ORIGINAL ARTICLE

Plantar pressure distribution and static balance in child judo practitioners

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B Data Collection
C Statistical Analysis
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Abstract

Background and Study Aim: Participation in sports, including martial arts, serves as an important form of daily physical activity for children and adolescents due to the numerous physical and mental health benefits. The aim of this study is to broaden the knowledge about the plantar loading and balance during static testing in school-aged judo participants compared with an untrained age-matched control.

Material and Methods: The study involved 49 children aged 10-12 years: 26 who trained judo regularly and 26 untrained controls. Plantar pressure and balance were measured on a baropodometric platform.

Results: Peak rearfoot pressure of the right and left limb, as well as average rearfoot pressure and forefoot pressure distribution of the left limb, were greater in the judo group. In turn, the control group was found with a significantly higher forefoot peak pressure and forefoot percent. Balance testing revealed greater center of pressure sway path length in the control group in the eyes open condition.

Conclusions: Participation in judo may modulate right and left rearfoot plantar loading. Further studies are needed to confirm the plantar pressure characteristics of judo practitioners and determine if these loading patterns may lead to mechanical overload and injury.

Key words: center of gravity • center of pressure • combat sports • forefoot • martial arts • rearfoot

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INTRODUCTION

Physical activity – *noun* exercise and general movement that a person carries out as part of their day [58].

Judo – *noun* a Japanese martial art in which opponents use balance and body weight, with minimal physical effort, to throw each other or hold each other in a lock [59].

Competition (according combat sports theory [60]) **–** refers to a contest between individuals, groups, teams or nations, which has been arranged in advance according to the principle of equal chance.

Competition training – *noun* athletic training that specifically prepares the athlete for the competition situation [59].

Randori – sparring in judo in which both participants practice attacking and defending [61].

The center of pressure – is the point where the total sum of a pressure field acts on a body, causing a force to act through that point. The total force vector acting at the center of pressure is the value of the integrated vectorial pressure field. The resultant force and center of pressure location produce equivalent force and moment on the body as the original pressure field. Pressure fields occur in both static and dynamic fluid mechanics [62].

Competition – is a rivalry where two or more parties strive for a common goal which cannot be shared: where one's gain is the other's loss (an example of which is a zero-sum game) [63].

The evolution of bipedal walking among humans introduced several anatomical changes in the feet. An upright and erect posture placed the center of gravity directly over the feet, requiring the plantar surface to support the entire weight of the body [1]. Besides several skeletal adaptations, unique among humans was the development of a foot arch that provided a strong and elastic base of support during standing and locomotion. The design of the longitudinal arch attenuates shocks and transient forces while acting as an energy-saving spring to maintain efficiency during locomotion [2].

While the feet provide a base of support for the entire body, it is the balance system that maintains body equilibrium and orientation in all activities of daily living [3]. The balance system constitutes a multi-level series of processes that integrate perceptual information from the proprioceptive, vestibular, and ocular systems to coordinate a series of responses primarily by changing body position and movement [4]. Its function is to counteract external and inertial forces and maintain the center of gravity within the base of support as provided by feet in contact with the ground [5]. The resultant ground reaction force vector on the surface is known as the center of pressure (COP) or the point at which the total sum of all pressure points is located under the feet. Dysfunction in any of the contributing systems can not only affect the body's ability to maintain balance but also be responsible for a number of disorders and ailments [3].

COP is frequently measured in clinical and research settings to assess balance and the effects of normal or pathological conditions on postural control [6]. Measuring the distance traveled of the COP on a two-dimensional surface or what is known as sway path length is a common measure in balance assessments as it can quantify the amount of postural sway exhibited by an individual and serve as an indirect measure of balance control [7]. The amount of pressure and the distribution of pressure is also recorded to provide additional data on plantar structure and function.

A high level of fitness and participation in regular physical activity with balance exercises can improve postural control in a wide variety of populations [6]. Among children and youth, one of the most common forms of physical activity is participation in sports [8]. Increasingly popular among youth are martial arts, which combine hand-to-hand combat techniques with mental and ethical discipline [9]. Practitioners learn how to control the body and mind in self-defense scenarios against an opponent while improving multiple qualities including strength, endurance, flexibility, speed, and balance. One particularly popular form of martial arts is judo, which is derived from Japanese combat techniques employed by samurai for self-defense [10]. One of the core features of judo besides is the role of balance and breaking balance, which practitioners use to their advantage to throw and then immobilize an opponent with various forms of submission [11].

Studies have found that the activity profile of judo, with frequent changes in movement, position, and orientation, leads to improvements in both proprioception and balance control [12]. This is concurrent with the literature which finds that regular physical activity has a positive effect on the development of balance as well as normal foot structure [13]. Individuals who participate in sports show a greater transverse foot profile, higher arch height, and smaller prevalence of flat feet or toe deformities [14]. Previous research has found that children playing sports barefoot show better balance control and overall performance compared with shod cohorts particularly in sports that have a jumping component [15].

Despite the fact that judo is performed without footwear, little is known on the effects of judo on foot structure particularly data on plantar distribution and balance. The aim of this study is to broaden the knowledge about the plantar loading and balance during static testing in school-aged judo participants compared with an untrained age-matched control.

The questions raised in this study are whether there exist differences between these two populations in plantar pressure distribution profiles and in COP sway path length as a measure of balance control.

MATERIAL AND METHODS

Participants

Male and female children aged 10-12 years were recruited from local primary schools. The first group involved 26 children who trained judo for approximately 1 year, attending three sessions per week for 90 min and two 90-min intensive

Table 1. Descriptive statistics for group anthropometric data.

Variable	Judo group (n = 26)		Control group (n = 26)	
	x̄	SD	x̄	SD
Body height [cm]	147.5	±7.43	150.82	±11.16
Body mass [kg]	42.34	±9.95	46.65	±13.5
BMI [kg/cm^2]	19.3	±3.49	20.16	±4.26

physical education classes twice per week as part of their school curriculum. The control group involved 26 subjects who did not participate in any sports but attended three 45-min basic physical education classes per week. The mean age of the sample was 11.2 ±1.33 years and basic anthropometric characteristics are presented in Table 1.

Procedures

Plantar pressure and balance were measured with a FreeMED baropodometric platform integrated with FreeSTEP software (Sensor Medica, Rome, Italy) (Figure 1). Testing was performed barefoot and involved quietly standing on the platform. Two 10-s trials were administered, the first performed with eyes open and the second with eyes closed. During the test, the examiner stood next to the subject to catch the subject in case of a fall. Plantar pressure measures that were considered in the eyes open condition included forefoot and rearfoot average and peak plantar pressure as well as the percent distribution of forefoot-rearfoot plantar pressure. Balance was assessed by measuring COP sway path length in both the eyes open and closed condition.

Statistical analysis

All statistical calculations were performed with SPSS Statistics ver. 25 software package (IBM, USA). The Shapiro–Wilk test was used to determine the distribution of the data set. The plantar pressure measures were compared between the groups with Student's *t* test. Due to the non-parametric distribution of COP sway path length, the Mann-Whitney *U* test was adopted as an equivalent of Student's *t* test. Statistical significance was accepted at $p \leq 0.05$ for all procedures. The data are presented as mean, standard deviation (SD or ±) or median (Me) with minimum (Min) and maximum (Max) values.

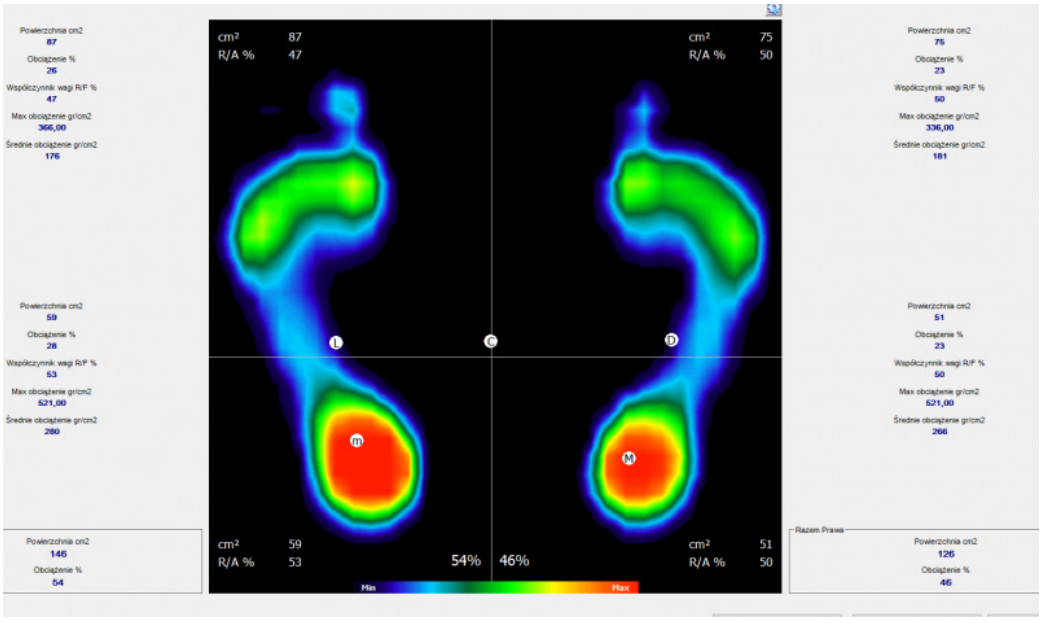

Figure 1. Computer analysis of the FreeSTEP software. Static foot load test (source: https://koordynacja.com.pl/2020/05/06/freestep-2-0-oprogramowanie-do-badan-biomechanicznych/ [in Polish])

Table 2. Peak and average forefoot and rearfoot plantar pressure and between-group comparisons.

Measure [gr/cm^2]	Judo group (n = 26)		Control group (n = 26)		T	P
	x̄	SD	x̄	SD		
Peak right forefoot pressure	527.46	±160.78	579.83	±220.54	−0.939	0.353
Peak right rearfoot pressure	893.46	±253.60	884.23	±297.97	0.215	0.830
Peak left forefoot pressure	455.00	±165.16	573.13	±233.38	**−2.063**	**0.045***
Peak left rearfoot pressure	1053.19	±298.72	946.26	±272.89	1.302	0.199
Average right forefoot pressure	247.61	±60.85	251.52	±67.69	−0.211	0.834
Average right rearfoot pressure	410.23	±113.12	431.50	±145.70	−0.420	0.677
Average left forefoot pressure	216.50	±54.52	250.52	±73.40	−1.822	0.076
Average left rearfoot pressure	485.38	±138.97	477.30	±136.79	0.205	0.839

$\bar{x}$ mean; *SD* standard deviation; *$p \leq 0.05$

RESULTS

Peak rearfoot pressure of the right and left limb as well as average rearfoot pressure of the left limb was greater in the judo group. For the remaining measures, greater values were observed in the control group. However, only the difference in peak forefoot pressure of the left limb was significant and was greater in the control group (Table 2).

The judo group was found with a slightly greater percentage of right forefoot and left rearfoot loading than the control group although this difference was not statistically significant. However, left forefoot loading was significantly greater in the control group (Table 3).

Balance control as measured by COP sway path length in the eyes open and closed conditions is presented in Tables 4 and 5, respectively. While minimum and first quartile percentiles as well as the median were slightly higher in the control group, none of these differences were statistically significant.

DISCUSSION

There is abundant literature on the positive aspects of youth participation in extracurricular sports [16-19]. Children and youth involved in school and club sports show better quality of life, health status, physical fitness, social skills, and mental health than those not involved in sports [20, 21]. Martial arts in particular have seen a surge in popularity as they combine self-defense techniques with broad improvements in fitness and health, with many studies confirming numerous positive health outcomes associated with martial arts participation [22-24]. Benefits among younger participants have also been reported, such as where boys aged 8-13 years who began training martial arts and combat sports (competition training based on direct contact exercises) in childhood practicing judo showed enhanced development of muscle strength [25], endurance [26], coordination [27], practicing karate flexibility [28], and balance compared with cohorts with no history of martial arts practice – e.g. 14-15 year old boys judokas [29].

Table 3. Percent distribution of plantar pressure between forefoot and rearfoot loading of the right and left limb and between-group comparisons.

Measure [%]	Judo group (n = 26)		Control group (n = 26)		t	p
	x̄	SD	x̄	SD		
Z	20.34	±8.39	19.00	±10.45	0.493	0.625
Right rearfoot loading	28.11	±9.08	30.73	±12.49	−0.637	0.528
Left forefoot loading	15.80	±13.15	18.13	±9.52	**−4.342**	**0.000***
Left rearfoot loading	35.34	±5.61	33.35	±10.96	0.651	0.518

$\bar{x}$ mean; ***SD*** standard deviation; *$p \leq 0.05$

Table 4. COP sway path length in the eyes open condition and between-group comparisons.

Measure [mm]	Judo group (n = 26)				Control group (n = 26)				U	p
	Me	Min	Max	Interquartile range	Me	Min	Max	IQR		
COP sway path length	376.58	158.81	682.75	333.7651-435.5595	380.06	178.12	874.9	330.6649-435.5595	298.000	0.984

Me median; **IQR** interquartile range

Table 5. COP sway path length in the eyes open condition and between-group comparisons.

Measure [mm]	Judo group (n = 26)				Control group (n = 26)				U	p
	Med	Min	Max	IQR	Med	Min	Max	IQR		
COP sway path length	417.99	228.08	681.86	365.9151–435.5595	437.82	268.12	674.9	353.8641–435.5595	277.000	.264

Me median; **IQR** interquartile range

Balance is based on a complex combination of systems that is treated as a general ability and not skill-specific [30]. The role of balance in child development is particularly important, with studies finding strong correlations between physical activity interventions and measures of fitness including balance and oxygen consumption in young, healthy children and a positive relationship between frequent physical activity and balance performance [31]. While some studies have not confirmed this relationship between physical activity and balance as ascertained by postural sway, the literature concurs that a high level of balance control is necessary to achieve appropriate levels of physical activity [32].

It has been posited that the modality of physical activity as well as level of performance and training history can modulate dynamic and static postural control and that different physical activities can involve the balance system to a different degree, such as judo being more dependent on the visual system rather than the vestibular and proprioceptive systems [33, 34]. For example, while judo is performed barefoot, several studies have found that footwear may affect the proper development of foot structure and function compared with being barefoot [35]. While the advantages and disadvantages of footwear on motor control and function have been widely discussed in the literature [36, 37], there is still no consensus as few studies have investigated the long-term effects of the barefoot condition [38]. However, intervention studies on the role of barefoot gait on coordination have reported that post-jump landing postural stability as well as balance control in the static condition are impaired when barefoot [39-41]. These studies have advised that barefoot walking may post difficulties in maintaining balance in the standing position for certain cohorts.

Among children and adolescents, differences in dynamic balance were observed between barefoot and footwear conditions in which the shod participants showed enhanced balance control than those barefoot [42]. However, this may be explained by the fact that activities performed barefoot are more unfamiliar for normal participants and do not provide a sense of stability [43]. Furthermore, a study involving children reported that footwear can play an important role in foot development particularly proper foot arch characteristics [38]. In the present study, the judo practitioners showed enhanced balance compared with the control group and perhaps due to this cohort training barefoot although these differences were not significant in either the eyes open or closed condition. This may be explained by the relatively short training history of the judo group.

Unfortunately, the research on adolescent judokas lacks data on dynamic balance, and in principle the body balance disturbation tolerance skills [44] (which is the essence of judo, sumo, sapas, etc.). Meanwhile, the results of the Rotational Test (RT) prove the high adaptation in this respect of adult judo athletes (male and female) compared to athletes of other disciplines [44]. Moreover, RT (non-apparatus version) turned out to be the most diagnostic (sensitive to environmental changes) tool among those measuring coordination abilities in various conditions of survival groups of soldiers

and students [45-50]. Unique studies of juvenile judokas with the use of another non-apparatus test (more on this test category in [51]), namely the Marching test, were made by Maśliński et al. [52]. Cognitively interesting may be the results of the research using this test category compared to the data from the modern baropodometric platforms.

The ability of modern baropodometric platforms to assess plantar pressure data in both static and dynamic conditions has provided researchers valuable information on foot and lower limb biomechanics and a wide range of populations [53]. Analysis of plantar pressure particularly among athletes revealed differences in loading patterns and postural adjustments depending on the practiced sport [54]. In the present study, the judo group showed greater plantar loading in the rearfoot of both the right and left limb compared with the control group. This could be explained by the specificity of judo training involving specific footwork during competition (randories and tournament fights). Other studies analyzed sex differences in forefoot-rearfoot plantar pressure ratio in young children although the effect of age as well as inter-individual differences were not studied but find that the static condition is most conducive to testing as it is the most stable and reliable position for testing, in which COP of the foot is centrally located at approximately 40% of the length of the foot from the heel [55].

Comparisons of foot structure among martial arts revealed that judo practitioners have greater left foot width and length than karate practitioners and also present an excess hallux valgus angle compared with published normative values [56]. This was indicative of several anatomical adaptations, suggesting that this population should be monitored for the negative effects of long-term martial arts training [56]. Another study involving martial artists analyzed the effects of long-term karate training on spinal mobility to find karate practitioners show a greater range of movement compared with an untrained cohort [57]. However, the ranges of the karate practitioners exceeded accepted norms, suggesting that some martial artists may benefit from targeted exercises designed to compensate for these deficiencies [57].

CONCLUSIONS

Children training judo showed greater peak rearfoot pressure of the right and left limb and greater average rearfoot pressure of the left limb compared with an age-matched untrained cohort. Further studies are needed to confirm the plantar pressure characteristics of judo practitioners and determine if these loading patterns may lead to mechanical overload and injury.

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