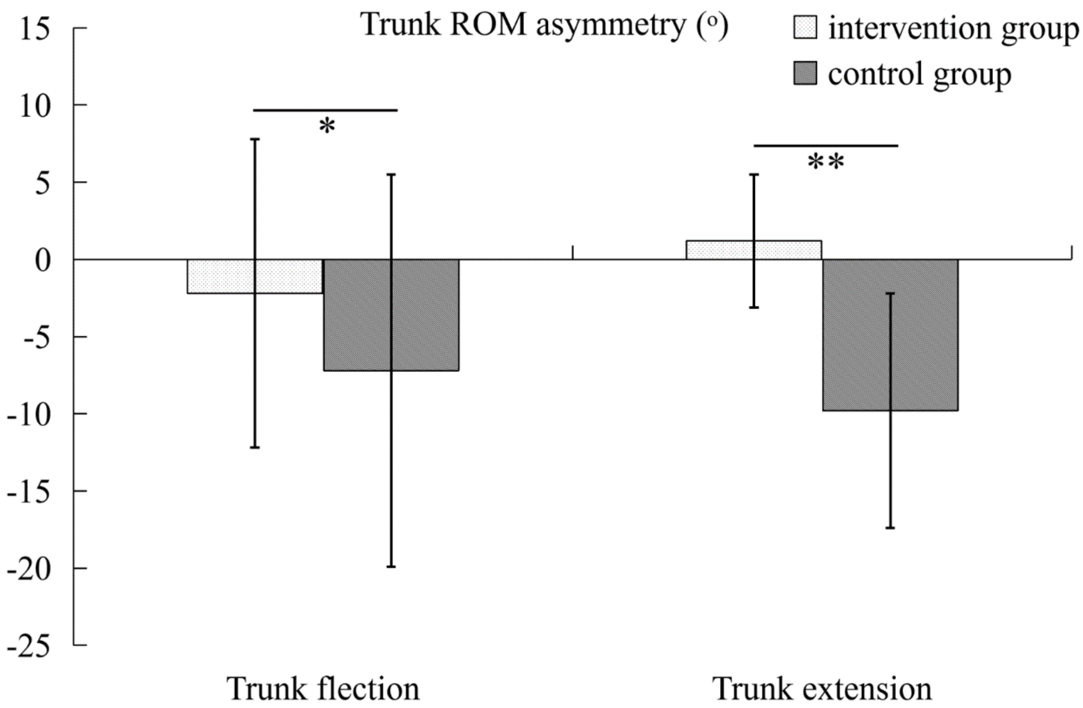

Figure 5-6. Asymmetry of trunk flection and extension in intervention and control groups after the trial. *$p < 0.05$, **$p < 0.01$, between the intervention and control groups. The error bars represent one SD from the mean.

5.4. Discussion

A vital finding of this research is that a neuromuscular training program consisting of 4 core stability and 1 dynamic balance training decreased the occurrence of shoulder and lumbar pains and injuries associated with badminton among university badminton players. In comparison with the control group, after the trial, the occurrence of shoulder pains and injuries was significantly lower and the occurrence of lumbar pains and injuries was lower without significant differences in the intervention group. Improvements in several variables of physical fitness were also identified.

Regarding injury prevention program in overhead motion sports, previous studies of baseball demonstrated that a prevention program consisting of stretching exercises was effective in decreasing the occurrence of throw-related injuries of shoulder and elbow in youth and high school baseball players (Shitara et al., 2017; Sakata et al., 2019). A previous study of handball revealed that a training program focusing on shoulder strength and flexibility, scapular strength and thoracic mobility, was effective in decreasing the occurrence of shoulder injuries (Andersson et al., 2017). In this study, the neuromuscular training program without shoulder stretching exercises, targeting core stability and balance ability which are identified as risk factors for shoulder pain, obtained the similar result that reduced the occurrence of shoulder pains and injuries.

5.4.1. Shoulder, Trunk ROM and Balance ability

Changes in both sides of shoulder ROM, *i.e.*, GIRD, ER gain and TROM loss, were demonstrated as risk factors for shoulder injuries in overhead motion sports. (Tyler, 2014; Shanley, 2015; Wilk et al., 2015; Moore-Reed et al., 2016; Camp et al., 2017; Keller et al., 2018; Achenbach et al., 2019). Previous studies of baseball using stretching exercises revealed that shoulder ROM, including IR, ER, TROM and GIRD improved between pre- and post-intervention (Escamilla et al., 2017; Sakata et al., 2018; Sakata et al., 2019). A systematic review of randomized trials revealed that stretching exercises were effective in improving posterior shoulder tightness and GIRD in youth overhead sports players (Mine et al., 2017). In this study, in the intervention group no significant differences of GIRD, ER gain and TROM loss were found between pre- and post-intervention. After the trial, the dominant shoulder ER as well as the nondominant shoulder ER was significantly greater than pre-trial. We speculated that trunk strength and balance ability training improved trunk movements sequences and changed the biomechanics of overhead motion. Proper trunk movement sequences would be associated with more efficient transfer of momentum to upper limbs (Oyama et al., 2014) that may lower shoulder joint loading and result in changes of shoulder ER.

Numerous previous studies suggested that core stability and balance ability exercises improved overhead motion performance and prevented injuries in overhead motion sports players (Samson et al., 2007; English and Howe, 2007; Lust et al., 2009; Velde et al., 2011; Wilk et al., 2011; Silfies et al., 2015; Karadenizli et al.,2016; Hassan, 2017). Meanwhile, overhead motion sports players with upper limb pains and injuries have lower core stability and weaker balance ability (Garrison et al., 2013; Pogetti et al., 2018). In study 3 (Chapter 4), we identified that decreased trunk rotation and weak balance ability were risk factors for shoulder pain. Therefore, based on the previous studies and study 3, the neuromuscular training program targeting core ability and balance ability was utilized in this study. A previous study of baseball using core stability training exercises revealed that hip flection and hip IR moments have been reduced after the trial in high school players (Pfile et al., 2013). Another study of basketball revealed that basketball players increased trunk flexion and decreased trunk lateral bend by core-muscle and neuromuscular training of trunk (Sasaki et al., 2019). We found that the changes in trunk flection and extension of the intervention group were significantly lower compared with the control group after the trial. Contrary to the previous studies, the control group showed increased trunk flection and extension. We speculated that due to weak trunk muscles strength, the participants of the control group increased trunk ROM to perform overhead motion smoothly that resulted in greater changes in trunk flection and extension after the trial as a consequence. In other words, trunk muscles training maintained the core stability better in the intervention group.

As for balance ability, a previous study of badminton using Star Excursion Balance Test measurement revealed that after core strength training, dynamic balance ability improved in youth badminton players (Ozmen and Aydogmus, 2016). Other studies on basketball revealed that the composite scores (Benis et al., 2016; Bouteraa et al., 2020), posteromedial and posterolateral (Benis et al., 2016) of Y balance test and single leg stance (Bouteraa et al., 2020) improved after core stability and balance training in female players. Likewise, a previous study of volleyball, basketball and soccer high school female players utilizing trunk strength and balance training demonstrated that single-limb postural balance improved (Paterno et al., 2004). In this study, two balance ability measurements, that is single leg stance and Y balance test were used to evaluate the balance ability of the participants. In contrast to the previous studies, posterolateral of Y balance test and single leg stance didn’t improve after the trial in the participants of the current study. However, compared with pre-intervention, posterolateral and composite scores on right side of the participants significantly improved after the intervention that in line with the previous studies.

5.4.2. SLR

Generally, a hamstrings exercise is to prevent hamstring muscles injuries (Dyk et al., 2019). However, the hamstrings flexibility was revealed that can influence pelvic function which leads to lumbar pain (Mistry et al., 2014, López-Miñarro et al., 2010; Sadler et al., 2017). Decreased hamstrings flexibility was a risk factor for lumbar pain (Sadler et al., 2017) whereas increased hamstrings flexibility was demonstrated to be a risk factor for lumbar pain in study 3. Therefore, we utilized Nordic hamstrings training to prevent lumbar pain. A recent previous study of overhead motion sports (Williams et al., 2018) as well as other studies of basketball (Sasaki et al., 2019), football (Nakase et al., 2013) and recreationally active athletes (Bourne et al., 2016) demonstrated that Nordic hamstrings training was effective that not only improving hamstring muscles strength but also promoting gluteus muscles strength. In the intervention group of the current study, before the trial there were significant differences on SLR degrees between the dominant and nondominant sides whereas after the trial no significant differences were found between both sides. The finding of this study indicates Nordic hamstrings training is effective in increasing hamstring muscles tightness that in line with the previous studies.

The forehand overhead stroke motion of badminton, similar to overhead motion, is referred to as a kinetic chain which allows energy generated by lower limbs and trunk muscles to be transferred to the upper limbs for completing the overhead motion (Van and Kibler, 2006; Zhang et al., 2016). Any deficit in the kinetic chain may cause pains and injuries associated with the overhead motion (Jayanthi and Esser, 2013; Sekiguchi et al., 2017). Moreover, we found that lumbar pain was associated with shoulder pain independent of training time in study 1 (Chapter 2), and we also found that decreased trunk rotation and weak balance ability were risk factors for shoulder pain and extra hamstrings flexibility was a risk factor for lumbar pain in study 3. In this study, we clearly demonstrate that trunk muscles training can potentially maintain the core stability, Nordic hamstrings training can improve hamstring muscles tightness and balance training can enhance dynamic balance ability. Plus, we demonstrate that the neuromuscular training program is effective in decreasing the occurrence of shoulder pain/injury and lumbar pain/injury.

5.4.3. Limitations

Some limitations of our study are acknowledged. Firstly, this study is not a randomized controlled trial and the sample size is small, especially sample size of the control group is small. Due to the small sample size of this study, various statistical analysis methods were not adequately performed. Secondly, the neuromuscular training program, including core stability training, balance ability training and hamstring muscles training was a multicomponent program. Therefore, the sole effectiveness of each training method cannot be separated. Thirdly, in terms of balance ability, we utilized dynamic ability training instead of static balance ability although single leg stance was identified as a risk factor for badminton injuries in study 3. Future studies should investigate the effectiveness in preventing badminton injures using static balance ability training like single leg stance. Finally, in terms of training compliance, the higher compliance of injury prevention program in sports resulted in the lower injury rate (Silvers-Granelli et al., 2018). We asked the participants to perform the neuromuscular training program at least once a week, but we were unable to monitor the participants' training each week because of COVID-19 pandemic, so that high compliance cannot be ensured. In addition, due to the COVID-19 pandemic, all the participants had to shorten the badminton training time that the average training time of per week was 542.5 minutes, about half of pre-trial. Decreased training workload might be another possibility which lowered the occurrence of badminton pains and injuries of the intervention group in this study.

5.5. Conclusion

A prospective controlled trial was conducted to estimate the effects of a neuromuscular training program targeted at the reduction of shoulder pain/injury and lumbar pain/injury associated with badminton in university badminton players. The prevention program was effective that not only decreasing occurrence of shoulder pain/injury and lumbar pain/injury, but also maintaining and improving physical fitness.

Chapter 6

General discussion

6.1. Summary of the results

Based on previous studies, four studies (Study 1, 2, 3, and 4) were executed to bridge the gap in badminton injury research. Using the epidemiological perspective with the four-step sequence, we investigated epidemiology of badminton injuries, then we identified risk factors of badminton injuries based on the epidemiological surveillance in Study 1. As a result, inexperienced techniques were identified to be a risk factor for badminton injuries in Study 1, therefore, in Study 2, we demonstrated the effects of a teaching method using task analysis for forehand overhead stroke skill in novice and inexperienced beginners. In Study 3, we compared physical fitness and pain among different age badminton players and detected risk factors for badminton injuries using medical check-up. Decreased trunk rotation, weak balance ability and extra hamstrings flexibility were identified to be the risk factors for badminton injuries in Study 3, thus, in Study 4, we verified the effectiveness of a neuromuscular training program.

Identify accurate data on epidemiology of pains and injuries related to badminton is crucial for badminton players to prevent badminton injuries. Previous studies investigated badminton injuries in junior high school age, high school age and university badminton players (Goh et al., 2013; Miyake et al., 2016), but the epidemiology of badminton pains and injuries was unspecific. Moreover, except for gender and age (Marchena-Rodriguez et al., 2020), no risk factors were found based on epidemiological surveillance. In Study 1 (Chapter 2), the results showed that badminton pains and injuries were frequent, mostly involved lower limbs among elementary school-aged and university badminton players. For elementary school-aged badminton players themselves, traumatic injuries occurred more than overuse injuries, but overuse injuries sharply increased with age. Injury incidence rate had an upward trend with increasing age. On the other hand, injury incidence rate had a downward trend with increasing duration of experience, which indicates that inexperienced techniques might be a risk factor of injuries for elementary school-aged badminton players. Training time of per day is a risk factor for shoulder pain which should be limited to ≤ 2.5 hours per day. Lumbar pain, shoulder pain and knee pain were associated with each other when training time was more than 2.5 hours per day. Moreover, lumbar pain was significantly associated with shoulder pain independent of training time. The findings might help coaches, physicians and physiotherapists target the most at-risk region and pay attention to potential injury risks in knee as well as in trunk and shoulder.

Indubitably, the association of badminton forehand overhead stroke technique errors/improper phases and injuries is clarified by biomechanics or other methods in future studies, therefore, it is essential to explore badminton teaching methods for players and coaches to learn and correct badminton skills. Plus, inexperienced techniques were identified to be one of the risk factors for badminton injuries in Study 1 (Chapter 2). Therefore, in order to reduce the risk of badminton injuries caused by inexperienced techniques, in Study 2 (Chapter 3), a badminton skill teaching test was performed to evaluate the effectiveness of a task analysis teaching method for badminton skills acquisition in inexperienced high school students. The results showed that teaching method using task analysis was effective in improving badminton skill learning, correcting improper phases (badminton skill technique errors) and boosting motor skill abilities. The results indicated that the task analysis teaching method might be a promising approach to correct inexperienced techniques and to prevent badminton injuries.

Studies on risk factors for badminton injuries using medical check-up are scarce. In Study 3 (Chapter 4), a medical check-up method was utilized to examine whether physical dysfunction, which has been identified as risk factor for other overhead motion sports injuries (Wilk et al., 2015; Karadenizli et al.,2016; Keller et al., 2018; Pogetti et al., 2018; Achenbach et al., 2019), exists in badminton players with pain/injury or not. To do so, we checked physical fitness including hand grip strength, HBD, SLR, balance ability and ROM of shoulders and trunk using medical check-up in elementary school-aged badminton players and university badminton players. And we also investigated pain of the participants. The results showed that decreased trunk rotation and weak balance ability were risk factors for shoulder pain and extra hamstrings flexibility was a risk factor for lumbar pain in university badminton players. In addition, elementary school-aged badminton players showed more flexible hamstrings, weaker balance ability and greater ROM. In addition, both of elementary school-aged badminton players and university badminton players experienced pain in shoulder and lumbar. These findings can help players improve and maintain targeted physical fitness for pain/injury free badminton participation.

In Study 4 (Chapter 5), the fourth step of the four-step sequence epidemiological perspective, an injury prevention program targeting the risk factors was performed. We investigated the effectiveness of a neuromuscular training program consisting of core stability training, hamstring muscles training and balance ability training which have been demonstrated effective in other sports players (Paterno et al., 2004; Pfile et al., 2013; Nakase et al., 2013; Benis et al., 2016; Shitara et al., 2017; Williams et al., 2018; Sakata et al., 2019; Bouteraa et al., 2020). The results showed that the neuromuscular training program was effective in not only reducing the occurrence of badminton pains and injuries, but also improving hamstring muscles strength and balance ability as well as maintaining core stability in university badminton players. The results support that, in sports players, improvement of physical fitness by neuromuscular training can prevent sports injuries.

In total, three different groups of players, including elementary school-aged badminton players, high school-aged novice students, and university badminton players participated in the national tournament, were targeted in this thesis. Additionally, we demonstrated the effectiveness of a teaching method for badminton motor skills acquisition in Study 2 (Chapter 3) and the effectiveness of a neuromuscular training program for lowering injury incidence in Study 4 (Chapter 5).

Recognition and motor abilities are crucial for learners to understand the basic components of the motor skill movement pattern and coordinate the limbs with trunk appropriately (Haibach-Bench et al., 2017). According to the mountain of motor development, the motor development stage of elementary school-aged learners is recognized as context-specific motor skills period (Figure 6-1) (Clark and Metcalfe, 2002; Favazza and Siperstein, 2016; Haibach-Bench et al., 2017). From this stage, they begin to refine fundamental motor patterns, such as throwing, catching and hopping, to sport-specific movement patterns (*e.g.*, a striking pattern may be modified for baseball or racket sports) and develop physical fitness (Stodden et al., 2013; Haibach-Bench et al., 2017). People whose biological changes resulting from injuries may cause the person to enter the compensation period that may back to a lower position of the mountain (Haibach-Bench et al., 2017). Therefore, it is important for elementary school-aged badminton players to master proper badminton motor skills and to develop physical fitness that may promote better long-term badminton participation across the lifespan. In our experiment of elementary school-aged badminton players, we found that inexperienced techniques of their badminton motor skills must be acknowledged due to their weak recognition ability, motor ability and little knowledge of badminton motor skills. On top of that, we discovered that many child players learn badminton motor skills or modify improper badminton motor skill phases by imitating rather than understanding. Therefore, we believe that a teaching method using task analysis is suitable for elementary school-aged badminton players of different levels to develop and improve badminton motor skills. With respect to university badminton players with proficient badminton motor skills, a teaching method using task analysis to find and modify micro improper specific of badminton motor skill phases might be limited. In future, combining the teaching method with biomechanics are supposed to be studied in university badminton players. To sum up the results of this study, compared with a teaching method using task analysis, the neuromuscular training program is more appropriate for university badminton players to prevent badminton-related injuries.

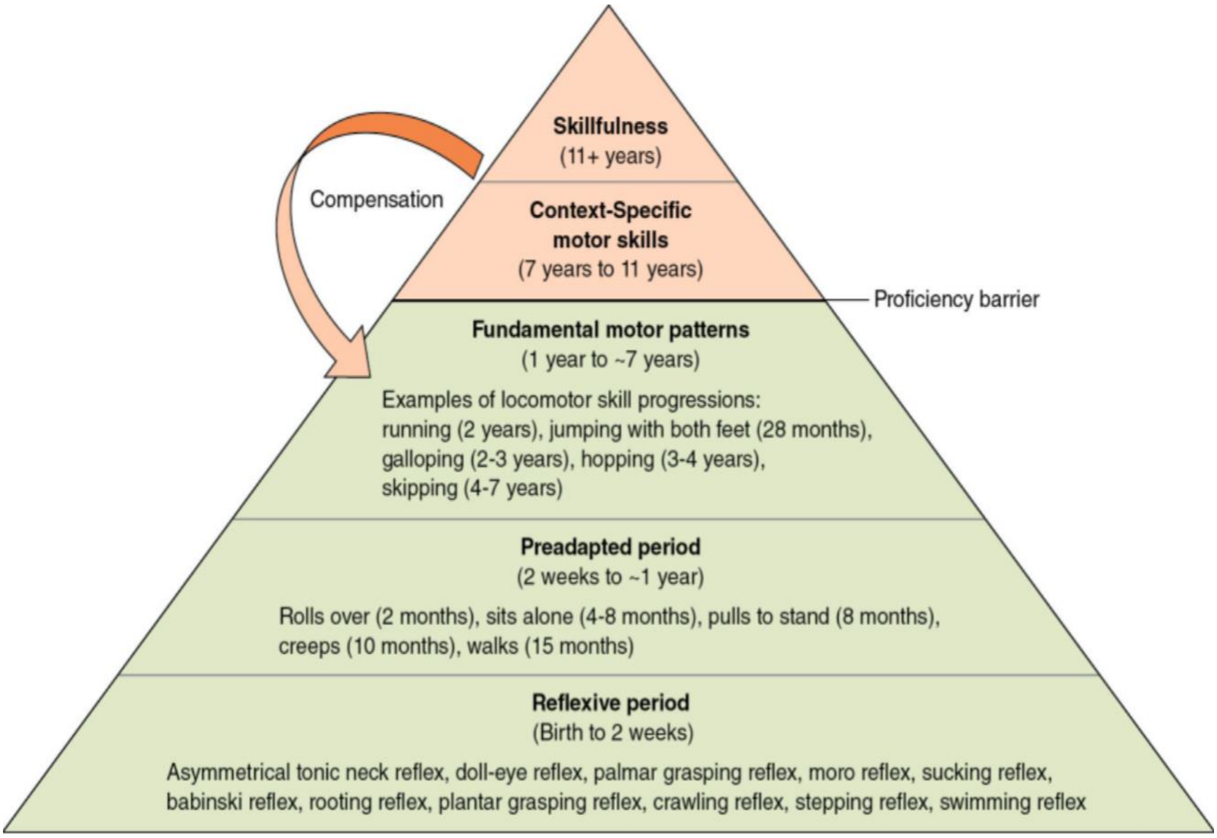

Figure 6-1. The mountain of motor development (Haibach-Bench et al., 2017). These ages are approximations.

Together, to enhance badminton injury prevention program and to assure injury-free badminton participation, epidemiological surveillance, badminton teaching method, medical check-up, and neuromuscular training program were used to achieve the goals. Firstly, we used epidemiological surveillance to identify increased age, inexperienced techniques and training time of > 2.5 hours per day to be risk factors for badminton injuries in school-aged badminton players. Then, to lower the risk of inexperienced techniques, we demonstrated and provided that a teaching method using task analysis is effective in developing and modifying badminton motor skills for high school novices. Next, we used medical check-up to identify decreased trunk rotation, weak balance ability and extra hamstrings flexibility to be risk factors for badminton injuries in university badminton players. Finally, to lower the risk of physical dysfunction, we proved that a neuromuscular training program targeting core stability, balance ability and hamstring muscles flexibility is effective in not only decreasing incidence of badminton injuries but also improving and maintaining physical fitness.

6.2. Clinical implications

The present thesis performed four studies based on the sequence of injury prevention to improve the understanding of badminton injuries and to explore a prevention program. The findings from this study have implications for the prevention of pains and injuries associated with badminton. According to the findings of epidemiological study (Study 1/Chapter 2), coaches, parents and players can realize the anatomical regions vulnerable to injury, and the adequate training hours of school age badminton players so that they can assign training program scientifically.

Overhead motion technique errors were demonstrated to be mechanisms of injuries (Fleisig and Andrews, 2012; Oyama, 2012). Inexperienced techniques were identified as a risk factor for badminton injuries in Study 1 (Chapter 2). Although such researches in badminton were lacking, we explored a teaching method to improve badminton skill acquisition in Study 2 (Chapter 3). Instructing badminton players by task analysis teaching method, especially child players whose recognition and motor abilities are immature, can help learn proper badminton skill mechanics to minimize the risk of badminton injury.

The findings from this thesis also provide an insight into risk factors of badminton injuries using medical check-up. Study 3 (Chapter 4) indicates that physical fitness, especially trunk ROM, balance ability and hamstrings flexibility should be taken into consideration to prevent shoulder and lumbar injuries. Combining with the findings of Study 1 (Chapter 2), complaints of shoulder as well as those of lumbar and knee should be checked using medical check-up to detect risk factors by coaches, physiotherapists, and physicians.

Physical dysfunction results in abnormal biomechanics of badminton skill techniques. Abnormal biomechanics might alter joint loading and cause injury. The findings from this thesis also provide an insight as to how to improve physical dysfunction using a neuromuscular training program to prevent badminton injuries. Coaches, physiotherapists, and physicians might instruct badminton players to perform the neuromuscular training program (Study 4/Chapter 5) to improve physical fitness for injury prevention.

Therefore, based on the sequence of injury prevention, the findings in this thesis might contribute to enhance the understanding and prevention program of badminton injury.

6.3. Future Directions

In Study 1 and Study 3, we identified risk factors of badminton pains and injuries in badminton players aged 7-12 and 18-22 years using epidemiological surveillance and medical check-up. Complete understanding of sports injury in school-aged players can help focus on the most at-risk players for injury prevention programs. Nevertheless, data of epidemiological of surveillance and medical check-up badminton pains and injuries in players aged 13-17 years are not well understood.

Study 1 (Chapter 2) is a retrospective epidemiological study that is not so accurate. In future, prospective studies of badminton pains and injuries in large sample size of school-aged badminton players should be performed. Additionally, we found that incidence of pains of badminton players aged 7-12 years was higher than badminton players aged 18-22 years while incidence of injuries of badminton players aged 18-22 years was higher. Changes in incidences of pains and injuries in badminton players aged 13-17 years should be studied in future studies. Although training time of per day > 2.5 hours has been identified to be a risk factor for shoulder pain in Study 1, there has not been the evidence that limited training time of per day < 2.5 hours can prevent shoulder pain. In future, prospective studies are needed to investigate badminton-related pains and injuries in different categories of training time per day and verify that limited training time of per day can prevent pain/injury.

Intrinsic factors, such as power, joint rotation and muscles flexibility are fundamental for long-term badminton play. Any deficit in intrinsic factors may increase likelihood of badminton injury. Other overhead motion sports have used medical check-up to identify risk factors of related injuries (Garrison et al., 2013; Wilk et al., 2015; Karadenizli et al., 2016; Keller et al., 2018; Pogetti et al., 2018; Achenbach et al., 2019). Although we examined ROM and muscles flexibility to identify several risk factors of badminton injuries, the limitation of our study is that we have not used more methods of medical check-up which have been used in previous studies. In future, other methods, such as trunk rotation strength, lumbar lateral flexion and core stability test are needed to investigate physical dysfunction causing injuries in badminton players.

To prevent badminton pain/injury, a neuromuscular training program was introduced and the program was proven effective in reducing incidence of badminton pain/injury. However, the program showed no effects of improving shoulder IR deficits and weak static balance ability. Future studies are expected to add training program targeting these deficits. For example, other overhead motion sports have utilized shoulder stretching (Escamilla et al., 2017; Sakata et al., 2019) to improve shoulder IR deficits. A previous study of basketball has utilized balance training program consisting of swiss-ball kneeling hold balancing, two-handed chest pass balance exercise, and single-leg balance, to enhance static balance ability (Bouteraa et al., 2020).

As mentioned previously, it is crucial for coaches, physiotherapists, and physicians to identify improper badminton phases and related injuries. Therefore, the association of badminton skills and injury must be identified. In this thesis, we explored a teaching method which can correct improper phases of forehand overhead stroke. It can be a promising method for injury prevention when the association of phases and injury be identified. Although phases of forehand overhead stroke causing shoulder pain have been investigated, the characteristics of the phases cannot be identified because of a low precision examining method. In addition, lower limbs which have high incidence of pains and injuries should be also studied by a high precision examining method including motion analysis. Future studies are needed to examine the phases on joint loading and performance of limbs using biomechanical study.

6.4. Conclusions

In conclusion, study 1 detected that in school-aged players, increased age, inexperienced techniques and training time of > 2.5 hours per day are risk factors for badminton injuries using epidemiological surveillance. Study 2 indicated that in university players, decreased trunk rotation, weak balance ability and extra hamstrings flexibility are risk factors by medical check-up. Study 3 showed that badminton teaching method using task analysis is efficient to boost badminton skill acquisition and correct improper phases that should be applied for badminton injury prevention. And study 4 revealed that neuromuscular training program is effective in decreasing the incidence of badminton injuries.

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Acknowledgements

Without the support from family, friends, mentors, and others I would like to take this opportunity to thank you all.

I would like to express my sincere gratitude to Dr. Kazuhiro Imai for being my mentor for 3 years. It is incredible to think that none of this would have happened if you did not accept me into the Doctoral program at the University of Tokyo 3 years ago. Thank you for believing in me and providing me endless encouragement, guidance, countless opportunities that made me passionate about pursuing various possibilities sports medicine research and discovery. You are a greater teacher and a mentor. I have learned so much from you. I can tell that I am a more confident and effective sports injury researcher because of your guidance. Having you as a mentor has changed my life for the better. I truly appreciate everything that you have done for me.

I especially would like to deeply thank Professor Eiji Watanabe from Sensyu University who gave advice, and provided opportunities which have allowed me to collect data of different age and level badminton players to complete my dissertation. I could not have completed my dissertation if there were not for the help from you and numbers of badminton players who volunteered to participate in this study.

I am indebted to Professor Emeritus Takuro Yajima from Mejiro University for being a wonderful model to me. Being a research student of yours was one of the best things that happened to me at Tokyo. Thank you for your encouragement, help and support throughout the Doctoral program.

I would like to thank Professor Yuanchun Ren who was the great mentor throughout my Master's program at Beijing Normal University. Thank you for supporting, inspiring and encouraging me to pursue my academic goals throughout the Doctoral program.

I also thank Miss Xiaoxuan Liu, a member of Imai's laboratory for proofreading English, providing me advice and enriching my Japanese life. I am very lucky that I met you at the University of Tokyo.

I would like to thank Miss. Xiyi Bai for being a vital role to me. No matter how busy you are, you always helped me proofread English and practice oral presentation. Thank you for your patience and understanding.

Lastly, I owe the greatest appreciation to my family for your enduring and endless support in every possible way.