A Project entitled

BIOMECHANICAL DIFFERENCES IN THE MUSCLE ACTIVATION PATTERN OF DROP LANDING FROM A 60 CM-HIGH PLATFORM BETWEEN FLAT FOOT AND NORMAL PARTICIPANTS ON SAND AND RIGID SURFACES

submitted by

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DECLARATION

I, *FONG WAI MAN* declare that this research report represents my own work under the supervision of PROF CHOW HUNG-KAY, DANIEL and that it has not been submitted previously for examination to any tertiary institution.

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April 22, 2022

ABSTRACT

The present study compared the biomechanical differences in the muscle activation pattern of the lower extremity of drop landing from 60 cm-high platform between Flat Foot and Normal participants on sand and rigid surface. Eight male A1 athletes with flatfoot and four male A1 athletes with normal foot voluntarily participated in the project. The Qualisys Motion Capture system and electromyography were used to analyses the lower extremity muscle activation pattern data. The Max and Mean EMG findings revealed that there was no significant difference on the muscle activation pattern of the lower extremity between the flatfoot group and the normal group. Therefore, it can be concluded that flat-footed athletes may not be at a disadvantage with foot deformity when performing landing.

KEYWORDS: flatfoot, drop landing, sand, muscle activation pattern, EMG

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1. INTRODUCTION

Arch is critical in human movement, providing the feet with elasticity in walking, running, and jumping on different land surfaces, as well as shock absorption when making contact with land surfaces (Fu et al., 2016). A common type of foot deformity is Flatfoot. Flatfoot can be visualized as an inadequacy of the longitudinal arch in the midfoot and medial midfoot collapse, bulging medial foot margin, and rearfoot valgus (Tang et al., 2015). People who are suffered from flat feet have poor ability in transferring weight, absorbing shock and distributing load pressure. As a result, many suffer from joint injuries and stress fractures due to the biomechanical abnormality after even repeated small loads of shock, such as landing exercises (Chang et al., 2012).

In volleyball, jumping is considered to be one of the most dominant motions, used repeatedly in actions such as blocking, spiking, jump serve and overhead set with jump etc. It is also used in sports such as basketball, where a jump ball marks the start of every game. Whether you're hitting a jump shot, taking off for a lay-up, rebounding a ball, or blocking a shot, jumping and landing are motions essential to the game of basketball. Landing is the final phase of jumping, and when kinetic energy absorption is reduced by the participation of all lower extremity joints, muscles and ground reaction force, may cause a significant impact load on the body. The higher the impact load, the greater potential for injury (Davoodi et al., 2011).

The hip, knee, and ankle joints are the impact absorbers during a normal landing maneuver, and the impact of landing could be actively absorbed by eccentric muscle contraction in the lower extremity joints (Decker, et al., 2003). The risk of shock on landing may be intensified in a correlation of the altitude (Chang et al., 2012). Individuals with flatfoot problems worry about the risk of many overuse injuries reported by previous literature (Kaufman et al., 1999; Simkin et al., 1989). Therefore, to prevent injuries, it is important to absorb the shock and to distribute the load pressure efficiently by using various compensating strategies. Examples of such strategies include the coordination between the muscles and ligament (Yeow, Lee, & Goh, 2009).

However, despite the fact that prior research has been carried out to analyze the kinematic, kinetic and the ground reaction force of the lower extremity of flatfoot and normal group jumping and landing onto rigid surface, there is little evidence that points towards injury prevention from the perspective of differences in muscle activation pattern of landing between flatfooted and normal-footed participants onto sand and fixed surfaces. Therefore, the objective of this present study is to compare the muscle activation pattern of the lower extremity from the drop landing platform in individuals with flatfoot and normal foot onto the sand and rigid surfaces respectively.

The countermovement jump (CMJ) is an essential motor skill for a variety of sports including volleyball, soccer, and basketball. The countermovement vertical jump with arm swing of the elite male volleyball player ranged 70,67±4,55cm (Junior, 2015) whereas the average NBA player ranged 59,7±7,2cm (Rauch et al., 2020). Therefore, the drop landing height for this study was decided at 60 cm with the safety reason of testing participants in a barefoot situation.

2. SUBJECT AND METHODS

2.1 Participants

Eight elite male athletes with flat foot (Age = 27.84years±5.64; Height = 188.625cm±6.14; Weight = 83.61kg±7.83) and four elite male athletes with normal foot (Age= 26.08years±5.08; Height = 186.75cm±11.15; Weight = 82.73kg±15.78) volunteered to participate in this study. Inclusion in the study required a recently registered A1 player either in Volleyball Association of Hong Kong or Hong Kong Basketball Association. Participants were randomly asked to land off from the 60 cm-high platform onto a sand (hereafter: SAND) and rigid (hereafter RIGID) surface respectively. None of the participants had apparent or reported foot injury and surgery, nor had they been diagnosed with diabetes in the past year. They did not participate in vigorous exercise within 24 hours and had no symptoms of muscle fatigue before the test. Informed consent and Physical Activity Readiness Questionnaire (PARQ) were obtained from the athletes prior to the participation of the study. Ethical approval was obtained by the University Ethics Committee of The Education University of Hong Kong in December 2021.

2.2 Experiment Procedure

Participants were informed of the testing procedure on the day in brief. Prior to each measurement and test, participants were then instructed in detail. Participants did the baseline measurement and followed the footprint measurements of both feet. After a 20-minute warm-up which included cycling for 10 minutes on an LC7 Monark Exercise Cycle (Exercise AB, Vansbro, Sweden) at constant velocity of 20km/h with 0 W load, followed by 10 minutes of interchangeable dynamic and static stretching exercises, consisting of simple movements that gradually engaged the joints to move in almost full range of motion. A series of maximum voluntary isometric contraction (MVIC), including four standardized exercises, were performed before the landings. 10 tests total were performed on both legs. Participants were allowed to practice before every MVIC test at least once to satisfy the task familiarization. Two trials were recorded for each isometric contraction test. There was a minimum rest period of 30 seconds between each three-second contraction exercise.

Prior to the beginning of the landing session, participants were instructed regarding the execution of the landing on both surfaces. Bare-foot participants were instructed to land off from a 60 cm-high platform, in random order, onto SAND and RIGID. For all landings, participants started in a natural standing position with their feet at shoulder width, arms held naturally on both sides. Participants were instructed to land using their natural styles with one foot and both feet. Prior to the actual recorded landings, participants practiced beforehand to familiarize themselves with the task. At the “Go” signal, participants lifted one-foot up forwards and subsequently landed. After 3 trials, participants would switch to land on another surface. A minimum period of 30 seconds resting time was allowed between each trial. A landing was considered successful when the participant stepped off the platform without an upward and/or forward jump action and adopted a stable landing posture. Landing with a center of gravity changing to forward or backward was regarded as failure. In the end, six landings from a 60 cm-high platform, three landings on SAND and RIGID respectively were performed. The maximum and the mean values of each trial on both surfaces were used in the analysis.

2.3 Data Acquisition

A motion analysis system with 8 Oqus cameras was used to capture and analyze motions at a sampling rate of 120 Hz (Qualisys Motion Capture system). The Qualisys motion capture system was utilized as a golden standard marker-based motion capture system. The recordings were captured using Qualisys Track Manager (QTM) 2.17 (build 3800) with a sampling frequency of 250 Hz and exposure time of 200 μs (Qualisys AB, Gothenburg, Sweden). A total of 16 12.5 mm diameter super-spherical markers (Qualisys Motion Capture system) were attached to the lower body: the surface of the second proximal phalange, surface of the last proximal phalange, ankle joint, mid of the heel, lateral knee joint, greater trochanter, ASIS and PSIS. Qualisys Track Manager (QTM) 2.17 was used for data collection, Visual 3D Version 5 software and Microsoft Excel were used for data analysis. Marker trajectories and electromyography (EMG) data were captured synchronously using the QTM software. To measure lower extremity muscle activation pattern, 10 Trigno Avanti Sensors which weighted 14g with 27 x 37 x 13mm body size each (Trigno Systems, Massachusetts, USA) were placed at an inter-electrode spacing of 10 mm, parallel to muscle fibers of the bellies of the five lower extremity muscles: the abductor hallucis (AH), tibialis anterior (TA), lateral gastrocnemius (LGA), rectus femoris (RF), and biceps femoris (BF). EMG data were recorded at 1000 Hz and root mean square amplitudes were calculated. The maximum and mean values of the muscle contraction during the preparation phase (take off to initial contact) and landing phase (from initial contact to full contact) were used in the analysis. Individuals' peak EMG values during maximum voluntary isometric contraction (MVIC) were used to normalize EMG amplitudes.

The MVIC test is a test which generated maximum force for the targeted muscle under specific range of motion. Four MVICs were performed on each leg prior to landing, the set of standardized contraction test included: knee flexion seated with backrest vertical at knee flexed 60°, knee flexion at 55° knee flexion in sitting, knee extension at 45°, knee flexion in sitting and abduction maximally the proximal phalanx of the hallux against the resistance (*see* Table 1).

Table 1

Instructions for the MVIC test to the corresponding muscle group

MVIC	Muscle
Knee flexion at 55° knee flexion in sitting	Lateral gastrocnemius (LG)
Knee extension at 45° knee flexion in sitting	Biceps femoris (BF)
Abduction maximally the proximal phalanx of the hallux against the resistance	Abductor hallucis (AH)
Knee flexion, seated with backrest vertical, knee flexed 60°	Tibialis anterior (TA)
Knee extension at 45° knee flexion in sitting	Rectus femoris (RF)

Sources: (Hsu, Krishnamoorthy & Scholz, 2006); (Rutherford, Hubley-Kozey & Stanish, 2011); (Kim, Kwon, Kim & Jung, 2013).

2.4 Data Processing and Analysis

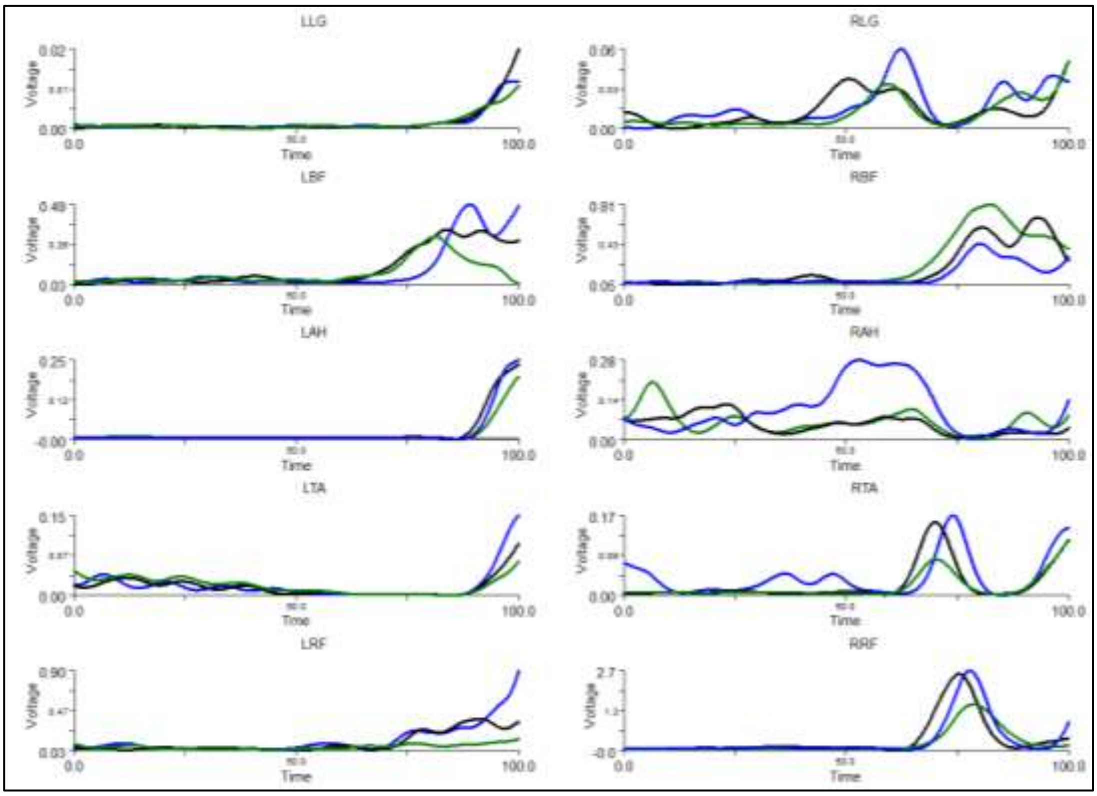
All EMG data was recorded in the QTM 2.17. To extract the raw EMG data for analysis in the Visual 3D software, the data had to be exported to a C3D file. For the landing analysis, it began with the import of C3D files to the Visual 3D software. Then, three events were created, including the take-off, initial contact, and the full contact of each landing trail in the software. Afterwards, the EMG data was full-wave rectified with a low-pass filter and ready to be utilized in the report. The landing data was divided into two phases. The first phase was the preparation phase (from take-off to initial contact) and the second phase was the landing phase (from initial contact to full contact). Four pages of landing data were plotted (the preparation phase on sand surface in Figure 1, the landing phase on sand surface in Figure 2; the preparation phase on rigid surface in Figure 3, the landing phase on rigid surface in Figure 4) and were exported to text files for further data processing in Microsoft Excel.

For the MVIC analysis, the beginning, and the ending event of muscle contraction of each channel had to be created before exporting the data in C3D file. Then opened the C3D file in the Visual 3D software and full-wave rectified the data with a low-pass filter. Matching the MVIC test with the correct muscle channel and plotting a group. 10 groups were plotted (as shown in Figure 5) and exported to text files for the rest of the data processing in Microsoft Excel.

For the last stage of data analysis, all EMG data was inserted into Microsoft Excel to be calculated. 2 main findings of landing included 1) The average of the maximum of each landing trial and 2) The mean of the average of each landing trial. The maximum value between the two trials of each MVIC test served as the primary results of the contraction exercise. The final EMG Data that was used to present the biomechanical parameter was expressed as ‘Percentages of MVIC’.

Figure 1

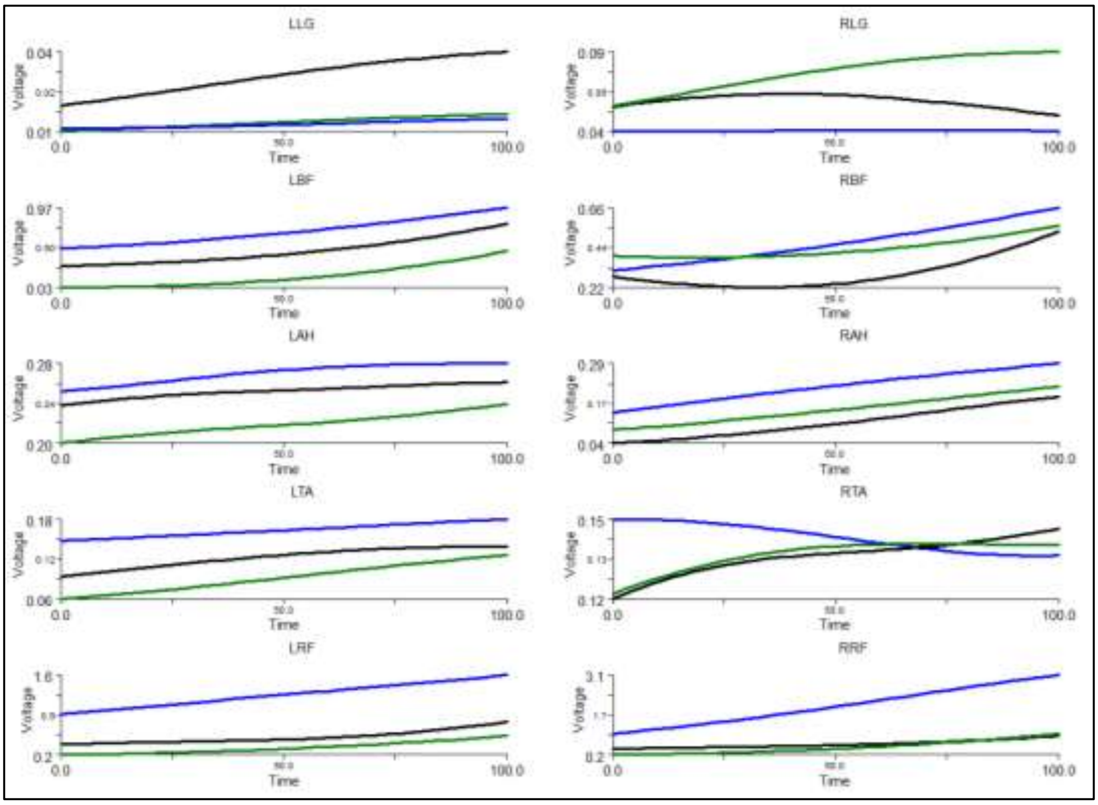
Preparation Phase (Take Off - Initial Contact) of Landing on SAND



Note: Abbreviations are as follows: LLG = Left Lateral *G*astrocnemius; LBF = Left Biceps femoris; LAH = Left Abductor halluces; LTA = Left Tibialis anterior; LRF = Left Rectus femoris; RLG = Right Lateral *G*astrocnemius*;* RBF =Right Biceps femoris; RAH = Right Abductor halluces; RTA = Right Tibialis anterior; RRF = Right Rectus femoris.

Figure 2

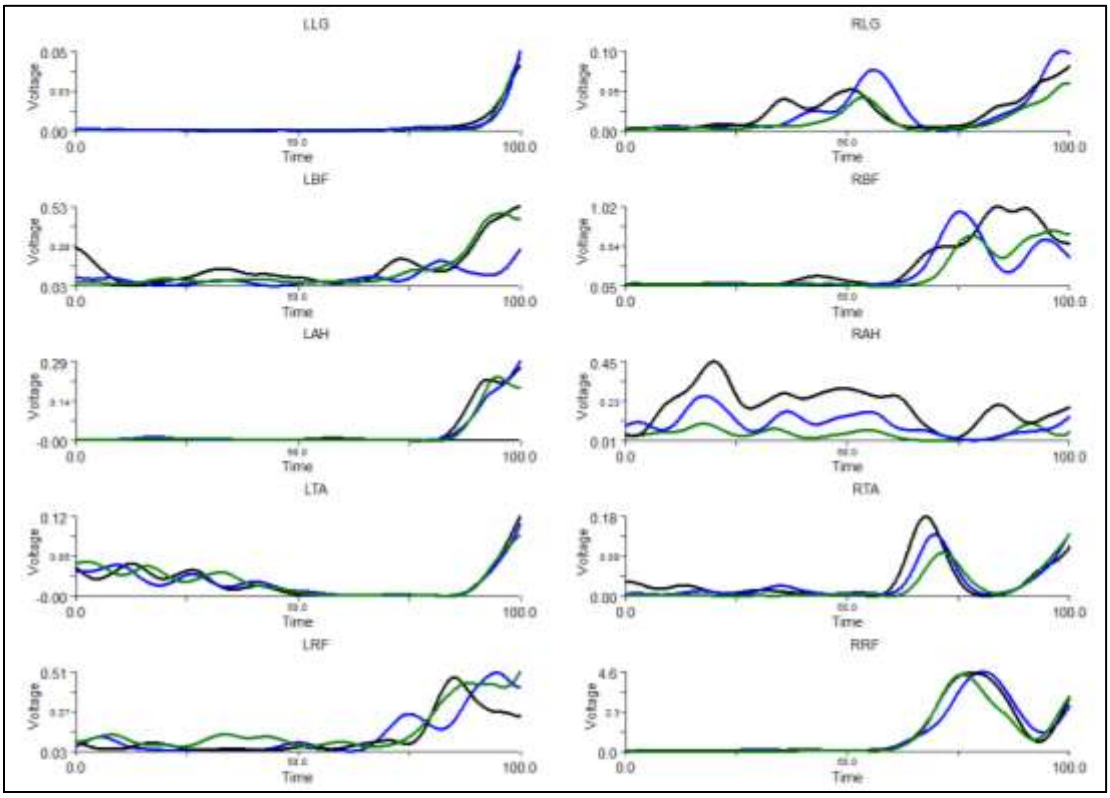
Landing Phase (Initial Contact - Full Contact) of Landing on SAND



Note: Line in black represents the first trial; Line in blue represents the second trial; Line in green represents the third trial. Abbreviations are as follows: LLG = Left Lateral *G*astrocnemius; LBF = Left Biceps femoris; LAH = Left Abductor halluces; LTA = Left Tibialis anterior; LRF = Left Rectus femoris; RLG = Right Lateral *G*astrocnemius*;* RBF =Right Biceps femoris; RAH = Right Abductor halluces; RTA = Right Tibialis anterior; RRF = Right Rectus femoris.

Figure 3

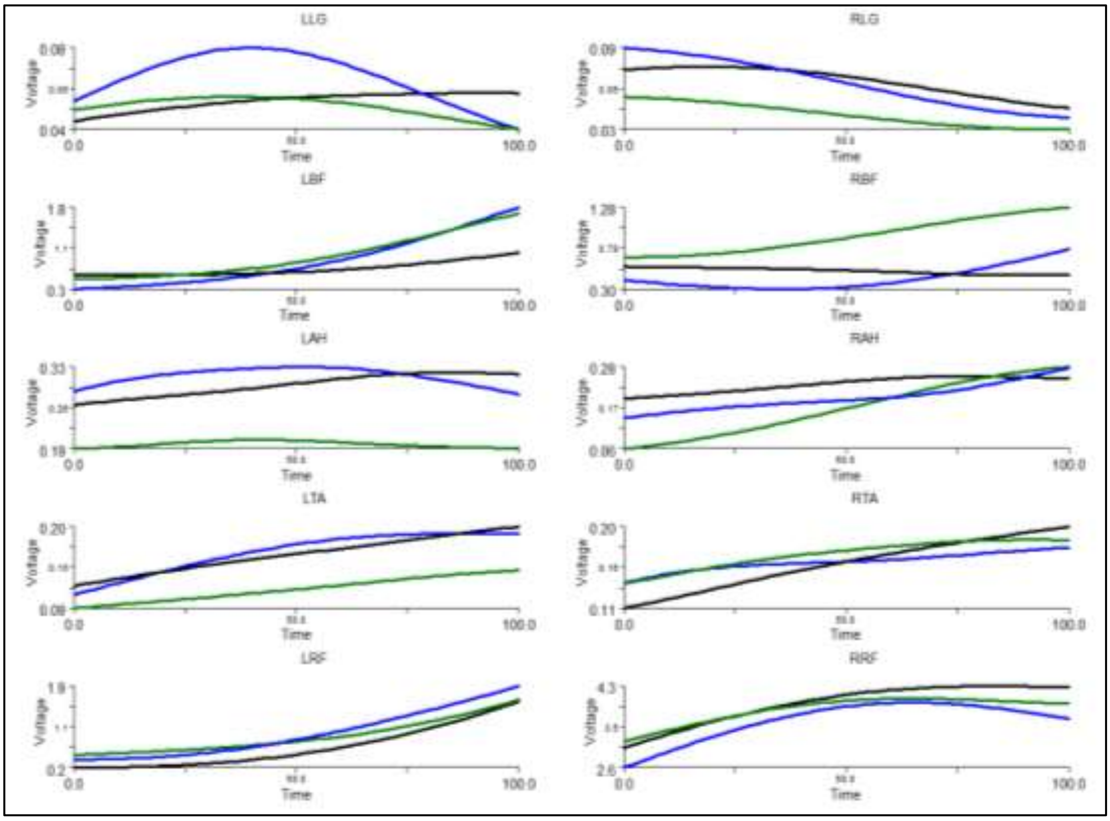
Preparation Phase (Take Off - Initial Contact) of Landing on RIGID



Note: Line in black represents the first trial; Line in blue represents the second trial; Line in green represents the third trial. Abbreviations are as follows: LLG = Left Lateral *G*astrocnemius; LBF = Left Biceps femoris; LAH = Left Abductor halluces; LTA = Left Tibialis anterior; LRF = Left Rectus femoris; RLG = Right Lateral *G*astrocnemius*;* RBF =Right Biceps femoris; RAH = Right Abductor halluces; RTA = Right Tibialis anterior; RRF = Right Rectus femoris.

Figure 4

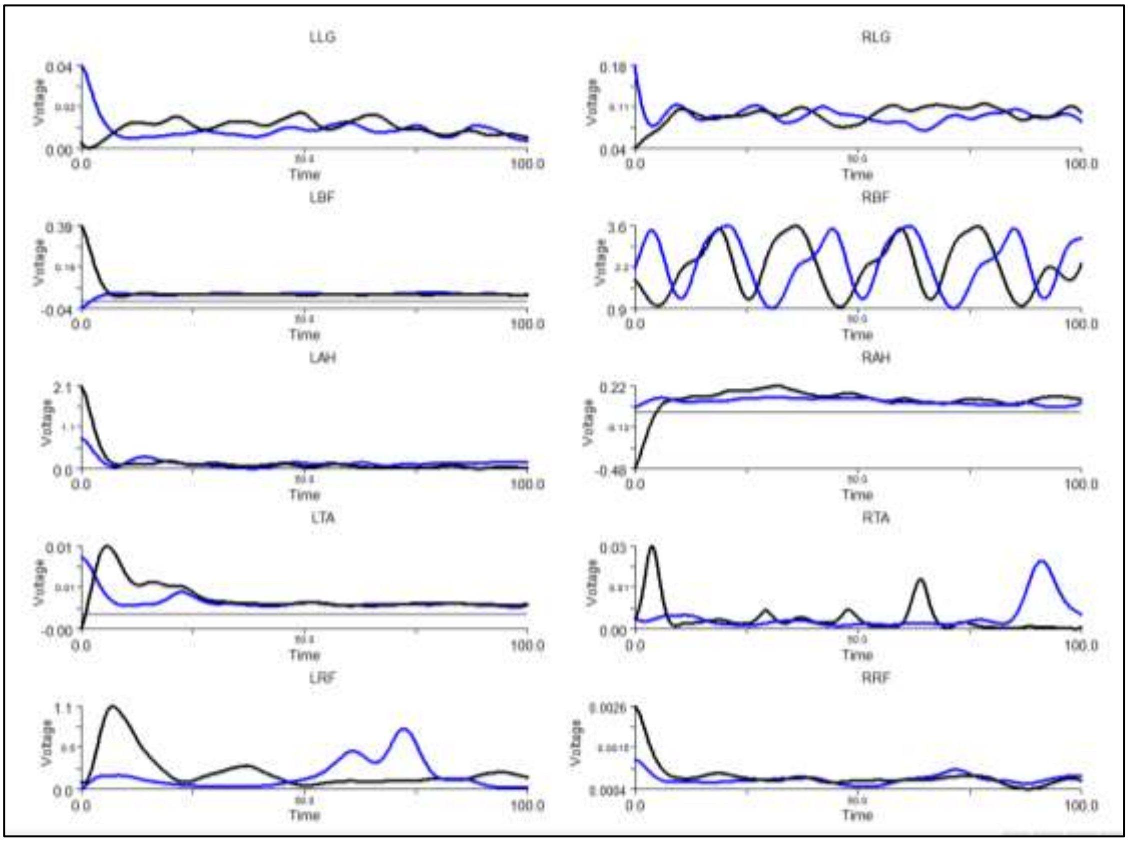
Landing Phase (Initial Contact - Full Contact) of Landing on RIGID



Note: Line in black represents the first trial; Line in blue represents the second trial; Line in green represents the third trial. Abbreviations are as follows: LLG = Left Lateral *G*astrocnemius; LBF = Left Biceps femoris; LAH = Left Abductor halluces; LTA = Left Tibialis anterior; LRF = Left Rectus femoris; RLG = Right Lateral *G*astrocnemius*;* RBF =Right Biceps femoris; RAH = Right Abductor halluces; RTA = Right Tibialis anterior; RRF = Right Rectus femoris.

Figure 5

The MVIC Test



Note: Line in black represents the first trial; Line in blue represents the second trial. Abbreviations are as follows: LLG = Left Lateral *G*astrocnemius; LBF = Left Biceps femoris; LAH = Left Abductor halluces; LTA = Left Tibialis anterior; LRF = Left Rectus femoris; RLG = Right Lateral *G*astrocnemius*;* RBF =Right Biceps femoris; RAH = Right Abductor halluces; RTA = Right Tibialis anterior; RRF = Right Rectus femoris.

2.4.1 Statistical Analysis

All statistical analyses were carried out using the JASP 0.16.1 (JASP, Amsterdam, The Netherlands) software. Baseline group comparison on demographic features and foot types were confirmed using the independent t-test for numerical data. Using a 2 (group: flatfoot group, normal group) x 2 (landing surface: sandpit, wooden plate) x 2 (side: left, right) ANOVA on the dependent variables: the peak and the mean muscle activation pattern to illustrate the biomechanical parameter. A 3-way repeated measure ANOVA with mixed samples was used to compare the biomechanical differences in the muscle activation pattern of the lower extremity between flatfoot and normal participants depending on the landing surface. Statistical significance was agreed for all p-values <0.05.

2.5 Experimental Instrumentation

2.5.1 The Sandpit

The landing on RIGID condition was performed on the wooden plate. To examine the landing on the SAND condition, a wooden pit (length: 63cm; width: 59cm; height: 31cm) with 1.8 cm thickness was constructed to contain the sand particles. To protect participants from faulted landings, a corner protector was used to cover the boundaries of the sandpit. Plastic sheets surrounded the sandbox (3m x 3m). The sand used in the experiment was collected from the Cafeteria Old Beach that was used for the local beach volleyball tournaments. The weight of the wooden pit was 2 kg. The total weight of the sandbox, including sand, came to 130kg.

2.5.2 The Orthoprint

The Orthoprint used to conduct the footprint measurement was borrowed from the Prosthetic and Orthotic Department of the Prince of Wales Hospital. The Orthoprint is comprised of two parts: the top with a piece of elastic fiber that the foot contacts with and the bottom is the plate where a paper sheet can be placed to print the footprint. The ink roll in the middle of the printer was used to spread the ink on the fiber for footprint measurement. The top with a piece of the footprint was taken under the normal walking with the heel making initial contact with the inked platform, which then left a footprint on the paper sheet. Participants began with two feet behind the foot printer, and then stepped one foot onto the platform, with the weight transferring from heel to toe. The other foot remained put and only took one step forward as the printing foot was about to leave the plate. Printing was only considered to be complete when the latter printing foot was removed entirely from the Orthoprint.

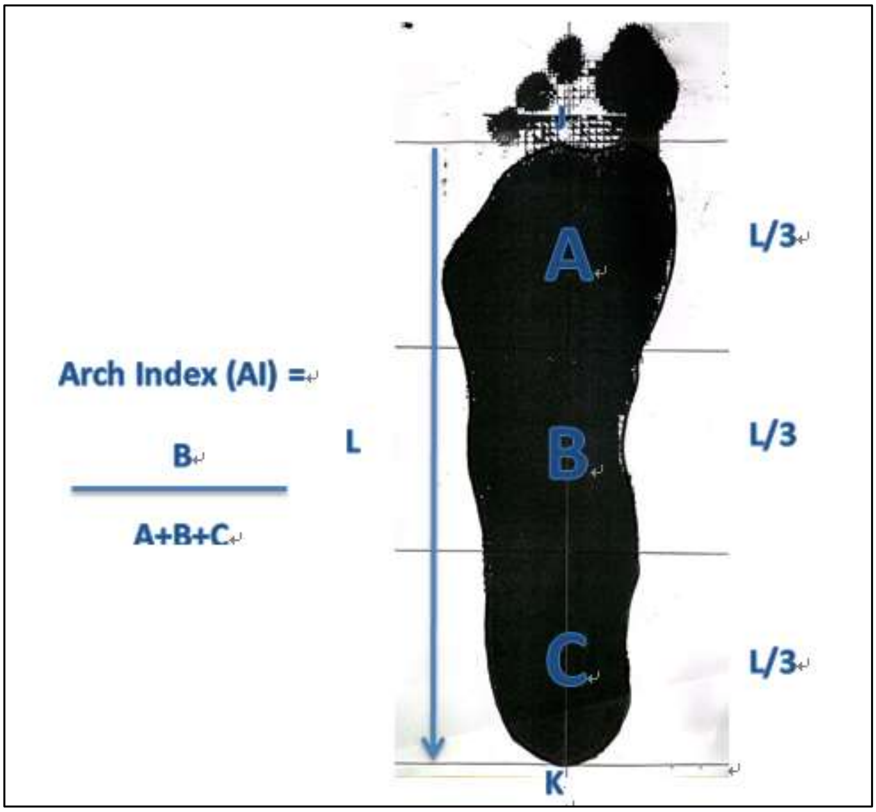
To calculate the foot arch index, a line, known as the ‘foot axis’, was first drawn from the tip of the second toe (point J in Figure 1) to the midpoint of the heel (point K in Figure 1). Then, in front of the metatarsal heads, a line perpendicular to the axis is drawn, tangential to the most anterior part of the footprint contour. Point J is the intersection point that crosses these two lines (*see* Figure 1). Then, line JK was separated into three equal parts with the toes (*see* Figure 1). Three perpendicular lines to the foot axis are drawn along line JK, dividing the entire foot into three regains: the forefoot (A), the midfoot (B) and the hindfoot (C). The sum of the whole footprint is A + B + C (*see* Figure 1) and the area in the midfoot (B) (shown in Figure 2) were then identified. Lastly, the foot type of a participant was calculated using the formula for the arch index (AI) (Cavanagh and Rodgers, 1987). AI is defined as the ratio of the middle third to the whole foot toeless footprint area (Fu et al., 2016). According to Cavanagh and Rodgers (1987), the calculation of Al is:

$$\text{arch index} = \frac{B}{A+B+C}$$

Based on their respective AI, participants received confirmation regarding their belonging group. The three-foot type classification, suggested by Cavanagh and Rodgers (1987), is as follows: high arch = AI ≤ 0.21; normal arch = 0.21 < AI < 0.26; flat arch = AI ≥0.26.

Figure 6

Arch index



Note: The footprint was taken on the Orthoprint and a paper sheet. The points *J* and *K* are identified as the tip of the second toe and the center of the heel. The footprint is outlined using a marker excluding the toes. The footprint is then divided into equal three parts by parallel lines which are perpendicular to the line JK. The arch index (AI) is presented as the ratio of the midfoot area *B* to the area of the whole foot without the toes (*A* + *B* + *C*). This was a flat arch with AI = 0.33.

3. RESULTS

In total, 12 males, comprised of 8 flat-footed participants and 4 normal-footed participants conducted the test. *Table 2* summarizes the demographic information, such as age, height, body weight and BMI, including the foot arch index in two groups. *Table 3* showed that there was no significant difference between both groups in the comparison of age, height, body weight or BMI ($p > 0.05$). However, the foot arch of the flat foot was significantly greater than the normal group ($p < 0.05$).

There are two important values of biomechanical parameters that it is focusing on in the present report, which are 1) the average of the maximum (Max) of each landing trial and 2) The mean of the average (Mean) of each landing trial. With no doubt, referring to all the figures of Max, there was no significant difference between both groups in terms of the average of the maximum of landing neither during the preparation phase (PP) nor the landing phase (LP) ($p > 0.05$). In a narrow comparison, the effect size within the subject, there was no significant interaction neither during PP nor LP in general ($p > 0.05$) apart from the surface effect in LG and TA. *Figure 7 and 8* showed that there was significant difference in LG either at PP or LP with subject effect ($p < 0.05$) and the significant difference existed in the relationship between side and surface on TA during the landing phase ($p < 0.05$) (in *Figure* 12). Referring to the descriptive plots of each muscle group in *Figure* 19, it concluded that all testing muscles of the flat-footed group contracted more on the fixed surface than the sand landing platform at both landing phases. Meanwhile, more muscle contractions occurred on the rigid plate than the sand surface during PP and LP on the normal group in general except the muscle activities of AH, which was a lot more contractions spent on the sand surface than the fixed plate. To compare the contraction load between two groups, the normal group had greater EMG amplitude than the flat foot group apart from the situation under the preparation phase in LG, in which the muscle activation pattern of the flat foot group vibrated more than the normal participants. Considering the muscle activation pattern among groups, there was different distribution of load among different muscle groups. In LG, specific to PP, the flat foot group contracted more on the left than the right on both landing surfaces than the normal group. However, in the landing phase, with the same situation, the flatfoot group contracted greater than the normal group, but RLG had a higher EMG value than LLG on sand performance; everything reversed when performing on fixed plate. In AH, normal participants had higher contraction of LAH than RAH on the sand surface at any phases and on the rigid plate at PP. Flat-footed participants contracted more on LAH than RAH on the rigid surface during the LP. In TA, the normal-footed group had a greater muscle activation pattern on LTA than RTA on any surfaces and periods. Coming to the comparison of the muscle activities between left and right leg within the group, the left leg of people with flat feet contracted greater than the right leg on both landing surfaces at different landing phases without the only occasion at the LP in LG in which the muscle stress switched to right on both landing phases. However, the contraction distribution in the normal group was different. Usually, normal participants contracted the muscle of the left leg more than the right leg when landing onto the sand and rigid surface regardless of any landing phase. However, higher EMG amplitude of RLG was recorded than the right leg when landing on the rigid plate at either preparation or landing phase; the contraction focus of AH switched from the left to right side from PP to LP while landing on the rigid surface, which meant that the muscle of right leg was more activated than the left side muscles. TA had the highest EMG value among three muscles on both groups

The mean of the average (Mean) is another indicator of the biomechanical parameter. According to all the figures of Mean, there was no significant difference between both groups in terms of the mean of the average of landing neither during PP nor LP ($p > 0.05$). Compared to the effect size within the subject, in general, there was also no significant interaction neither during PP nor LP ($p > 0.05$). However, the data in LG at LP revealed that there was a significant effect within the subject on the surface (p

< 0.05) (in *Figure 14*). The descriptive plots of each muscle group (in *Figure 20*) made a one-sided summary that all targeting muscles of the flat-footed group contracted more on the fixed surface than on the sand landing platform at both landing phases. On another side, normal footed participants had greater EMD value on the landing performance on the rigid plate than the sand surface during PP and LP under the exception of the muscle activities of AH, in which a lot more contractions occurred on the sand platform than the fixed plate. Doing the comparison of the EMG value between two groups, the normal group had greater EMG amplitude than the flat foot group completely. Considering the muscle activation patterns of different groupings, the distribution of load fluctuated. In LG, coming to PP, the normal foot group contracted more on RLG than LLG on both landing surfaces than the flat foot group. However, everything changed in the landing phase, flat-footed participants dominated higher muscle contraction than the normal-footed participant on the LLG than RLG on both landing surfaces. In AH, the normal group had higher contraction of LAH than RAH on the sand surface at any phase; higher amplitude on RAH than LAH on the rigid plate at PP. Flat-footed participants contracted more on LAH than RAH on the rigid surface during LP. In TA, the normal-footed group had a greater muscle activation pattern on LTA than RTA on any surfaces and periods besides the performance on a rigid plate at LP, which the Mean value was greater on RTA than LTA. When it comes

to comparing the muscular activity of the left and right legs within the same group, there was an overwhelming conclusion reported that the contraction pressure was distributed more highly on the left leg than the right leg with people flat-footed on any landing surfaces and landing phases. However, it was hard to tell a united conclusion regarding the normal group performance. In LG, normal participants contracted more on the RLG than LLG at different situations. In AH, higher EMG amplitude of RAH than LAH on a rigid surface happened on both landing phases but the distribution focus changed to left when performing on sand surface happened on both landing phases. In TA, vibration of LTA greater than RTA at PP on both landing surfaces and on the sand surface at LP in the normal group whereas RTA contracted more than LTA at LP when landing on the fixed plate. TA had the highest EMG value among three muscles on both groups

Table 2

Demographic and Foot Type of All Participants

	Group	N	Mean	SD	SE
Age (years)	F	8	27.837	5.636	1.993
	N	4	26.075	5.083	2.541
Height (cm)	F	8	188.625	6.140	2.171
	N	4	186.750	11.147	5.573
Body Weight (kg)	F	8	83.612	7.827	2.767
	N	4	82.725	15.781	7.890

Table 2

Demographic and Foot Type of All Participants

	Group	N	Mean	SD	SE
BMI	F	8	23.413	1.618	0.572
	N	4	23.550	2.625	1.312
Arch index	F	8	0.304	0.027	0.010
	N	4	0.230	0.008	0.004

Table 3

Demographic and Foot Type of All Participants

	t	df	p
Age(years)	0.526	10	0.611
Height(cm)	0.384	10	0.709
Body Weight (kg)	0.134	10	0.896
BMI	-0.114	10	0.912
Arch index	5.189	10	< .001

Note: The significance of independent samples t-test is set at the $p < 0.05$ level.

Figure 7

LG Max of Perpetration Phase

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
side	2246.342	1	2246.342	0.826	0.385	0.076
side ∗ Group	8251.413	1	8251.413	3.035	0.112	0.233
Residuals	27186.178	10	2718.618			
surface	14240.369	1	14240.369	8.470	0.016	0.459
surface ∗ Group	2061.833	1	2061.833	1.226	0.294	0.109
Residuals	16812.155	10	1681.216			
side ∗ surface	1705.558	1	1705.558	1.798	0.210	0.152
side ∗ surface ∗ Group	572.522	1	572.522	0.604	0.455	0.057
Residuals	9483.224	10	948.322			

Note: The significance of independent samples t-test is set at the p< 0.05 level.

Between Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
Group	23.128	1	23.128	0.002	0.962	2.370e-4
Residuals	97546.597	10	9754.660			

Note: The significance of independent samples t-test is set at the p< 0.05 level.

Figure 8

LG Max of Landing Phase

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
side	2703.216	1	2703.216	0.129	0.727	0.013
side ✻ Group	1300.218	1	1300.218	0.062	0.808	0.006
Residuals	209433.861	10	20943.386			
surface	15181.043	1	15181.043	6.129	0.033	0.380
surface ✻ Group	6502.688	1	6502.688	2.625	0.136	0.208
Residuals	24767.688	10	2476.769			
side ✻ surface	2601.667	1	2601.667	1.611	0.233	0.139
side ✻ surface ✻ Group	5560.170	1	5560.170	3.443	0.093	0.256
Residuals	16147.533	10	1614.753			

Note: The significance of independent samples t-test is set at the $p < 0.05$ level.

Between Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
Group	1776.760	1	1776.760	0.055	0.819	0.006
Residuals	320447.816	10	32044.782			

Note: The significance of independent samples t-test is set at the $p < 0.05$ level.

Figure 9

AH Max of Preparation Phase

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
side	84199.591	1	84199.591	2.317	0.159	0.188
side ∗ GROUP	3776.923	1	3776.923	0.104	0.754	0.010
Residuals	363397.969	10	36339.797			
surface	5039.767	1	5039.767	0.177	0.683	0.017
surface ∗ GROUP	9340.774	1	9340.774	0.329	0.579	0.032
Residuals	284203.459	10	28420.346			
side ∗ surface	17199.457	1	17199.457	0.732	0.412	0.068
side ∗ surface ∗ GROUP	18566.791	1	18566.791	0.790	0.395	0.073
Residuals	234966.830	10	23496.683			

Note: The significance of independent samples t-test is set at the $p < 0.05$ level.

Between Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
GROUP	114503.555	1	114503.555	3.083	0.110	0.236
Residuals	371443.768	10	37144.377			

Note: The significance of independent samples t-test is set at the $p < 0.05$ level.

Figure 10

AH Max of Landing Phase

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
side	122595.350	1	122595.350	0.930	0.358	0.085
side ∗ GROUP	19313.729	1	19313.729	0.146	0.710	0.014
Residuals	1.318e+6	10	131844.632			
surface	58461.985	1	58461.985	1.618	0.232	0.139
surface ∗ GROUP	119381.899	1	119381.899	3.304	0.099	0.248
Residuals	361367.802	10	36136.780			
side ∗ surface	43988.131	1	43988.131	1.139	0.311	0.102
side ∗ surface ∗ GROUP	88185.127	1	88185.127	2.284	0.162	0.186
Residuals	386104.018	10	38610.402			

Note: The significance of independent samples t-test is set at the $p < 0.05$ level.

Between Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
GROUP	53807.593	1	53807.593	0.501	0.495	0.048
Residuals	1.075e+6	10	107451.856			

Note: The significance of independent samples t-test is set at the $p < 0.05$ level.

Figure 11

TA Max of Preparation Phase

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η²
side	7.558e+6	1	7.558e+6	3.992	0.074	0.036
side ∗ Group	6.651e+6	1	6.651e+6	3.513	0.090	0.032
Residuals	1.893e+7	10	1.893e+6			
surface	73299.075	1	73299.075	2.986	0.115	3.514e-4
surface ∗ Group	1431.597	1	1431.597	0.058	0.814	6.863e-6
Residuals	245489.667	10	24548.967			
side ∗ surface	48312.427	1	48312.427	4.487	0.060	2.316e-4
side ∗ surface ∗ Group	28440.558	1	28440.558	2.642	0.135	1.363e-4
Residuals	107665.473	10	10766.547			

Note: The significance of independent samples t-test is set at the p< 0.05 level.

Between Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η²
Group	3.593e+7	1	3.593e+7	2.585	0.139	0.172
Residuals	1.390e+8	10	1.390e+7			

Note: The significance of independent samples t-test is set at the p< 0.05 level.

Figure 12

TA Max of Landing Phase

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η²
side	1.797e+7	1	1.797e+7	2.355	0.156	0.039
side ✻ Group	1.685e+7	1	1.685e+7	2.207	0.168	0.036
Residuals	7.632e+7	10	7.632e+6			
surface	1.241e+6	1	1.241e+6	4.839	0.052	0.003
surface ✻ Group	946867.224	1	946867.224	3.693	0.084	0.002
Residuals	2.564e+6	10	256373.484			
side ✻ surface	186864.966	1	186864.966	6.200	0.032	4.024e-4
side ✻ surface ✻ Group	126977.126	1	126977.126	4.213	0.067	2.735e-4
Residuals	301404.018	10	30140.402			

Note: The significance of independent samples t-test is set at the $p< 0.05$ level.

Between Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η²
Group	6.397e+7	1	6.397e+7	2.254	0.164	0.138
Residuals	2.838e+8	10	2.838e+7			

Note: The significance of independent samples t-test is set at the $p< 0.05$ level.

Figure 13

LG Mean of Preparation Phase

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
side	337.913	1	337.913	0.468	0.510	0.045
side ∗ GROUP	997.235	1	997.235	1.380	0.267	0.121
Residuals	7225.914	10	722.591			
surface	549.749	1	549.749	3.412	0.095	0.254
surface ∗ GROUP	411.475	1	411.475	2.553	0.141	0.203
Residuals	1611.443	10	161.144			
side ∗ surface	390.951	1	390.951	2.543	0.142	0.203
side ∗ surface ∗ GROUP	572.864	1	572.864	3.726	0.082	0.271
Residuals	1537.519	10	153.752			

Note: The significance of independent samples t-test is set at the $p < 0.05$ level.

Between Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
GROUP	1039.706	1	1039.706	3.939	0.075	0.283
Residuals	2639.246	10	263.925			

Note: The significance of independent samples t-test is set at the $p < 0.05$ level.

Figure 14

LG Mean of Landing Phase

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
side	3137.993	1	3137.993	0.459	0.513	0.044
side ∗ GROUP	5921.099	1	5921.099	0.867	0.374	0.080
Residuals	68302.265	10	6830.226			
surface	1705.726	1	1705.726	6.170	0.032	0.382
surface ∗ GROUP	15.344	1	15.344	0.055	0.819	0.006
Residuals	2764.706	10	276.471			
side ∗ surface	5.900	1	5.900	0.034	0.858	0.003
side ∗ surface ∗ GROUP	151.705	1	151.705	0.863	0.375	0.079
Residuals	1758.226	10	175.823			

Note: The significance of independent samples t-test is set at the $p< 0.05$ level.

Between Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
GROUP	2054.240	1	2054.240	0.285	0.605	0.028
Residuals	72071.120	10	7207.112			

Note: The significance of independent samples t-test is set at the $p< 0.05$ level.

Figure 15

AH Mean of Preparation Phase

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
side	378.937	1	378.937	0.082	0.780	0.008
side ✻ GROUP	430.149	1	430.149	0.093	0.767	0.009
Residuals	46204.618	10	4620.462			
surface	453.836	1	453.836	0.512	0.491	0.049
surface ✻ GROUP	310.716	1	310.716	0.351	0.567	0.034
Residuals	8862.551	10	886.255			
side ✻ surface	1745.665	1	1745.665	2.592	0.138	0.206
side ✻ surface ✻ GROUP	2900.371	1	2900.371	4.307	0.065	0.301
Residuals	6734.783	10	673.478			

Note: The significance of independent samples t-test is set at the $p < 0.05$ level.

Between Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
GROUP	3510.332	1	3510.332	1.444	0.257	0.126
Residuals	24305.774	10	2430.577			

Note: The significance of independent samples t-test is set at the $p < 0.05$ level.

Figure 16

AH Mean of Landing Phase

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
side	39011.616	1	39011.616	0.926	0.359	0.085
side ∗ GROUP	10265.345	1	10265.345	0.244	0.632	0.024
Residuals	421404.817	10	42140.482			
surface	18258.788	1	18258.788	1.576	0.238	0.136
surface ∗ GROUP	29093.155	1	29093.155	2.511	0.144	0.201
Residuals	115873.024	10	11587.302			
side ∗ surface	18795.006	1	18795.006	1.679	0.224	0.144
side ∗ surface ∗ GROUP	29315.711	1	29315.711	2.618	0.137	0.207
Residuals	111965.295	10	11196.529			

Note: The significance of independent samples t-test is set at the $p < 0.05$ level.

Between Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
GROUP	20769.049	1	20769.049	0.561	0.471	0.053
Residuals	370199.259	10	37019.926			

Note: The significance of independent samples t-test is set at the $p < 0.05$ level.

Figure 17

TA Mean of Preparation Phase

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
side	191970.439	1	191970.439	3.706	0.083	0.270
side ✻ Group	191277.044	1	191277.044	3.693	0.084	0.270
Residuals	518014.300	10	51801.430			
surface	9542.486	1	9542.486	2.565	0.140	0.204
surface ✻ Group	2567.629	1	2567.629	0.690	0.426	0.065
Residuals	37208.804	10	3720.880			
side ✻ surface	6123.857	1	6123.857	2.390	0.153	0.193
side ✻ surface ✻ Group	5643.587	1	5643.587	2.203	0.169	0.180
Residuals	25623.091	10	2562.309			

Note: The significance of independent samples t-test is set at the p< 0.05 level.

Between Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
Group	1.139e+6	1	1.139e+6	2.521	0.143	0.201
Residuals	4.517e+6	10	451683.456			

Note: The significance of independent samples t-test is set at the p< 0.05 level.

Figure 18

TA Mean of Landing Phase

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
side	558009.709	1	558009.709	3.048	0.111	0.234
side ✻ Group	322925.440	1	322925.440	1.764	0.214	0.150
Residuals	1.831e+6	10	183103.298			
surface	3.938e+6	1	3.938e+6	1.732	0.217	0.148
surface ✻ Group	4.439e+6	1	4.439e+6	1.953	0.193	0.163
Residuals	2.273e+7	10	2.273e+6			
side ✻ surface	5.824e+6	1	5.824e+6	1.991	0.189	0.166
side ✻ surface ✻ Group	6.055e+6	1	6.055e+6	2.070	0.181	0.172
Residuals	2.925e+7	10	2.925e+6			

Note: The significance of independent samples t-test is set at the $p < 0.05$ level.

Between Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
Group	1.696e+7	1	1.696e+7	2.217	0.167	0.181
Residuals	7.649e+7	10	7.649e+6			

Note: The significance of independent samples t-test is set at the $p < 0.05$ level.

Figure 19

The Descriptive Plot of the Max of Each Muscle

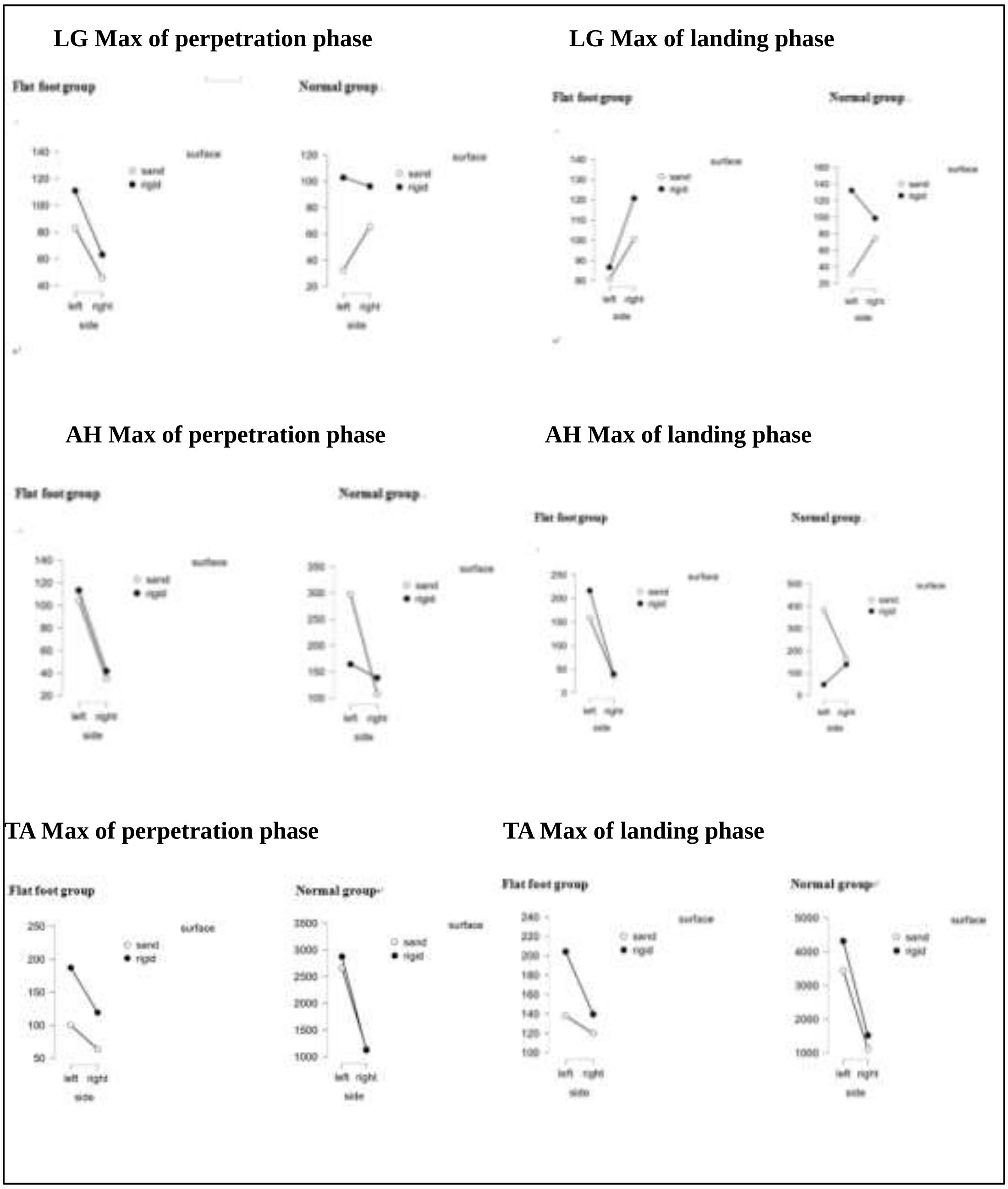
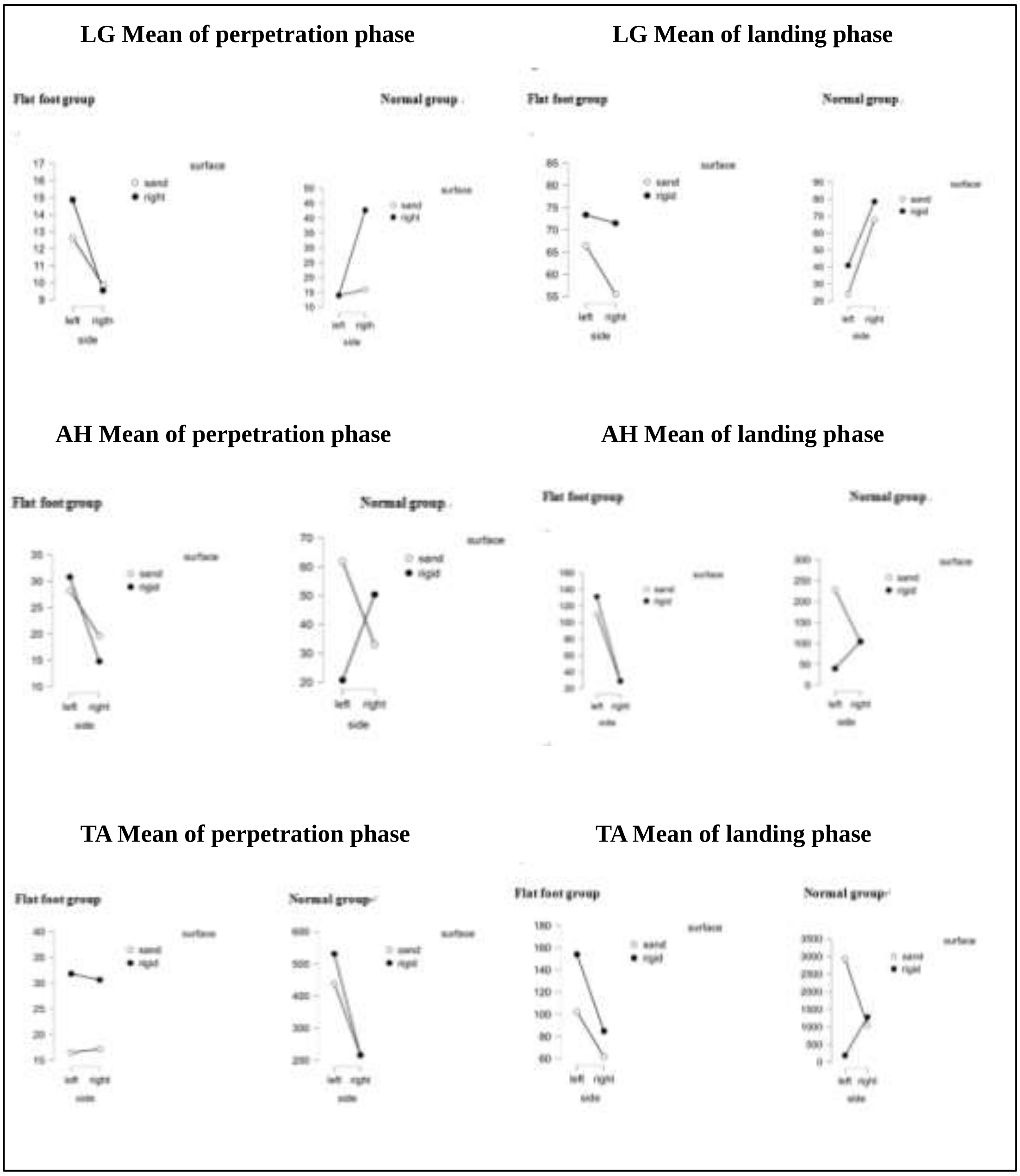


Figure 20

The Descriptive Plot of the Mean of Each Muscle



4. DISCUSSION

The present study compares the muscle activation pattern between flat-footed and normal-footed participants on sand and rigid surfaces on a drop landing test from a 60 cm-high platform. Results revealed that the EMG Max finding showed an insignificant difference between two groups. Meanwhile, the EMG Mean findings also showed no significant difference between the two groups, reflecting that extreme data was did not exist in research studies.

The Max and Mean results revealed that no drastic muscle load on flatfooted participant. However interestingly, referring to the descriptive plots, LG, AH and TA of normal–footed participants were more activated than that of flat-footed participants. This may imply that athletes with normal foot carry greater loads in their lower extremities than flat foot athletes.

The EMG value showed that TA was the most activated muscle of both groups, specifically at LP. This may be due to the fact that TA is an important muscle in maintaining movement and balancing the ankle joint, and when activated, is most significant among the three muscles used to maintain movement and balance at the landing phase (Jeon, 2020).

There was a significant effect within subjects on both surfaces in LG at both landing phases, meaning that the activation pattern of LG had large difference on sand and rigid surfaces respectively. It may be due to muscle contraction with the concentric of the LG on the initial and full contact. However, it is worth noting that LG contracts with different patterns when landing on different surfaces. Higher EMG value of landing on the rigid surface in the flat foot group reflected a problem in the low arch. Reduction of the structure elasticity may lead to FG needing to contract other muscles to maintain movement and balance posture.

The above findings serve as a reminder to flat-footed athletes that landing on rigid surfaces may cause greater load versus landing on sand surfaces. In contrast, normal groups had higher EMG value of landing on sand surface. This may contribute to the elasticity feature of the arch since people with normal foot are able to contract the AH when landing (Chang et al., 2012).

5. CONCLUSION AND LIMITATIONS

In conclusion, the EMG data revealed that no significant difference was detected between the biomechanical differences in the muscle activation patterns in flat-footed and normal-footed elite athletes on sand and rigid surfaces on a drop landing test from a 60 cm-high platform. Thus, it can be interpreted that flat foot athletes may not be at a disadvantage with foot deformity when performing landing motions. Results also imply the possibility of a lack of difference in the training design for flat-footed and normal-footed athletes since injury prevention caused by landing would not be a serious concern for flat-footed athletes.

Alternatively, the author suggests that prevention can be done via the adoption of short foot exercises to restructure the arch to build up the ability in transferring weight, absorbing shock, and distributing load pressure among flatfoot athletes. However, it can be acknowledged that relevant findings are currently unable to generate a strong conclusion due to the small sample size and uneven ratio of the comparison groups (8:4). In addition, with the improper data collection method, the data of BF and RF had to be rejected, which may affect the results of the study. Further research points towards an increase in number of participants with an even ratio and proper data collection procedure.

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