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Kata and kumite intensive training in female international karate-kas adjusts pedobarographic profiles of gait

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Abstract

Background: Karate consists of two somewhat different disciplines, kata, and kumite; each one may have a different effect on foot structure and dynamics in the longterm.

Aim: As pedobarography is indicative of foot function, the present study aimed to compare pedobarographic profile during gait between young females participating in international kata and kumite competitions and non-karate-ka females.

Materials and Methods: Displacement and velocity of the center of pressure, and peak pressure in ten regions of the foot of 10 kata-ka, 12 kumite-ka, and 16 non-karate-ka were measured with a pressure platform during barefoot walking.

Results: Peak pressure in the lateral-heel and lateral-toes of kata-ka and kumite-ka was significantly lower than non-karate-ka ($P<0.05$). Furthermore, peak pressure in the kata-ka midfoot was lower than non-karate-ka ($P=0.01$ in medial-foot, $P=0.01$ in lateral-midfoot). In the anteroposterior direction, center of pressure velocity and displacement were significantly different among the three groups ($P<0.05$).

Conclusion: It can be concluded that the practice of repeated intensive karate exercises has a demonstrable effect on foot progression, dynamic loading velocity, and plantar load distribution during gait. Moreover, practicing kata probably has a greater impact on the measured parameters.

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1. Introduction

Each sporting field could have a different effect on the structure and function of the lower extremities, and more particularly the foot, depending on training duration and intensity, type of movement, the surface on which exercise is done and the weight of the carried load [1]. Athletes, during training, often do exercises that may lead to either positive or negative adaptation of the musculoskeletal system [2, 3, 4, 5]. In this context, karate is a particularly interesting sport discipline to study because it involves numerous weight-bearing activities including impact with the ground like hopping or jumping movements, which exerts lots of mechanical forces on lower extremities [6].

Modern non-contact karate competitions consist of two separate disciplines: kumite and kata [7]. Kata-ka does the known and fixed transitional phases in predictable situations without hopping movement, whereas kumite necessitates the management of unpredictable conditions against a real opponent [8].

Although few studies has compared the physical performance of elite kumite and kata athletes [7, 8, 9], in most of the studies, karate has been considered as a single field and has not been divided into two specific disciplines of kata and kumite [4, 10].

Pedobarographic profiles, indicative of foot function during gait and other daily activities [11], are important in biomechanical studies and have been used to diagnose lower limb impairments [12], design shoes and foot orthoses [11] and prevent injuries [13]. Specifically, the trajectory of center of pressure (CoP) acting as a neuromuscular response to the imbalance of the body’s center of mass [14] can explain foot function [15], body balance [16], neuromuscular control [14], and joint kinetics during gait [17].

It was shown that gymnastic athletes are characterized by higher CoP displacement and velocity than basketball and volleyball in open eyes condition, and the two latter were found not to be different [18]. However, no differences were determined in CoP deviations between none of the soccer, basketball and swimming athletes and non-athletes during one-legged stance; the soccer players had more high-frequency sway and less sway than other groups [19].

One research showed that high intensity karate training over a very short period of time induced an improvement in static body balance in preadolescent karate-kas [20]. Also, it was determined that Chinese martial arts exercises improve postural control after a perturbation by lower maximal CoP and center of mass displacements [3].

It was shown that karate-ka's (KK) static plantar-pressure distribution in standing is affected by training on a soft surface (tatami), in which transverse and longitudinal arches of athlete practicing on a hard floor were different from karate-ka's practicing on the tatami [5]. Also, a high positive correlation was found between plantar Peak Pressure (PP) under each foot during standing and speed of strikes specific to karate, which supports that the striking speed is influenced by PP under each foot [21].

Finally, most of the studies about the CoP trajectory of athletes focused on static positions, and dynamic weight acceptance is less determined. Very few studies have been done in the field of elite sport and related intensive training on plantar-pressure patterns and, to the best of our knowledge, no study has compared the influence of specific intensive training in kata or kumite disciplines on plantar loading patterns during daily activities. If the results obtained from this study showed changes in plantar loading of karate-ka than non-KK, it would be necessary to determine that these changes either improve athlete performance or induce some long-term injuries. If so, some changes in karate training or rehabilitation programs are needed to prevent probable injuries.

Hence, this research aimed to compare the trajectory of CoP and plantar PP during gait among female athletes participating in international kata and kumite competitions with non-karate females to understand: 1. whether kata and kumite disciplines would induce significant plantar dynamic adaptations of gait relative to each other; and 2. whether any of these disciplines would decrease variables of interest compared to non-karate-ka (as controls) significantly.

2. Materials and Methods

2. 1. Participation

Thirty-eight healthy female athletes including 10 kata-ka (KA), 12 kumite-ka (KU), and 16 non-karate-ka (non-KK) participated in this study. A statistical power calculation was conducted to determine sample size, using G*Power software (an effect size of 0.33 and significance level of 0.05). The demographic profile of the participant is shown in Table 1.

Table 1. Demographic profiles in KA, KU, and non-KK

Group	Age (years)	Weight (kg)	Height (cm)	Body mass index (kg m^2)	Years of professional training
KA	18.75±2.37	65.63±4.50	160.50±4.95	25.50±1.85	9±1
KU	22.00±4.32	56.00±7.31	168.10±5.10	19.76±1.81	10±2
Non-KK	21.69±5.47	60.40±10.35	164.60±6.37	22.23±3.17	non-athlete

KA: kata, KU: kumite, non-KK: non-karate-ka

The inclusion criteria for karate-ka subject included: practicing the Shotokan style of karate, trained mainly on soft floor mats, right foot dominancy, continuous minimum 5 years of karate professional training. To control the effect of deformities on plantar-pressure measurements [15, 22], the lower limbs of the KK participants clinically examined, and non-KK participants with the same deformities were selected. The deformities were included tibial torsion (n=25), genu varum (n=26), genu recurvatum (n=30) and heel valgus (n=33). The rest inclusion criteria for non-KK group included: right foot dominancy, not being an athlete in karate or other sports. The exclusion criteria for all groups consisted of any deformity other than those mentioned earlier, history of foot deformities or surgery, lower limb discrepancy more than 1 cm, using specialized footwear or orthosis, injury, and pain at the time of the study, and other neurological and muscular abnormalities which might have affected the walking pattern. Before any measurement, all procedures were explained to the participants, and then all participants signed an informed consent document.

2. 2. Plantar-pressure measurements

Footprints of participants were acquired using one portable pressure platform system of Emed®n50 (Novel GmbH, Munich, Germany) during walking (between-day PP mean ICC of 10 regions=0.801) [23]. This capacitance measurement device, with a sensor area of 574x320 mm, a resolution of 4 sensors cm- 2, a sampling frequency of 50 Hz and a threshold recording pressure at 10kPa [23]. Data was recorded utilizing the proprietary Emed®/E software (version 23.1.14e). The participants of both groups were tested randomly on two consecutive days by an examiner at a local karate dojo.

The platform was embedded flat on the ground in midway along a high-density foamed walkway (5x1 m) to record usual natural stepping. Initially, the participants were asked to walk barefoot freely up and down the walkway until a natural walking rhythm and comfortable speed were obtained and their second step exactly placed on the platform [24]. The trial was beginning with the first contact on the platform and continued for 3 sec by default.

The average of three separate trials for each foot, obtained by Emed® software and then divided into 10 foot regions or masks, were taken the same as the diabetic foot division [25] using the ‘‘Automask’’ software. These masks divide the foot into medial (Mask 1) and lateral-heel (Mask 2), medial (Mask 3) and lateral-midfoot (Mask 4), forefoot including 1st (Mask 5), 2nd (Mask 6) and lateral (Mask 7) metatarsal heads, hallux (Mask 8), 2nd-toe (Mask 9) and lateral-toes (Mask 10).

Selected parameters were PP and the coordinates of the CoP extracted using the ‘‘multimask evaluation’’ software. PP represents absolute peak pressure in each mask during entire foot contact and is normalised to body weight. Based on the device’s default setting, the coordinates’ origin had been set on the anterior-lateral corner of the drawn rectangle surrounding each foot so that each trial has its own origin of coordinate. CoP displacement was normalized in the anteroposterior (y) and mediolateral (x) directions based on the foot length (FL) and width (FW), respectively [17, 26]. Displacement and average velocity of CoP were calculated using MATLAB software.

To neutralize the impact of foot structure on PP and CoP path [26], the arch index (AI) was extracted using the Emed® ‘‘Geometry’’ software with an equation of "$AI = A_2/A_1+A_2+A_3$" where A_1=hindfoot area, A_2=midfoot area, A_3=forefoot area without toes. An AI between 0.21-0.26 was considered as a normal foot. An AI less than 0.21 and above 0.26 were regarded as pes-cavus and pes-planus deformities, respectively [27].

2. 3. Statistics

Shapiro–Wilk test was used to test normality of data distribution of dependent variables including displacement and velocity of CoP and PP in 10 masks and independent variable including 3 groups of KA, KU and non-KK. One-way Analysis of Variance (ANOVA) (F value) and post hoc Fisher tests were used to compare normally distributed dependent variables between KA, KU and non-KK. Also, Kruskal-Wallis (χ^2 value) and Mann-Whitney U tests were used to compare abnormally distributed variables between three groups and each pair of groups, respectively. SPSS V21.0 software was used for statistical analysis. The level of statistically significant difference was taken $P<0.05$.

3. Results

The ANOVA results showed that the difference of age (F=1.243, P=0.303) and weight (F=0.99, P=0.38) was not significant between the groups, but the difference of height and body mass index (BMI) was significant between KA, KU and non-KK (F=6.37, P=0.001 and F=3.64, P=0.03, respectively).

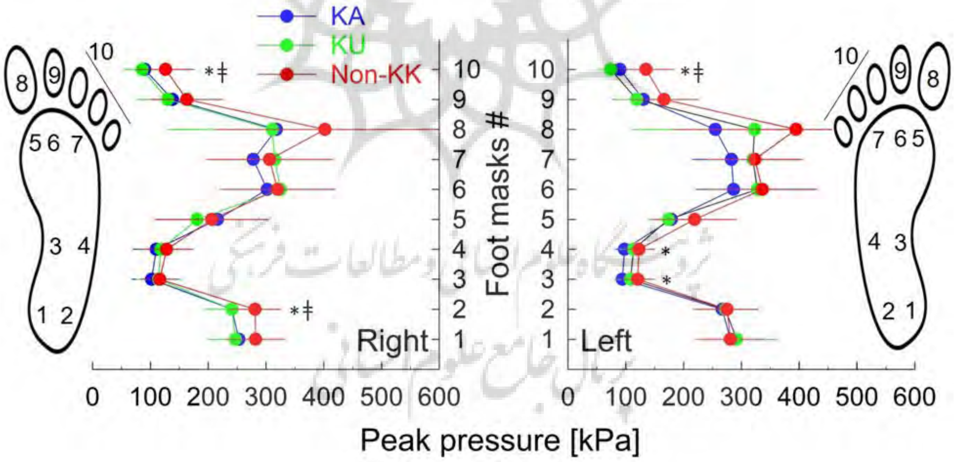
The AI means of right and left feet of all groups were in the normal range (0.21-0.26) [27]. There were no significant differences in the proportions of normal, pes-cavus and pes-planus between groups (*P*>0.05; Table 2).

Significant differences were observed between the PP in the lateral-heel (F=3.88, *P*=0.03) and lateral-toes (F=3.66, *P*=0.03) of the right foot. Specifically, these differences were seen between the pair of KA and non-KK (*P*=0.03) and the pair of KU non-KK (*P*=0.02) in the lateral-heel (Mask 2 of the right foot in Figure 1); and the pair of KA and non-KK (*P*=0.04) and the pair of KU and non-KK (*P*=0.02) in the lateral-toes (Mask 10 of the right foot in Figure 1).

Table 2. The arch indexes, the number of foot type in KA, KU, and non-KK and pair comparison of groups

Group	Arch indexes		Normal foot n (%)	Cavus foot n (%)	Flat foot n (%)	χ^2 (P)		
	Right	Left				KA vs KU	KA vs non-KK	KU vs non-KK
KA (n=10)	0.24±0.05	0.25±0.02	6(60%)	2(20%)	2(20%)			
KU (n=12)	0.23±0.03	0.22±0.05	6(50%)	2(16%)	4(33%)	0.48 (0.78)	0.95 (0.62)	0.11 (0.94)
Non-KK (n=16)	0.24±0.02	0.24±0.11	9(56%)	3(16%)	4(25%)			

KA: kata, KU: kumite, non-KK: non-karate-ka, n: number



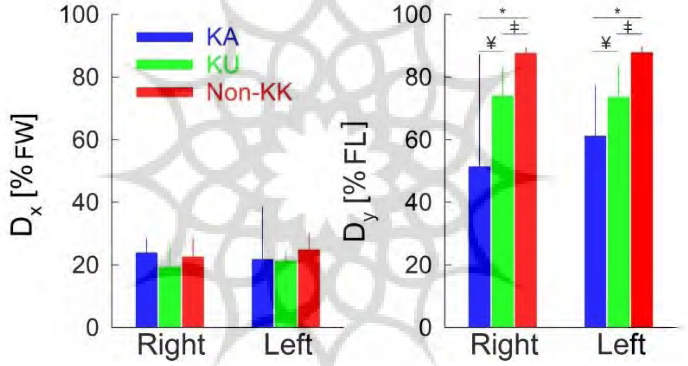
* Significant difference between KA and non-KK and ‡ between KU and non-KK at 0.05 level

Figure 1. Peak pressure of right and left foot in 10 masks in kata (KA), kumite (KU) and non-karate-ka (non-KK). Masks include medial (Mask 1) and lateral (Mask 2) heel, medial (Mask 3) and lateral (Mask 4) midfoot, 1st (Mask 5), 2nd (Mask 6), and lateral (Mask 7) metatarsal heads, hallux (Mask 8), 2nd-toe (Mask 9) and lateral-toes (Mask 10).

Moreover, when PP in the left foot compared between the groups, PP showed a significant difference in the medial-midfoot (F=3.46, *P*=0.04), lateral-midfoot (F=3.34, *P*=0.04) and lateral-toes (F=10.05, *P*=0.0001). Particularly, the difference in PP was significant in the medial-midfoot (*P*=0.01), lateral-midfoot (*P*=0.01) and lateral-toes (*P*=0.005) between the KA and non-KK, and in lateral-toes between the KU and non-KK (*P*=0.0001) (Masks 3,4 and 10 of the left foot in Figure 1). Consequently, non-KK had higher PP than KA and KU in all mentioned masks of the right and left foot.

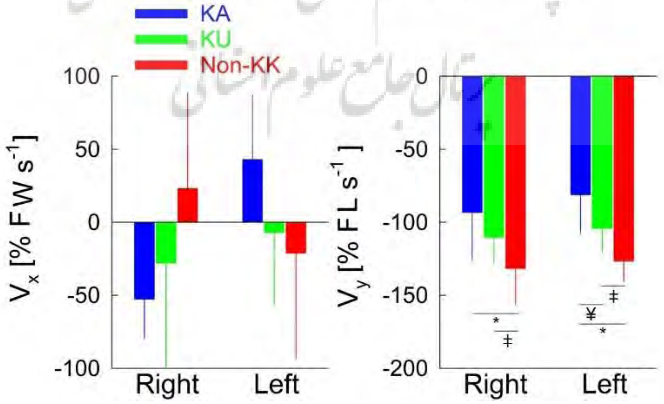
Although the difference of mediolateral CoP displacement (Dx) was not significant between the groups, the difference of anteroposterior CoP displacement (Dy) was significant in both feet between the groups ($\chi2=20.44$, *P*=0.003 in right foot; F=22.26, *P*=0.0001 in left foot). Accurately, the differences have seen between the KA and KU (*P*=0.02), between the KA and non-KK (*P*=0.001) and between KU and non-KK (*P*=0.001) for the right foot and between the KA and KU (*P*=0.008), the KA and non-KK (*P*=0.0001) and the KU and non-KK (*P*=0.001) for the left foot (Figure 2). Overall, Dy was seen significantly different between each pair of groups.

The difference of anteroposterior CoP velocity (Vy) was significant in both the right ($\chi^2=12.50$, *P*=0.002) and left ($\chi^2=18.27$, *P*=0.0001) foot. The difference was significant between KA and non-KK (*P*=0.001) and KU and non-KK (*P*=0.01) in the right foot and between the KA and non-KK (*P*=0.0001), the KU and non-KK (*P*=0.0005) and the KA and KU (*P*=0.008) for the left foot (Figure 3). As shown in Figure 3, the non-KK had the highest Vy values during the stance phase of gait.



* Significant difference between KA and non-KK, ǂ between KU and non-KK and ¥ between KA and KU at 0.05 level

Figure 2. Mediolateral (Dx) and anteroposterior (Dy) displacement of CoP in the right and left foot kata (KA), kumite (KU) and non-karate-ka (non-KK)



* Significant difference between KA and non-KK, ǂ between KU and non-KK and ¥ between KA and KU at 0.05 level

Figure 3. Mediolateral (Vx) and anteroposterior (Vy) velocity of CoP in right and left foot of kata (KA), kumite (KU) and non-karate-ka (non-KK). Positive V values indicate moving toward the origin of the coordinate of the foot and negative V values indicate moving away from the origin of the coordinate of the foot.

4. Discussion

Based on the results, without considering the side of the lower limb, KA had significantly lower PP in the lateral-toes, lateral and medial-midfoot and lateral-heel than non-KK. Moreover, PP of the lateral-heel and lateral-toes in KU was lower than non-KK. No difference has been observed between PP of KA and KU (Figure 1).

KK gait resulted in lower PP compared to non-KK, which probably would be affected by regular training on the soft and unstable ground surface and subsequent changes in the arches of the foot [5] and foot-to-floor contact area during the stance phase. Consistently, one study showed that karate-ka training on the soft surface had lower plantar-pressure than on the solid surface [5]. Since all KK barefoot training is performed on the tatami, this may enhance the effect of the surface on the athlete's feet. Perhaps altered PP in KK is an adaptation of the musculoskeletal system to karate movement requirements [4].

No significant difference was observed in PP of masks between the KA and KU (Figure 1), but there was a significant difference in CoP velocity and displacement between the KA and KU (Figures 2 and 3). The CoP near the maximal pressure areas may provide only limited data about the overall distribution of plantar-pressure of the foot and a general pattern [28] may have led to the inconsistency between CoP data and plantar-pressure in this study.

All the three groups had the same mediolateral CoP displacement with Dx value about 20% FW. This observation is consistent with a previous study on healthy participants reporting a value of 18% FW [26]. Furthermore, non-KK anteroposterior CoP displacement was around 87% FL, but the KK participants had less than normal displacement, around 85% FL in healthy participants [26].

Based on decreased anteroposterior CoP displacement in the KK (both KA and KU) (Figure 2), it may be concluded that the participants in the KK may have a smaller range of motion and possibly more rigid lever for the push-off step of gait [26] than the participants in the non-KK. It has been found that the calf group is the major controller of CoP in the anterior direction, while tibialis anterior and flexor muscle groups control mainly CoP in the posterior direction [29]. Hence, a limited CoP trajectory during walking in this direction could be indicative of the high activity of the responsible muscles in the KK than non-KK.

However, electromyography recordings are needed to confirm this finding. This difference is likely more pronounced in karate with its unilateral guard, which involves bearing the body's weight and external forces by a small area of a single foot [30]. Along with this feature, karate exercises are usually performed on the soft surface (tatami) that is more challenging for maintaining balance and on which requires a higher activity of muscles than on a stiff surface [31]. Furthermore, kata requires a higher degree of balance as a key factor compared to kumite [32]. Thus, balance training and better balance in the kata may explain some of the differences in CoP variables between the KA and KU.

Also, non-KK had faster anteroposterior CoP progression than KU and these two groups showed quick transferring of weight from the rearfoot to the forefoot compared to KA (Figure 3). Given the contribution of muscle power to CoP displacement [29], the efficiency of muscles in the KK has been likely improved in the anteroposterior direction compared to the non-KK. Repeated karate techniques predictably may enhance this superiority.

The limitations of the present research include the small number of available international KK competitors, lack of synchronized electromyography recordings with pedobarography and the significant difference between the BMI of the groups. Although the examiner instruction regarding normal walking of subjects, walking strategy is another limitation which may probably affect on results of this paper.

Although this study has confirmed some adaptations in KA and KU, determining the usefulness or otherwise of these adaptations and resolving possible problems would require more investigation. This study was an introduction towards a better understanding of the dynamic adaptation of gait following karate disciplines high-intensity training.

5. Conclusions

The present research showed that some adaptations from high-intensity kata and kumite professional training cause variation in some weight bearing of foot masks. These variations reduce the KK plantar-pressures during walking compared to non-KK, Furthermore, the KK participants showed altered CoP displacement and velocity on the stance phase of walking. Precisely, kata may have a greater impact on foot function. Given the significant difference between kata and kumite in terms of some parameters, greater attention is recommended to the difference between the two disciplines in future studies of karate.

Conflict of interest

The authors declared no conflicts of interest.

Authors' contributions

All authors contributed to the original idea, study design: Conceptualization [all authors], Methodology [all authors], Investigation [1 and 2 authors], Writing, Original draft [all authors], Writing, Review and Editing [all authors], Resources [1, 2, 3 authors]; Supervision [4, 5 authors].

Ethical considerations

The authors have completely considered ethical issues, including informed consent, plagiarism, data fabrication, misconduct, and/or falsification, double publication and/or redundancy, submission, etc. The study was approved by the Sport Sciences Research Institute review board (IR.SSRC.REC.1398.036).

Data availability

The dataset generated and analyzed during the current study is available from the corresponding author on reasonable request.

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