

The Characteristics of Static Plantar Pressure and Potential Pain Profiles in Elite Badminton Players

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ABSTRACT

The purpose of this study is to explore the badminton players' plantar loading characteristics and pain profiles in static standing. Experiments were undertaken on twenty elite badminton players (EB), twenty-four subelite badminton players (SB) and twenty-eight non-athletes (controls). 'JC Mat', the optical plantar pressure measurement, was applied to examining all subjects' arch index (AI), plantar pressure distributions (PPD), and footprint characteristics. Pain assessment and self-reported health status were undertaken for evaluating the badminton players' common pain locations. Findings from the control group, the AI fell into the normal range. The badminton players' arch type was classified as high-arched feet. PPD at the lateral longitudinal arch and the lateral heel of both feet, and the medial heel of the left foot was significantly higher in the badminton players, particularly the EB, than in the controls. PPD at the lateral metatarsal bone of both feet was significantly lower in the badminton players than in the controls. Compared with the SB, the EB had lower PPD in the lateral metatarsal bone of both feet. Footprint characteristics supported the results of the AI and PPD, and this reflected the corresponding pressure profiles. The badminton players' lateral ankle and knee joints, and gastrocnemius were the most common pain locations. The badminton players' AI and PPD were generally classified as high-arched supinators, and their pain profiles paralleled the symptoms of foot supination. The findings reflected the possible link between badminton injuries and supinated feet and the correlation is worth further studies.

KEYWORDS: elite badminton players; subelite badminton players; arch index; plantar pressure distributions; supinated feet

INTRODUCTION

Badminton is a high-intensity racket sport which requires rapid jumps and lunges, quick changes in direction, and instant arm movements with a wide variety of body postures.[1] Footwork is the fundamental skill in badminton competitions and enables athletes to reach the shuttlecock as quickly as possible while maintaining good balance and body control. [2] According to previous studies, the frequent execution of a lunge step in a badminton competition is generally considered to be the main risk factor for lower extremity

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injuries.[3] This is mainly because badminton players exhibit higher vertical ground reaction forces which are approximately 2.1 to 2.5 times their body weight. [2-4] This, in turn, may cause their feet to experience a great amount of stress and lead to fatigue and painful conditions.[5] Badminton players' dominant leg usually bears a great load, and their tendons are susceptible to suffer from overstrain.[5] Ankle joints, knee joints, lower legs, feet and thighs are the common injuries which occur in badminton players' lower extremities. Importantly, due to badminton players' unique and repetitive movements, their Achilles tendon, plantar fascia, anterior talofibular ligament of the specific musculotendinous and ligamentous structures were verified to be at higher risks of serious injuries than athletes who were involved in other types of sports.[6]

Foot arch, an anatomical structure of the foot, is constituted of ligaments, muscles and bones, and could be regarded as a shock absorber in the human body.[7] When running and jumping, the medial longitudinal arch (MLA) provides adequate elastic forces and twisting forces for absorbing the ground reaction force, and this is helpful for attenuating the shock from movement, mitigating injuries and deferring fatigue.[8] Arch height of the MLA is generally treated as the influential and key determinant of the function of the foot and lower limbs.⁹ High-arched individuals were found to be associated with more laterally located bony injuries of the foot, ankle, knee, and lower extremity stress fractures.[10] Yet, low-arched individuals usually showed a greater incidence of medially soft tissue injuries, such as patellar tendinitis, plantar fasciitis and knee pain.[11,12] Based on previous studies, the arch index (AI) from footprints could be considered to be the reliable and valid method for characterizing the foot and MLA height.[12-17] The measurements of static arch height and arch height ratio of the foot may assist clinicians in estimating foot posture during dynamic activity in patients with lower-limb injuries.[18] Clinicians also commonly use static posture of the MLA to infer dynamic foot function in order to assess the potential for several foot-specific pathologies [19] and for lower extremity dysfunction which may increase injury risk.[20] A recent prospective study suggests that the static characteristics of the flatfoot, high-arched foot and rearfoot range of motion are the risk factors for developing lower extremity overuse injuries in general.[21] Furthermore, the plantar pressure assessment of the footprints is one of the effective methods for evaluating the plantar loading characteristics during functional activities. The parameters gained from the plantar pressure assessment can be useful not only for understanding the variations in the plantar loading in different regions of the foot, but also for detecting the foot pathologies.[22,23] High plantar pressure is thought to be the potential factor for sports-related injuries in the lower extremity.[24] When plantar pressure in each region of the foot is distributed evenly, sports injuries could be reduced effectively.[25]

In a sense, badminton players' static plantar pressure characteristics are possibly significant for predicting their potential pain profiles. Nevertheless, few studies have been undertaken for exploring plantar pressure characteristics in badminton movements.[3,4,26] With a few exceptions, though, these studies tended to focus on dynamic footwork rather than static standing.

2. Objectives:

Given the above context, the purpose of this study, therefore, was to investigate the differences among elite badminton players (EB), subelite badminton players (SB) and healthy non-athletes in terms of their static plantar pressure characteristics. The related parameters which were examined within this study are listed below: the arch index, three regional and six distinct sub-regional plantar pressure distributions (PPD), and footprint characteristics of both feet. Apart from this, data gained from the pain assessments and badminton players' self-reported health status within this study were used for evaluating the pain locations which occurred frequently in the body. It was our assumption that badminton players were classified into high arch type, and that their PPD were particularly concentrated in the rearfoot and the lateral foot regions. The plantar pressure characteristics and pain profiles may correlate with the features of the supinated foot.

MATERIALS AND METHODS

3.1. Subject Selection:

The subjects participating in this study comprised three specific groups of college and university students in Taiwan. One of the groups, labelled as the 'elite badminton group', was composed of 20 right-handed first-division male badminton players. For the elite badminton group, the length of being the qualified first-division players is to have more than successive five-year experiences in badminton competitions. All subjects within the elite badminton group in this study were recruited from the sport university, school of kinesiology and three city sports centers in Taipei, Taiwan. Another group, the 'subelite badminton group', was constituted of 24 right-handed male badminton players who were the same age range (between 17 and 21 years old) as the elite badminton group. All subjects in the subelite badminton group were single-sport university athletes and participated only in team-based badminton training. They were playing badminton at least once a week at sports centers in Taipei. The other group, the control group within this study, included 28 healthy age-matched male university students without specialties in sports nor regular time for exercise (the average time for exercise weekly was less than 2 days or 6 hours).

Each subject's age, gender, height, body weight and body mass index (BMI) were recorded in the research

process. Considering the effect of the body weight on shape characteristics of the foot arch, each subject's BMI within this research was required to range between 18.5 and 24 and this particular range was defined by the World Health Organization (WHO) as healthy weight. A total of 72 subjects participated in this study, and their average age, height, weight and BMI value were shown in Table 1. All subjects' pain and health assessments were based on the self-reported health status and measurements which were diagnosed by the professional physiotherapist at the rehabilitation department. The pain and health assessments were essential for this research to ensure that all subjects had no history of previous fracture and surgery, and that they were free from injuries in their ankle joints, knee joints, hip joints, spine, and bones and muscles of their lower limbs within a year as this study was underway. Prior to the experiments, all participants were informed of the purpose of the present study. They read and signed an informed consent form approved by the institutional review board. The entire process of the experiments within this study followed the guidelines of the local Ethical Committee and the recommendations of the Declaration of Helsinki.

3.2. Instruments and Equipment:

'JC Mat', provided by View Grand International Co., Ltd., Taiwan, was the optical plantar pressure instrument and served as the main research tool for the present study. The measurement technology and principles of JC Mat were similar to the operation principles of Harris footprint measurement instrument. The key attributes of JC Mat were as follows: (1) the subtle characteristics of the foot were easily distinguished; (2) the plantar pressure distribution and footprints coincided with the weight calibration data (data not shown); (3) there were 25 sensors in each square centimeter for the plantar pressure measurement, and thus, 13600 sensors were on each side (32*17 cm) of JC Mat; (4) the pressure sensing was sensitive and the scope of the sensor was large. A smooth and delicate plantar pressure image was shown in the form of round dots; (5) the static pressure profiles from footprints and barefoot images were captured instantly; and (6) the built-in FPDS-Pro software was competent for analyzing the following parameters: the arch index, plantar pressure values, balance of the center of gravity, toe angles and footprints.

3.3. Methods and Procedures:

It took approximately seven months to select the subjects and conduct the experiments for this study. Before the experiments were undertaken, all subjects were informed of the purpose and processes of this study and their consent to participate in this research was obtained. For the sake of consistency and trustworthiness of the experiments, time for each experiment was set between 2pm and 4pm. All subjects were required to measure their body weights and heights when the experiments were conducted. This was helpful for recording the basic and accurate data of subjects' physiological conditions in terms of weights and heights. The subjects' weights and heights which were recorded during the experiments, associated with the given formula (body weight (kg)/height (m²)), served as the base for calculating the BMI values for this study. Apart from this, the subjects in the experimental processes were asked to follow the instructions listed below:

(1) Roll both trouser legs up to above the knees if necessary, in order to prevent the clothing from limiting movements of the extremities.

(2) Stand with bare feet on the sensing cushion with marks of the specific measuring range of JC Mat.

(3) Relax the body; then, control and balance the center of gravity by standing with feet shoulder-width apart and with body weight evenly distributed on both feet.

(4) Stampede for 6-8 steps, and then, stand still with a natural and comfortable posture and arms hanging straight down at sides.

(5) Face the guide of the experiment, and look the guide straight in the eye. Keep the body stationary and balanced until there were no obvious changes in the pressure values of both feet measured by JC Mat.

When the condition above was met, the subjects' static pressure profiles were acquired immediately.

3.4. Pain Assessment and Self-Reported Health Status of the Subjects:

The process of the subjects' pain assessment and self-reported health status was conducted through the assistance of a professional physiotherapist at the rehabilitation department. This process functioned as the basis for the subject selection criteria, the subjects' physiological symptom assessment and confirmation of the pain location. After the plantar pressure measurement, all subjects were asked to undergo the skeleton arrangement and soft tissue pain assessment. The term 'lower limb pain' used in this study was defined as the musculoskeletal pain which occurred during the past month and originated from the structures of the foot, ankle, knee, lower leg and thigh. This definition excluded intermittent cramps, dermatological conditions, digital calluses and night-time paresthesia from analysis. A standardised protocol for the questioning and examination techniques was used within this research for determining the precise nature of the complaint (e.g., metatarsalgia and plantar fasciitis). The procedures for evaluating the pain location which occurred frequently in the subjects were presented as follows:

(1) The professional physiotherapist evaluated and documented the subjects' self-reported health status and

pain location which occurred frequently in the body.

(2) The subjects were asked to stand with bare feet and roll both trouser legs up to above the knees if necessary.

(3) Inspection of subjects' lower extremities by pressing their foot (including phalanges, metatarsal bones, navicular bone, cuboid bone and calcaneus), ankle joints, knee joints, hip joints, tibias, fibulas and femur, and then, assessing the bones arrangement of their lower extremities.

The procedures for assessing the soft tissue pains were listed as follows:

(1) The professional physiotherapist pressed the subjects' self-reported pain location and re-checked the corresponding location on the opposite side of the pain location.

(2) Based on their clinical experiences, the professional physiotherapist pressed and examined the specific points in the subjects' common pain locations, including plantar metatarsal heads, plantar fascia, the inferior margin of navicular bones, the Achilles tendon, the medial and lateral sides of ankle joints, the medial and lateral fossas of knee joints, gastrocnemius, tibialis anterior and posterior, biceps and quadriceps femoris. This allowed the physiotherapist to definitely confirm the subjects' common pain locations.

3.5. Data Analysis:

In order to examine the subjects' plantar pressure distributions in different regions and sub-regions of both feet, the images of the static footprint of both feet were digitized and imported into the specific computer program, FPDS-Pro software. The software allowed the footprint to be divided into three equal regions (region A, B and C) and six sub-regions (sub-region 1, 2, 3, 4, 5 and 6) (see Figure 1) via the following techniques: firstly, the software formed a nearly vertical line on the footprint image. The nearly vertical line extended from the tip of the second toe to the center of the heel, and was drawn tangent to the most anterior and posterior parts of the footprint excluding the toes. Secondly, the software generated a set of four parallel lines which were perpendicular to the nearly vertical line and divide the footprint into three equal parts.

In this study, 'regions A, B and C' of the footprint were defined, respectively, as the 'forefoot, midfoot and rearfoot'. 'Sub-regions 1, 2, 3, 4, 5 and 6' were defined, respectively, as the 'lateral metatarsal bone (L.M.), lateral longitudinal arch (L.L.A.), lateral heel (L.H.), medial metatarsal bone (M.M.), medial longitudinal arch (M.L.A.) and medial heel (M.H.)'. The arch index ratio method developed by Cavanagh and Rodgers assumed that the arch index (AI) was calculated as the ratio of the area of the middle third of the footprint divided by the entire footprint area excluding the toes, i.e. $AI = B / (A + B + C)$. Based on Cavanagh and Rodgers' assertion, a normal arched foot was defined by the ratio between 0.21 and 0.26, a high-arched foot was defined by the ratio lower than 0.21, and a flat-arched foot was defined by the ratio higher than 0.26.

3.6. Statistical Analysis:

Descriptive statistics used for this study was to summarize all subjects' ages, heights, weights, BMI values and experience. Numerical data gained in the research process was presented as mean \pm SD. One-way ANOVA was used for distinguishing the differences among three groups in terms of their arch index, three regional and six sub-regional plantar pressure distributions. Post-ANOVA, paired t-testing with Scheffe correction were used for dealing with the between-group comparisons. All statistics were calculated with the Statistical Package for the Social Sciences for Windows (Version 17.0; SPSS Inc., Chicago, IL). Statistical significance was defined as $P < 0.05$ (marked as *) between the EB and control groups, $P < 0.05$ (marked as †) between the SB and control groups, and $P < 0.05$ (marked as #) between the EB and SB groups.

Table 1: Demographic characteristics and training experience in elite badminton (EB), subelite badminton (SB) athletes, and controls.

Demographics	Control	EB	SB
Numbers	28	20	24
Age (years)	19.1 \pm 0.7	19.5 \pm 1.6	19.8 \pm 1.3
Height (cm)	170.2 \pm 8.4	174.1 \pm 8.5	170.2 \pm 3.4
Mass (kg)	66.2 \pm 6.4	67.2 \pm 8.8	64.5 \pm 5.5
BMI	22.8 \pm 0.7	22.1 \pm 1.6	22.3 \pm 1.7
Experience (years)	---	7.9 \pm 1.9	4.5 \pm 1.5

Data are represented as mean \pm SD. The control group: male university students with neither specialties in sports nor regular time for exercise (the average time for exercise weekly was less than 2 days or 6 hours). The elite badminton group: right-handed first-division male badminton athletes. The subelite badminton group: single-sport university athletes and participated only in team-based badminton training (playing at least once a week).

Table 2: Pain assessment and the self-reported health status in the badminton players.

Pain areas	EB (n= 20)	Proportion	SB (n= 24)	Proportion
<i>Bone</i>				
Lateral ankle joint	13/20	65%	15/24	62.5%
Lateral knee joint	11/20	55%	12/24	50%
Shoulder joint	11/20	55%	9/24	37.5%
Elbows and wrists	9/20	45%	6/24	25%
Calcaneus	8/20	40%	8/24	33.3%
Plantar metatarsal bone	5/20	25%	7/24	29.2%
<i>Soft tissue</i>				
Gastrocnemius	16/20	80%	17/24	70.8%
Achilles tendon	14/20	70%	13/24	54.2%
Anterior cruciate ligament	12/20	60%	11/24	45.8%
Quadriceps femoris	8/20	40%	9/24	37.5%
Lower back	8/20	40%	12/24	50%
Plantar fascia	3/20	15%	2/24	8.33%

Pain assessment and self-reported health status of the elite badminton players (EB) and subelite badminton players (SB) was conducted through the assistance of a professional physiotherapist at the rehabilitation department.

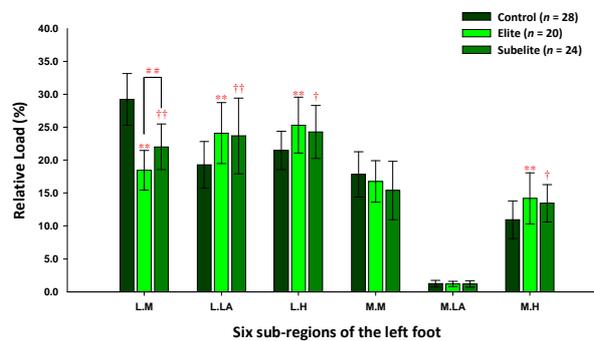


Fig. 1: Plantar pressure distributions of six sub-regions of the left foot in static standing. Data are expressed as mean \pm SD. * $P < 0.05$, ** $P < 0.01$, significant differences between the EB and control group. † $P < 0.05$, †† $P < 0.01$, significant differences between the SB and control group. # $P < 0.05$, ## $P < 0.01$, significant differences between EB and SB group.

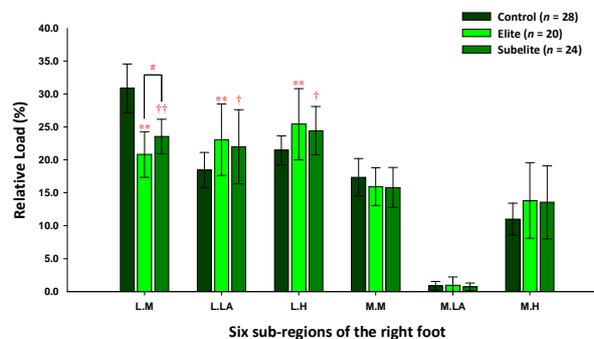


Fig. 2: Plantar pressure distributions of six sub-regions of the right foot in static standing. Data are expressed as mean \pm SD. * $P < 0.05$, ** $P < 0.01$, significant differences between the EB and control group. † $P < 0.05$, †† $P < 0.01$, significant differences between the SB and control group. # $P < 0.05$, ## $P < 0.01$, significant differences between EB and SB group.

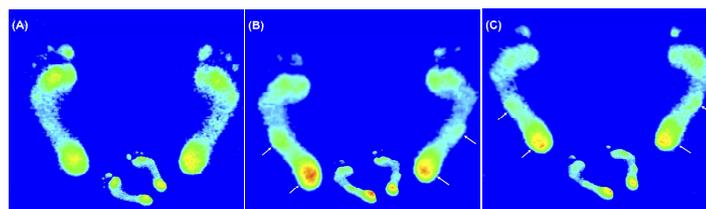


Fig. 3: Footprints of both feet among the (A) control group, (B) elite badminton group and (C) subelite badminton group. White arrows indicate the higher pressure profiles.

Conclusions:

It could be summarized from the findings by saying that badminton players' arch index and plantar pressure characteristics were generally classified as high-arched supinators. The results from the pain assessment and the self-reported health status confirmed that the lateral ankle/knee joint and the gastrocnemius were the most common musculoskeletal pains in badminton players. These findings were consistent with the symptoms of foot supination. Although some studies have stressed the link between badminton injuries and footwork, little research has been conducted for exploring the relationships between badminton injuries and foot supination. Therefore, the correlation between badminton injuries and the development of the foot supination is worth further studies.

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