Influence of the stances in the straight punch's impact force in karate

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A Study Design
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Abstract

Background and Study Aim: In the early literature on karate, it is empirically suggested that biomechanical variable such as executing time and impact force are affected by the stance. The aim of the research is to verify the hypothesis: there is no difference in the maximum impact force between natural (*shizen-tai*) and front (*zenkutsu-dachi*) stances; the maximum impact force may differ between the two stances because of the weight distribution on the lower limbs, and a greater engagement of body parts (effective mass) and joints.

Material and Methods: The impact force of a straight punch was acquired for eight highly trained back belt karate practitioners (age: 47.5 ±10.13 years; height: 1.76 ±0.03 m; mass: 86.08 ±17.43 kg; expertise: 32.13 ±8.87 years) using two load cells (maximum capacity: 2000 N) fixed between two parallel boards with the same dimensions of a target. The subjects executed a straight punch while adopting two stances: natural and front stance targeting the force measurement device at full power. The effect of natural and front stances on the impact force (peak) was analysed using the nonparametric Wilcoxon rank test. Additionally, the nonparametric bootstrap resampling technique was employed to investigate the robustness of the results.

Results: The impact force (peak) of the straight punch is average 2260.79 ±538.44 N and average 2645.59 ±538.44 N for the natural and front stance, respectively. A straight punch in front stance presents statistically significant higher impact force (peak) than the same technique while adopting a natural stance.

Conclusions: In the front stance (*zenkutsu-dachi*), karate athletes are able to engage more body parts and consequently increase effective mass during impact, which transfers greater momentum, and consequently generates a high impact force. These results were corroborated by the nonparametric bootstrap paired t-statistic which rendered similar conclusions.

Key words: front stance (*zenkutsu-dachi*) • natural stance (*shizen-tai*) • punching boards • punching pads • sandbags

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Punch – *verb* to strike someone or something with the fist, e.g. in boxing or martial arts [30].

Impact force – *noun* a force that is a result of colliding with another body, e.g. when a runner's foot hits the Grodnu [30].

Stance – *noun* the position in which a player holds the body in attempting to hit a ball, e.g. in cricket or golf [30].

INTRODUCTION

Karate is a Japanese martial art that has been officially included in the next 2020 Tokyo Olympic Games. In karate, biomechanical variables such as the execution time and impact force are the determining factors in successful outcomes in a contest or effectiveness in self-defense. These two variables are influenced by a combination of five factors: age, fitness, physiology, health and expertise. In the early literature on karate, it is empirically suggested that biomechanical variable such as executing time and impact force are affected by the stance [1-3].

Besides these empirical works, very few scientific studies have been conducted to investigate the effect of the stances on these biomechanical variables. The execution time has been analysed in only two studies, one by Liu and Wang [4] and the other by Wang and Liu [5]. Liu and Wang found that the stance affects the execution time during a jab (*kizami-zuki*). Similarly, Wang and Liu concluded that the stance affects the execution time also for a reverse punch (*gyaku-zuki*).

The second biomechanical variable, which is of interest in this study, i.e., impact force, has been the focus of more investigations, with a more prolific series of works in the literature. These studies employ distinct methods to estimate the impact force: cinematography [1, 6-8], the Strength of Materials Theory [6, 9], force plates or force sensors [10-13], accelerometry [14-17], and instrumented punching board [18, 19, 17].

Despite these research efforts, there remains much uncertainty about the biomechanics of karate such as the relationship between the magnitude of the impact forces and the stances. To fill this gap, this study has two objectives:

(1) To acquire the impact force (peak) of a straight punch (*choku-zuki*) while adopting two stances: natural (*shizen-tai*) and front (*zenkutsu-dachi*) stances, and

(2) To investigate the effect of these two stances on the maximum impact force.

It is hypothesize that there is no difference in the maximum impact force between natural (*shizen-tai*) and front stances (*zenkutsu-dachi*). The maximum impact force may differ between the two stances because of the weight distribution on the lower limbs, and a greater engagement of body parts (effective mass) and joints.

MATERIAL AND METHODS

Subjects

The sample in this study consists of eight highly trained back belt Karate practitioners (age: 47.5 ±10.13 years; height: 1.76 ±0.03 m; mass: 86.08 ±17.43 kg; expertise: 32.13 ±8.87 years. All subjects are healthy males who voluntarily participated in the experiments. Additionally, the subjects provided written consent according to the ethics committee of the State University of Santa Catarina (UDESC).

Table 1. Anthropometric and biomechanical data for the subjects.

Subject	Age [years]	Height [m]	Mass [kg]	Expertise [years]
1	61	1.75	88.3	43
2	58	1.82	76.7	40
3	52	1.75	122.0	38
4	45	1.73	78.1	38
5	42	1.76	78.7	31
6	53	1.78	63.5	25
7	34	1.78	84.6	22
8	35	1.72	96.7	20
Average SD	47.5 ±10.13	1.76 ±0.03	86.08 ±17.43	32.13 ±8.87

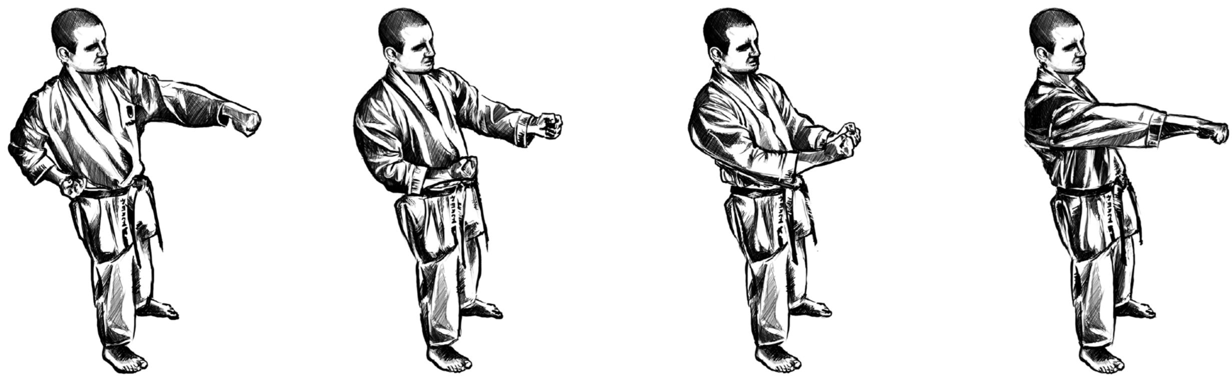

Figure 1A. Natural stance (*shizen-tai*).

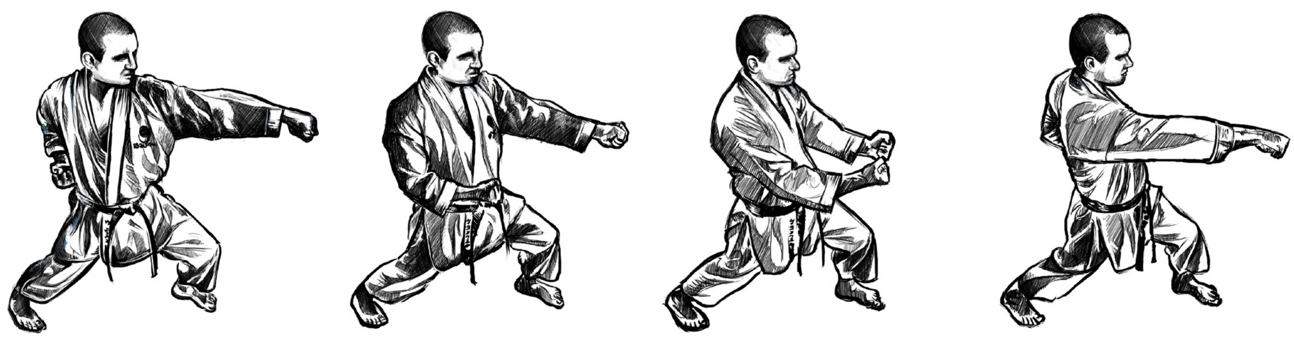

Figure 1B. Front stance (*zenkutsu-dachi*).

The order variable of individual results and anthropometric and biomechanical data (Table 1) presented in the tables is experience (years of training). With the equality of this indicator: age.

Apparatus

To acquire the impact force (peak) of the straight punch, the experiment employed two load cells (maximum capacity: 2000 N, sampling rate 2000 Hz model Kratos CDN) fixed between two parallel boards with the same dimensions of a target. The target consisted of a rectangular striking surface 20 × 22 × 0.15 cm (length × width × thickness) made of EVA (density 0.14 g cm^{-3}). The target was fixed to one of these boards and then the apparatus was fixed to the wall using a pair of rails to allow the target height to be adjusted.

Experimental Protocol

After a proper warm-up and a couple of trial punches, the subjects executed a straight punch while adopting two stances: natural (*shizen-tai*) and front (*zenkutsu-dachi*) stance targeting the force measurement device at full power. Both stances are illustrated in Figure 1. The natural stance (Figure 1A) was elected since it is the first stance learned in karate, presenting high incidence during early years of karate training. Using natural stance as the baseline, the more complex stances are taught and trained. The front stance (Figure 1B) was chosen based on its high incidence in both regular training and competition matches [20]. Each subject performed five straight punches (*choku-zuki*) for each stance with a long resting period between punches. Additionally, the order of the punches performed by each subject was randomized across the participants. It is important to emphasize that the subjects were not informed of the study's objective.

Statistical Analysis

The study employed the nonparametric Wilcoxon Rank Test to analyse and draw conclusions from the sample data. This test is designed to drawn inferences from samples by comparing the performance of the same individual in two different

Table 2. Impact force (peak) normalized by the weight for natural stance (*shizen-tai*).

Subject	Normalized variable by trial					Average SD
	1	2	3	4	5	
1	2.16	1.85	1.66	1.71	1.54	1.84 ±0.24
2	3.22	3.50	3.41	3.11	3.48	3.31 ±0.17
3	2.30	2.17	1.73	1.40	1.94	1.90 ±0.36
4	3.08	2.66	2.51	2.87	2.85	2.78 ±0.22
5	4.08	3.25	2.97	3.44	3.21	3.43 ±0.42
6	4.91	3.52	3.87	3.16	3.33	3.86 ±0.70
7	2.95	3.45	3.11	2.74	3.59	3.06 ±0.35
8	1.38	1.42	1.73	1.35	1.61	1.47 ±0.17

Table 3. Impact force (peak) normalized by the weight for front stance (*zenkutsu-dachi*).

Subject	Normalized variable by trial					Average SD
	1	2	3	4	5	
1	2.44	3.01	2.49	2.34	1.87	2.43 ±0.41
2	4.16	3.84	3.30	4.08	3.94	3.86 ±0.34
3	2.28	1.33	1.94	1.59	2.77	1.98 ±0.57
4	4.56	3.55	4.12	3.62	3.41	3.85 ±0.48
5	3.79	4.07	3.60	3.32	3.52	3.66 ±0.29
6	3.67	3.77	4.07	3.69	4.15	3.87 ±0.23
7	3.46	3.34	3.50	3.43	2.86	3.32 ±0.26
8	2.00	2.09	1.94	2.13	2.32	2.10 ±0.15

conditions, in this study case: the impact force (peak) in two different stances. This nonparametric test is better than the traditional paired t test with these data at hand because it does not depend on normality and homoscedasticity assumptions. Beyond this, the experimentally collected data has only observations for N = 8, subjects which render it difficult to apply the parametric paired t test and verify the validity of its basic assumptions.

To decrease the effects of individual differences among the subjects the impact force (peak) was normalized by simply dividing it by the body weight of the respective subject. This normalization method is the most popular method in biomechanics to neutralize or decrease the differences resulting from the distinct physical characteristics of the subjects such as height and weight [21].

RESULTS

Tables 2 and 3 present the normalized impact force (peak) measured for all the subjects for natural and front stances, respectively.

The average normalized impact force (peak) is 2.71 ±0.88 for the natural stance and 3.13 ±0.85 for the front stance; and the median is 2.91 for the natural stance and 3.42 for the front stance (Table 4). For both stances, the higher than the average values of the median indicate an asymmetry, i.e., the data is skewed to the right. Thus, any statistical treatment of the data should concentrate on methods that use the median as a measure since the median is less affected by outliers.

From the results presented in Table 5, the null hypothesis is rejected at 0.01 probability level. Consequently, there is substantial evidence that the front stance produces a higher impact force than the natural stance. The *t* bootstrapped

Table 4. Descriptive statistics for the normalized maximum impact force.

	Natural stance (shizen-tai)	Front stance (zenkutsu-dachi)
Average	2.71	3.13
sd	0.88	0.85
Median	2.91	3.42
Minimum	1.35	1.33
Maximum	4.91	4.56

Table 5. Descriptive statistics for the normalized maximum impact force.

T+ statistic	Wilcoxon Rank Test p-value
36.00***	0.008
t statistic	p-value from bootstrapped t statistic
3.65*	0.0676

Notes: *** statistically significant at $p = 0.01$ level, * statistically significant at $p = 0.10$ level.
The study adopted 5000 bootstrapped samples.

paired statistic and their associated empirical *p*-value were calculated as well.

DISCUSSION

The study was designed to measure the impact force (peak) of a straight punch executed in two different stances. However, the acquiring device does not mimic the human body inertia, or the inertia of such training apparatus as punching boards, sandbags or punching pads. It is widely accepted that measurements of impact forces are highly affected by the size, inertia and rigidity of the target. However, the equipment used is capable of reliably indicating whether the stances have any significant effect on the impact force.

The study estimated that the impact force for front stance (2645.59 ±538.44 N) is higher than that of the natural stance (2260.79 ±538.44 N) and this difference is statistically significant (p<0.01). The explanation for the difference can be found in the concept of effective mass, i.e., a measure of the inertial contribution of the subjects' bodies to the transfer of momentum during an impact [23, 24]. It has been well established that the effective mass is an important variable when analysing impact since it directly affects the impact force [6, 9, 25] in such a way that an increase in the effective mass results in an increase in the impact force.

This increase is a consequence of three factors. The first involves the significant increase in muscle contractions and co-contraction around the joints directly connected to the impact, as initially reported by Blum [9]. The contractions increase the stiffness of all body segments involved in the impact and results in a reduction in the total deformation, which increases the effective mass [26-28]. The second is related to the number of body segments engaged during impact, i.e., the more segments engaged in a movement results in higher potential to enhance effective mass [6, 24]. Considering the two stances studied in this work, only the punch in the front stance presents rear leg drive as well as, pelvis and trunk rotation, which contribute significantly to increase the effective mass involved in the technique. The third factor, the impact force benefits from the stretch shortening cycle. This occurs because the punch in the front stance starts from a position where the pelvis and the shoulder are rotated away from the target, a mechanism that was discussed by Turner et al. [27].

The results of this study are consistent with those reported by Feld et al. [7] and Wilk et al. [8]. However, Nakayama [1], Walker [6], Voigt [10], and Schwartz et al. [14] reported impact forces that are higher than the results of this study. On the other hand, Dworak et al. [11], Gulledge and Dapena [12], Chiu and Shiang [15], Aguiar de Souza [17], Girodet et al. [19] and Aguiar de

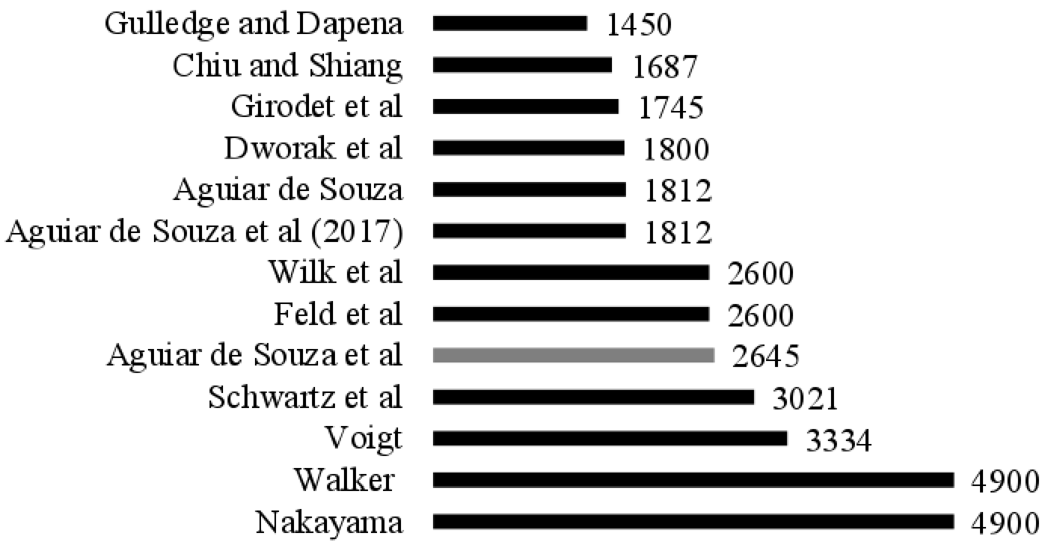

Figure 2. Comparison with similar studies (units N).

Souza and Marques [18] have reported lower results than those of this study. In Figure 2, the results of this study are listed with results from similar studies for comparison purposes.

The discrepancies observed between the results of this study and previous studies can be attributed to a number of different factors. Most of these studies neglect to determine the nature of the variable being measured, i.e., the studies do not indicate whether the values used are the peak, average, or median values of the impact force. Because of this lack of consistency on the definition, it is difficult to compare the impact forces obtained in our study and previous works. Methodologies also play an important role on the acquisition of a representative value for the impact force, since as mentioned previously, measurements of impact forces are highly affected by the size, inertia and rigidity of the target. Additionally, because the subjects of this study are highly trained individuals, it is reasonable to assume that they can perform the technique with very small variations from an optimal technique, and this may result in higher values of impact force.

This study includes some limitations. First, findings of the study were based on a small number of subjects and a small number of valid trials for each of the subjects. This limitation was overcome by adopting a distribution-free test statistic which have high power in hypothesis testing procedures, even in small samples (see Hollander et al. [29]). This is a recurrent problem in most studies involving martial arts since it is difficult to find a large number of highly trained martial. This is largely because it requires a significant number of years to reach the expertise level necessary to perform the techniques efficiently. The small number of valid trials in this test was unavoidable to avoid injuries since, despite the sock absorbing material (EVA), the target was too rigid. This rigidity contributed to higher impact forces than those reported in previous studies. In future investigations, it might be possible to use a different target with rigidity adjusted to mimic realistic training apparatus.

Despite these limitations, this study presents a valid methodology to quantify the maximum impact force, providing coaches with guidelines for adjusting the techniques and executions of technical training to produce optimal results. As a practical application of the findings we suggest that karate athletes should learn how to:

(1) increase muscle contractions and co-contraction around the joints to increase the body stiffness to transfer force efficiently to the target,

(2) engage more body segments during the technique to increase the effective mass, and consequently the maximum impact force,

(3) favor stances that facilitate the two items mentioned a priori, increasing the efficiency of the techniques regarding the maximum impact force.

Furthermore, additional studies are necessary to compare the effect of other stances, muscle and segments coordination strategies on the maximum impact force.

CONCLUSIONS

The results of Wilcoxon paired test for the null of no difference between two stances indicated that the null hypothesis shall be rejected at a 0.01 probability level. We are able to infer that there is significant difference in the performance of the athletes between the two stances. For the technique and conditions investigated in this study, the front stance (*zenkutsu-dachi*) produced significantly higher values of maximum impact force than the natural stance (*shizen-tai*). In this stance, athletes are able to engage more body parts and consequently increase effective mass during impact, which transfers greater momentum, and consequently generates a high impact force. These results were corroborated by the nonparametric bootstrap paired t-statistic which rendered similar conclusions.

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