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SHORT COMMUNICATION

BIOMECHANICAL ANALYSIS OF COUNTERMOVEMENT JUMP PERFORMANCE AMONG SPORTS PLAYERS WITH FLATFOOT AND NORMAL FOOT STRUCTURES

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ABSTRACT

The purpose of this study was to compare the kinetic parameters of counter-movement jump between sports players in flatfoot and normal foot groups. In this cross-sectional study, random sampling method was used to draw a group of 20 players with normal foot and a group of 20 players with flatfoot. Navicular drop test was used to classify two groups (flat foot and normal foot). Quattro Jump Kistler force platform (model 9290DD) was used to record kinetic parameters of Countermovement jump. The findings of this study showed that the players with flatfoot exhibited higher peak vertical ground reaction forces (VGRFs) ($p < 0.001$) and lower push-off force impulse ($p < 0.001$) than players in normal foot group; however, no significant differences were observed in jump height and average force between the normal foot and flatfoot groups ($p > 0.05$). The results revealed that flatfoot has no effect on jump height but have significant impact on other kinetic parameters of jump performance. Players with flatfoot produced higher VGRFs during landing which may lead to greater forces imposed on foot region as compared to the players with normal foot which can induce various musculoskeletal injuries.

Keywords: Countermovement jump, flatfoot, kinetics, Quattro Jump Kistler force platform

INTRODUCTION

Jumping is considered one of the foremost common manoeuvres performed by sports players. The countermovement jump (CMJ) is a highly-used movement to help coaches to assess the performance changes (Chavda *et al.*, 2018). CMJ is used to assess the athletic performance of lower limbs and is appealing for being quick to perform, non-fatiguing and requires minimal familiarization, yet it can yield valuable insight into an athlete's neuromuscular function and stretch-shortening cycle capabilities (McMahon *et al.*, 2018; Aragón, 2000). An athlete's CMJ performance is relevant in a variety of sports and is commonly quantified by jump height or flight time, which is considered as an indicator of vertical jump performance (Rago *et al.*, 2018). Force-time curves of CMJ contain kinetic information that can be accurately assessed provides valid and reliable results using a force platform (Laffaye *et al.*, 2014). CMJ performance is typically defined by vertical jump height. Although jump height provides gross performance and physical readiness information, it fails to characterize explosiveness because it does not account for temporal and rapid force production characteristics of CMJ (Krzyszkowski *et al.*, 2022).

The lower extremities are prone to injury if there is any form of structural abnormalities, such as flatfoot (Arastoo *et al.*, 2014). Flatfoot incorporates insufficiency of longitudinal arch in mid foot and medial mid foot collapse, bulging medial foot margin, and hind foot valgus (Tang *et al.*, 2015). Flat feet should not simply be seen as a static alignment problem of ankle-foot complex; it might also be the result of a dynamic functional alteration in the lower limb (Arastoo *et al.*, 2014). There is a specific relationship between arch types and sports injuries (Chang *et al.*, 2010). The flatfoot results in abnormal loading and rotational stresses on the foot and lower extremity that lead to injury when subjected to the stress of athletic endeavours (Michelson *et al.*, 2002, Ho *et al.*, 2019). However, the association between flatfeet and jumping performance has not been fully investigated (Fu *et al.*, 2016). A few studies have compared kinetic parameters among the players with flatfoot and normal foot during jumping tasks. In sports training, small differences in kinetic parameters between athletes of similar performance levels can decide success or failure in sports. Thus, this study was aimed to investigate the differences in kinetic parameters of the countermovement jump among various sports players with and without flatfoot.

MATERIALS AND METHODS

In this cross-sectional study, 40 players (20 flatfoot and 20 normal foot subjects) were recruited according to the inclusion and exclusion criteria. These 40 players were selected using random sampling method from group of 160 volunteer male team sports players (basketball, volleyball and football) in Guru Nanak Dev University, Amritsar, Punjab, India. Inclusion criteria were age between 18 and 24 years old and players were included if they had normal-arched foot or flat foot. Players were excluded if they reported a history of serious injuries, such as ligament tears, bone fractures, any operative treatment for the lower extremity and the presence of subjective symptoms that could interfere with jumping ability. Written informed consents were obtained from all the players before data collection. This study was approved by the Institutional Ethical Committee of Guru Nanak Dev University, Amritsar and conducted in accordance with the Declaration of Helsinki.

For analysis of countermovement jump performance, kinetic variables ($VGRF_S$, push-off force impulse, jump height and average force) were collected using the Kistler force platform at a frequency of 500 Hz. The values of all parameters were recorded using Kistler MARS software for Quattro jump. All players performed 10 min of warm up which included stretching exercise and 5 sub-maximal jumps. Players were instructed to complete the countermovement jump using preferred countermovement depths. All players performed three countermovement jump trails with hands on their hips and 2 min rest was provided between trials.

To identify the presence of flatfoot in the players, navicular drop test was adopted (Mueller *et al.*, 1993). A flat foot is defined as a foot that demonstrated a navicular drop of more than 1.0 cm. A normal-arched foot exhibits equal or less than 1.0 cm of navicular drop (Mueller *et al.*, 1993). We have ensured the foot is in the neutral position at the subtalar joint (position the patient so that their lower extremities are fully supported while they are standing). Then, measure the navicular tuberosity's distance from the supporting surface and mark the area that is most prominent (floor or step). Then, after obtaining the patient to relax position, use a ruler to measure the navicular's sagittal plane excursion. Alternately, the test can be run backward, measuring from a relaxed state all the way up to neutral talar position while standing (Menz et al., 1998; Deng et al., 2010). Based on the results of navicular drop test, the players were classified into normal foot group with navicular drop 4.10 ± 2.22 mm and flat foot group navicular drop 10.03 ± 2.22 mm.

Peak vertical ground reaction forces during landing are the instant of landing where the foot first contact the ground and the ground reaction force shows a sharp impact (Linthorne, 2001; Hargrave *et al.*, 2003). $VGRF_S$ were computed as maximum vertical force that was normalized by body weight.

Push-off force impulse is an integral of force with respect to time between lowest position and take-off, and the push-off phase is when the jumper moves upward by extending the knees and hips (Dufek *et al.*, 1991; Linthorne, 2001). Jump height is vertical displacement achieved by the COM from take-off to the vertex of the flight trajectory and it was calculated from flight time. Average force is a force generated during propulsive phase and it was calculated during the upward movement of CMJ.

Statistical analysis was performed using SPSS v26.0. Descriptive statistical methods were adopted to describe the variables. Shapiro-Wilk test was used to check normal distribution of data. Independent t-test to find differences in peak vertical ground reaction forces, push-off force impulse, jump height and average force between two groups. The effect sizes were interpreted following Cohen's guidelines (Cohen, 1988). Before performing the multivariate analysis of variance, the Levene's test was first used to determine the homogeneity of variances, but this test was not significant for any of the variables ($p \geq 0.05$). The significant level was set as ($p < 0.05$).

RESULTS AND DISCUSSION

The demographic characteristics of 40 players comprising of 20 normal foot subjects and 20 flatfoot subjects is presented in Table 1. Normal foot and flatfoot groups showed navicular drop of 4.10 ± 2.22 and 10.03 ± 2.22 mm, respectively. The values of navicular drop test were significantly different between both groups ($p < 0.001$). The VGRF's and push-off force impulse showed significant differences (p-value = 0.001, 0.001; respectively) while no significant differences were found in jump height and average force between the two groups (p-value = 0.10, 0.81) [Table 2]. There were significant differences between mean scores of flatfoot and normal foot players in $VGRF_S$ ($F = 34.89$, df = 1, $p < 0.05$) and push-off force impulse ($F = 31.74$, df = 1, $p < 0.05$); whereas no differences were found in jump height and average force ($p > 0.05$) (Table 3).

Table 1: Demographic characteristics of all Players with normal foot and flat foot

Variables	Normal foot (mean ± SD)	Flat foot (mean ± SD)
Age (year)	20.38 ± 1.59	19.61 ± 1.35
Weight (kg)	65.76 ± 11.92	63.35 ± 7.41
Height (cm)	170.97 ± 8.55	170.39 ± 8.03
Body mass index (kg m^{-2})	22.53 ± 3.20	21.93 ± 3.20

Table 2: Comparison between countermovement Jump kinetic parameters (VGRFs, push-off force impulse, jump height and average force) of players with normal foot and flatfoot

Variables	Normal foot	Flatfoot	t-value	p-value	Cohen's d (effect size)
$VGRF_S$ (N) (times body weight)	4.65 ± 0.59	5.93 ± 0.79	5.90	< 0.001*	1.82
Push-off force impulse (Ns)	241.28 ± 40.12	176.7 ± 21.0	-5.63	< 0.001*	-2.01
Jump height (m)	0.361 ± 0.02	0.347 ± 0.02	-1.68	0.10	-0.52
Average force (N)	1619.10 ± 339.2	1639.40 ± 210.8	-0.23	0.81	-0.07

Note: N = Newton, $VGRF_S$ = Vertical ground reaction forces, Ns = Newton second; Statistically significant associations ($p < 0.05$)

The present study revealed that peak VGRF's during landing of players with flatfoot were higher than the players with normal foot structures. This may be due to the fact that medial longitudinal arch (MLA) is responsible for appropriate shock absorption (Khamis and Yizhar, 2007) and distribution resulting from landing and MLA collapse and inappropriate biomechanics in flat-footed players may lead to the production of a greater VGRF rather than the absorption of imposed loads (Hanson *et al.*, 2007). The results of the present study on VGRFS were consistent with those of previous research (Chang *et al.*, 2012; Choi *et al.*, 2012; Mohammadi *et al.*, 2018). VGRFS during landing is the instant of landing, where the feet first contact the ground. The ground reaction force shows a sharp impact (Linthorne, 2001). VGRFs were greater in pronated foot players than in players with normal foot structures during jump landing activities (Chang *et al*., 2012). This study also showed that the peak VGRF's of players in flatfoot group was 1.26 times body weight higher than players with normal foot group and the values of peak VGRFS in players with flatfoot was found to be higher than reported in previous studies. This might be due to the fact that our population was composed of highly active sports players who participated in high-intensity sports.

Table 3: MANOVA for $VGRF_S$, push-off force impulse, jump height and average forces in flatfoot and normal foot groups

Variables	Sum of squares	Mean square	F	p-value
$VGRF_S$ (N) (times body weight)	17.26	17.26	34.89	< 0.001*
Push-off force impulse (Ns)	43802.67	43802.67	31.74	< 0.001*
Jump height (m)	0.002	0.002	2.84	0.10
Average force (N)	4334.25	4334.25	0.05	0.817

Note: N = Newton, $VGRF_S$ = Vertical ground reaction forces, Ns = Newton second; Statistically significant associations ($p < 0.05$)

In this study, value of push-off force impulse was significantly lower in players with flatfoot than players with normal foot structures. The reason for this significant variation may be explained by the fact that the toe flexor muscles are critical in controlling the generation of force during the push-off phase of CMJ (Unger and Wooden, 2000). Individuals with flatfoot have lower toe flexor strength, which might explain why flatfoot players have lower push-off impulse values (Tashiro *et al.*, 2015). The net vertical impulse produced during the propulsive phase of the CMJ is a powerful predictor of jump performance (Hanson *et al.*, 2007). Push-off Force impulse is integral of force with respect to time between lowest position and take-off. Push off phase is when the jumper moves upward by extending the knees and hips (Linthorne, 2001). No comparison with other studies has been provided since no studies have investigated the difference in push-off force impulse between two groups. No significant difference was observed in average force between two groups. The reason for this can be that higher forces are generated by foot muscles that support the MLA in individuals with flatfoot posture to compensate for the flatfoot posture (Zhang *et al.*, 2017). This study found no obvious differences between the jump height of flatfoot group and normal foot group. The previous study who reported that there is no effect of foot type on vertical jump height (Fu *et al.*, 2016). We assumed that this result may be due to the reason that individuals with flatfoot have been reported to have greater ankle muscle strength. There may be a possibility that increased muscle strength of lower extremity in flatfoot group may have compensated for the lack of the overall advantage provided by spring mechanism of the ankle, resulting in similar jump height. The study concluded that, the larger VGRF's in players with flat foot compared to players with normal foot reflect the greater force imposed on these players' lower extremities, which may result in higher susceptibility to musculoskeletal injuries. The findings of this study suggest that classification of foot type in both clinical and research areas may be necessary to maximize the benefits of any proposed therapeutic interventions.

Conflict of interest: There is no conflict of interest.

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Ethical statement: The ethical approval has been taken from the Institutional Ethical Committee of Guru Nanak Dev University, Amritsar, Punjab, India with institutional approval number 752/HG on dated 28/09/21.

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