Relationship between age and expertise with the maximum impact force of a reverse punch by shotokan karate athletes

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Abstract

Background and Study Aim: Karate is a Japanese martial art that traditional apparatus such as the punching board (*makiwara*) to improve effectiveness (stroke precision) and physical strength. However, little is known about the magnitude of the impact forces, and its connection to anthropometric and biomechanical variables. To fill this gap, the cognitive goal of this study is the knowledge about two phenomena: (i) the maximum impact force on a punching board generated by a reverse punch (*gyaku-zuki*) in a front stance (*zenkutsu-dachi*) in conditions as close as possible to the regular practice, and (ii) the relationship between anthropometric (age) and biomechanical (expertise) variables with the maximum impact force.

Material and Methods: The maximum impact force was acquired by strain gauges for eight shotokan karate athletes male black belts: age 20.25 ±4.13 years; height 1.74 ±0.04 m; body mass 72.41 ±9.62 kg; expertise:7.64 ±4.33 years (mean, SD). The effect of two variables, i.e., age, and expertise, on the maximum impact force was analysed by a linear regression model based on the bootstrap resampling method.

Results: Both variables age and expertise present statistically significant correlation with the maximum impact force. However, this dependence manifests itself in a quadratic form, in which a decreasing effect is present and dictates the behaviour of the maximum impact force. The maximum impact force for all trial ranged from 1310.82 N to 2314.53 N with an average of 1812.01 N. A negative correlation was observed between the age and the standard deviation of the subject's performance. This indicates that the expertise accumulated over the years may exert a stabilising effect.

Conclusions: It was found that age and expertise have relationships with the maximum impact force as documented in the literature. However, these influences have a critical point of which they have a decreasing effect on the maximum impact force. The critical point for the age is 31 years old and, the critical point for the expertise is 11 years of lifetime training. After these critical points, the karate athlete would be advised to search for ways to compensate for the decreasing marginal effects, such as nutrition or complementary practices under the guidance of a professional.

Keywords: global science space • reverse punch (*gyaku-zuki*) • punching board (*makiwara*)

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Impact force – *noun* a force that is a result of colliding with another body, e.g. when a runner's foot hits the ground [26].

Biomechanics – *noun* the study of body movements and of the forces acting on the musculoskeletal system, used in sport for analysing complex movements to improve efficiency and help avoid injury [26].

Biomechanical analysis – *noun* the assessment of the proper use of techniques in sport and exercise biomechanics [26].

Tameshiwari – a traditional exercise in many martial arts which involves breaking stationary objects such as boards, bricks, blocks and tiles with bare hands or barefoot techniques.

Technique – *noun* a way of performing an action [26].

Technique – specific procedures to move one's body to perform the task that needs to be accomplished [27].

Performance – *noun* the level of which a player or athlete is carrying out their activity, either about others or relation to personal goals or standards [26].

Performance assessment – *noun* a biomechanical analysis of an athlete's performance by a professional [26].

Stance – *noun* the position in which a player holds the body in attempting to hit a ball, e.g. in cricket or golf [26].

Pronation – *noun* the tendency of the feet to roll slightly inwards while running, cushioning the foot from impact [26].

Prone – *adjective* **1.** lying face downwards. Opposite **supine** **2.** used for describing the position of the arm with the palm facing downwards [26].

Supination – *noun* ineffective rolling inward of the foot while running, with the result that the foot is inadequately cushioned [26].

INTRODUCTION

Karate is a Japanese martial art that gained popularity quickly during the second half of the 20th century, with over 50 million practitioners worldwide at present. Based on local fighting styles originated in Okinawa (Japan), it has developed to become not only an effective method for self-defence but also to improve physical fitness and mental discipline in its practitioners through strenuous exercising [1]. An example of exercising in karate is the practice with the punching board (*makiwara*). This apparatus is a rustic version of a modern punching bag: a board fixed vertically at the bottom, with a padding on the top which is used as a target for hand and leg techniques. The apparatus is believed to improve, to increase the mechanical strength of the bones, and to gradually increase the maximum impact force generated by the karate techniques. However, such claims, like many similar claims in combat sports [2], are unsubstantiated: they are based on intuition, experience and sometimes are based on ideological rather than scientific principles.

To fill this gap and to understand the karate biomechanics a reasonable number of studies were published. However, only a few studies have produced estimates of the maximum impact force generated during the execution of a karate punch. These studies employ distinct methods to estimate the maximum impact force: cinematography [3-6], the strength of materials theory [4,7], force plate or force sensor [8-11], accelerometry [12-15], instrumented punching board [14,16]. Together these studies provided the framework for acquiring a representative value for the maximum impact force generated during a reverse punch on a punching board.

However, the majority of these studies present three major limitations:

(i) A small number of highly-trained subjects,

It is well known, that caution must be applied with a small sample size since the results might not accurately represent the maximum impact force generated during this technique. This problem is recurrent in most of these works because highly trained martial arts athletes are not so easy to find and it requires years to reach the expertise level necessary to perform the techniques efficiently.

(ii) Measurement adequacy,

Most of these studies used instrumentation techniques which may interfere with the technical execution and indirectly affect the results. For instance, the wiring necessary for the accelerometers has to be tapped to the limbs of the athlete executing the technique what is uncomfortable and completely distinct of a normal execution. Another important difference is the target itself. Punching force plates padded with foam and fixed to a rigid wall is not comparable to punching a *makiwara*. Consequently, the instruments and the techniques are impacted and therefore can be assumed not to represent the real situation experienced during regular practice accurately.

(iii) Correlation between the maximum impact force and relevant variables:

The studies do not try to correlate the maximum impact force with any anthropometric or biomechanical variable such as age and expertise. However, it is expected that they influence the physical performance of the athletes since some of these variables are affected by the biological functions. Consequently, it can be assumed that the maximum impact force must be affected by these variables as a result of the decline in biological functions.

This study offers two main contributions to this area of research. First, it employs a strictly traditional *makiwara* that was instrumented and calibrated to acquire the maximum impact force in a condition similar to the normal practice at the karate clubs. The use of a traditional *makiwara* was intended to reduce the occurrence of measurement errors in the variable of interest in this study, i.e., the maximum impact force.

Second, the study employs a nonparametric bootstrap resampling technique to improve the accuracy of the inference from the sample, a technique introduced by Efron and Tibshirani [17]. This robust technique allows correlating the biomechanical variables of interest with the maximum impact force. To date, the studies in the literature have been focused on the maximum impact force only. Besides these two points, this study presents an exploratory statistical study to identify the anthropometric and biomechanical variable that has the greatest influence on the maximum impact force from all the variables obtained from the athletes.

In this context, this study has two objectives. First, to measure the maximum impact force generated on the punching board during the execution of a highly incident technique in conditions as similar as possible to the ones faced during regular training. Second, to correlate the maximum impact force with anthropometric (i.e., age) and biomechanical (i.e., expertise) variables.

The cognitive goal of this study is the knowledge about two phenomena: (i) the maximum impact force on a punching board generated by a reverse punch (*gyaku-zuki*) in a front stance (*zenkutsu-dachi*) in conditions as close as possible to the regular practice, and (ii) the relationship between anthropometric (age) and biomechanical (expertise) variables with the maximum impact force.

MATERIAL AND METHODS

Subjects

Eight healthy male volunteers shotokan karate athletes (age: 20.25 ±4.13 years; height: 1.74 ±0.04 m; body mass: 72.41 ±9.62 kg; expertise: 7.64 ± 4.33 years; (mean, SD) participated in this study, and provided informed consent under the approval of the Federal University of Rio Grande do Sul (UFRGS) ethics committee. All subjects were black belts with significant results regarding competition (state, national) during the year before the experiment. Anthropometric and biomechanical data for each participant are specified in Table 1.

Apparatus

This study employed a traditional punching board (*makiwara*) with dimensions recommended on classic books by karate masters such as Funakoshi [1] and Nakayama [3]. The punching board was manufactured using untreated Jatoba (*Hymenaea courbaril*) with a density of 760 kg/m^3.

The dimensions of the punching board employed in this study are illustrated in Figure 1. The target, i.e., the surface (region) of impact was manufactured traditionally using a pad of rice straw and fixed with a rope at the top of the punching board. The rope was made of sisal (*Agave sisalana*), a natural fibre with a density of 1450 kg/m^3.

The maximum impact force was obtained, through four strain gauges in a Wheatstone bridge fixed directly on the punching board on both major faces (front and back) following longitudinal orientation. These strain gauges were further calibrated using a load cell (model ZX 5T, Alfa Instrumentos Eletronicos, Ltda) with a maximum capability of 5000 N, in the interval from 500 N to 2000 N. The calibration of the load cell and the strain gauges are depicted in Figures 2 and 3, respectively. The impact force signals generated by the strain gauges were initially amplified using a signal amplifier and then recorded on a computer.

Experimental Protocol

All subjects performed a dominant-hand reverse punch (*gyaku-zuki*), while adopting a front stance (*zenkutsu-dachi*), targeting the *makiwara* at full power. The reverse punch was performed starting from the static posture described in this paragraph. The subjects adopted a front stance (*zenkutsu-dachi*) with the front foot pointing

Table 1. Anthropometric and biomechanical data for the subjects (age: order variable).

Subject	Anthropometric			Biomechanical expertise [years]
	Age [years]	Height [m]	Mass [kg]	
1	16	1.77	85.9	4
2	17	1.75	71.9	4
3	17	1.68	55.8	5
4	18	1.66	72.5	6
5	21	1.78	80.9	9
6	21	1.72	63.8	12
7	24	1.82	78.5	5
8	28	1.73	70.0	16
Average SD	20.25 ±4.13	1.74 ±0.04	72.41 ±9.62	7.64 ±4.33

Supine – *adjective* **1.** lying on the back. Opposite **prone 2.** used for describing the position of the arm with the palm facing upwards [26].

Jatoba (**Hymenaea courbaril**) – is a tree common in the Caribbean, Central America, and South America. It is a hardwood that is used for furniture, flooring, and decoration.

Sisal (**Agawa siselana**) – is a species of *Agave* native to southern Mexico but widely cultivated and naturalised in many other countries. It yields a stiff fibre used in making various products.

Global science space – conventionally, the global science space is associated with the ability to provide the latest scientific knowledge through prestigious electronic scientific journals [37].

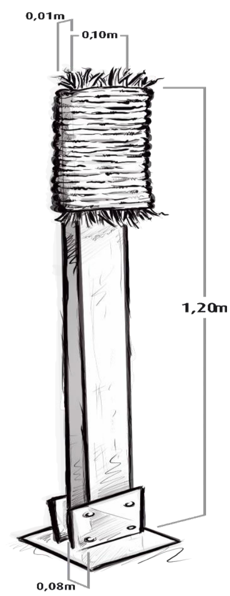

Figure 1. Dimensions of the *makiwara* employed in this study.

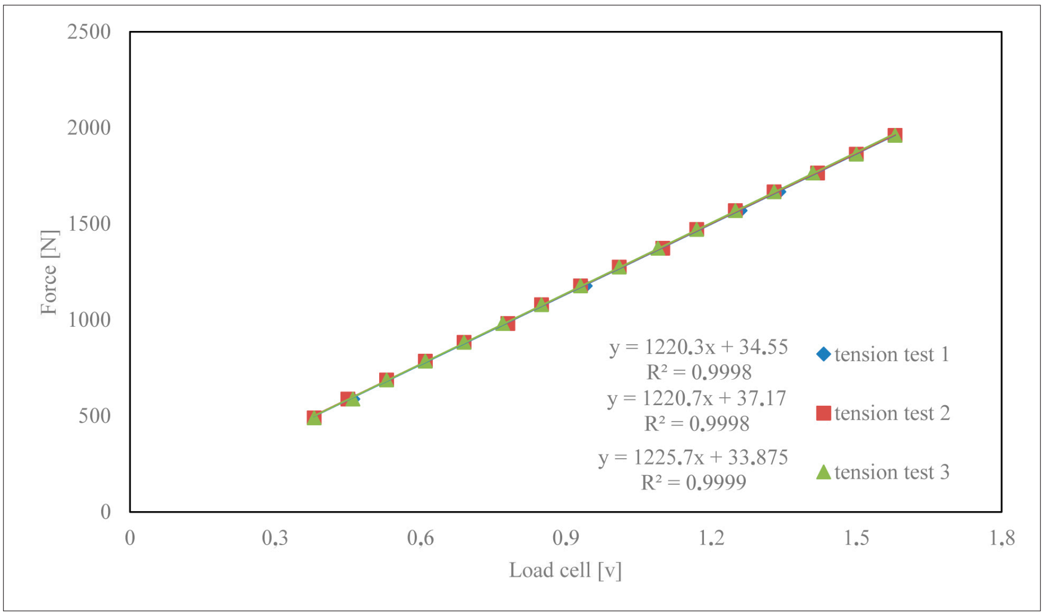

Figure 2. Calibration of the load cell.

towards the punching board and the rear foot slightly rotated laterally (Figure 4).

In this stance, the front knee is flexed so that it is directly above the toes of the front foot while the rear knee is slightly flexed. The weight distribution is 60% and 40% for the front and rear leg, respectively. The front stance length corresponds to two shoulders length, and its width is about one shoulder wide. The hips and torso are rotated at a 45° angle with relation to the target while the subjects face the punching board at arm's length. The front arm is fully extended, forearm in pronation, open fist aiming at the target (Figure 4a), which was adjusted to the solar plexus height of the subject executing the reverse punch. The rear hand was in supination with the fist clenched, resting slightly above the iliac crest. The stance and the technique used in all trials are illustrated in Figure 4. Additionally, the kinematic chain consists of the following stages:

(1) pressure on the rear foot heel;
(2) extension of the rear knee while maintaining a constant angle of the front knee;
(3) both tights, front and rear are contracted isometrically;
(4) hip rotation in the direction of the strike;
(5) momentum is transferred to the back, chest and shoulders;
(6) the striking arm is accelerated towards the target while the opposite arm is accelerated towards the iliac crest;
(7) right before impact, the striking hand forearm is pronated, with the elbow fully extended, while the opposite hand forearm is supinated and the elbow is flexed about 90°.

The reverse punch was elected based on its incidence during competitions and regular training sessions [18, 19] which is also true for the adopted stance [20]. Each subject performed a total of five reverse punches with a long resting period between punches. Additionally, the order of the punches performed by each subject was randomised across the participants. It is important to emphasise that before the trials, each subject was instructed to warm up and perform five reverse punches to familiarise themselves with the instrumented punching board used in this study.

Statistical Analysis

The method applied in this work assumes that a random sampling was extracted from a population of karate athletes in which the maximum impact force is dependent on the anthropometric and biomechanical variables of the individuals in the population. Therefore, the existence of a quadratic relation between age and the maximum impact force was tested. Similarly, the same relation was considered for the expertise and the maximum impact force. This type of function is quite often applied to capture decreasing or increasing marginal effects.

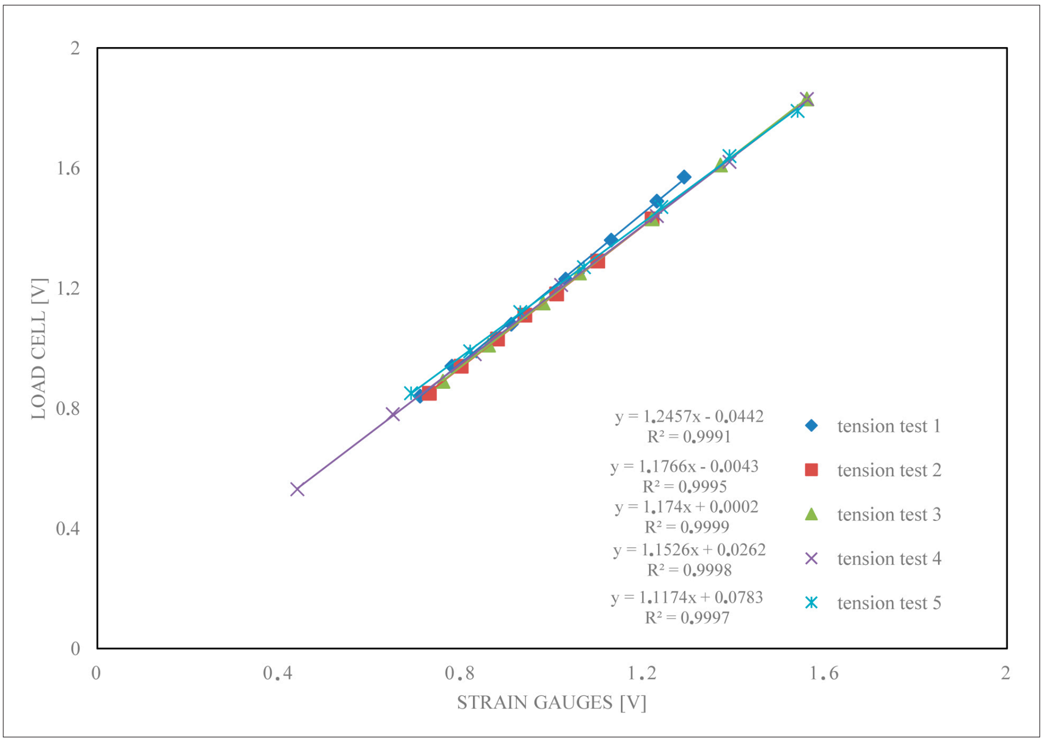

Figure 3. Calibration of the punching board strain gauges.

Figure 4a

Figure 4b

Figure 4c

Figure 4d

Figure 4e

Figure 4f

Figure 4. The stance and the technique used in all trials.

The central idea behind this hypothesis is that during lifetime training exists some optimal point of performance, and after it, the athlete faces a decreasing effect for each additional year of expertise. This is based on the understanding that the human performance peaks at a specific point in time during the lifetime training. Additionally, because of many physiological functions, which may affect the maximum impact force, gradually deteriorate with ageing [21, 22], it is also reasonable to assume that a decreasing effect also can be observed in the variable age. The major limitation of this approach is the low number of observations in this study. The bootstrap resampling technique is applied to estimate the unbiased and more efficient coefficients of interest in the population equation (1). This implies that no control variables can be put together in the model described by the equation (1). In a bivariate context, the population model is specified as,

$$
\begin{aligned}
&{}^{*}\, y_i = \beta_1 x_i + \beta_2 x_i^2 + \varepsilon_i \\
&\varepsilon_i \sim iid(0, \sigma^2)
\end{aligned}
\tag{1}
$$

Where y_i is the maximum impact force, x_i represents the anthropometric or biomechanical variables, and e_i is the error term with zero mean and constant variance independent and identically distributed. The coefficients of interest to be estimated are b_1 and b_2, in which $b_1>0$ and $b_2< 0$. In this specification, b_1 does not measure the change in y_i with respect to x_i; this can be clearer when the estimates are written as,

$$\hat{y} = \hat{\beta}_1 x + \hat{\beta}_2 x^2 \tag{2}$$

Moreover, the approximation of the average effect on y is expressed as,

$$\Delta\hat{y} \approx \left(\hat{\beta}_1 x + \hat{\beta}_2 x^2\right)\Delta x \text{, and } \frac{\Delta\hat{y}}{\Delta x} \approx \hat{\beta}_1 + 2\hat{\beta}_2 x \tag{3}$$

Then, for x = 0, it is observed that b_1 might be interpreted as the approximate slope between points x = 0 and x = 1. The second term, i.e., $2b_2x$ must be accounted for x > 1. Equation (2) may be used to predict the average, but, in general, the interest lies in marginal effects in this type of population model plugging the average x value of the sample, median, lower and upper quartile values in the equation (3).

Summarizing, if the estimated coefficients b_1 and b_2 are statistically significant, implies that age and expertise have a diminishing effect on the maximum impact force after some critical point. Therefore, the most probable critical point of the performance may be inferred from a population of highly-trained athletes. Before this point, an additional year of age or expertise produces an increase in performance, and after this critical point, any addition would represent a decrease in performance.

Another possibility to be explored in this study is to verify the existence of a correlation between maximum impact force and anthropometric or biomechanical variables by using a set of standardised variables. In this case, the population model described in equation (2) may be modified as,

$$
\begin{aligned}
&Z_{y_i} = \alpha_1 Z_{x_i} + \alpha_2 Z_{w_i} + u_i \\
&u_i \sim iid(0, \sigma^2)
\end{aligned}
\tag{4}
$$

where u_i is the error term with the same properties stated previously, and,

$$Z_{y_i} = \frac{y_i - \mu_y}{sd(y_i)} \tag{5}$$

$$Z_{x_i} = \frac{x_i - \mu_x}{sd(x_i)} \tag{6}$$

$$Z_{w_i} = \frac{w_i - \mu_w}{sd(w_i)} \tag{7}$$

where y_i is the maximum impact force and x_i and w_i are both anthropometric or biomechanical variables of interest measured in the *i*-th individual (i = 1,...,8), such as the age and expertise. The m_y, m_x, and m_w are the sample averages and sd (y_i), sd (x_i) and sd (w_i) are their respective standard deviations. The indicators of interest to be estimated are a_1 and a_2.

The equation (4) provides a useful and direct interpretation because the variables are standardised allowing direct comparison. The interpretation of the estimate is that if the regressor x_i increases by one standard deviation, on average, the maximum impact force y_i increases by a_j (j = 1,2) a_j standard deviation units. This approach has two more major advantages. First, the magnitude of the various estimates within and between models can be compared directly to search for the main influence on the maximum impact force. Second, this comparison is not sensitive to the units of measurement of x_i and y_i.

Because the sample of this study is small which is a very common condition in this kind of study, the nonparametric bootstrap resampling was adopted to provide better accuracy to the estimate, e.g., lower dispersion for the b_j and a_j coefficients.

Table 2. Maximum impact force measured on the punching board *(makiwara)*.

Subject	Maximum impact force [N] by trial					Average maximum impact force (N)	
	1	2	3	4	5	*M*	*SD*
1	1839.42	**1912.76**	1310.82	1829.34	1691.66	1716.80	240.60
2	1808.51	**1925.13**	1915.18	1775.20	1783.99	1841.60	72.83
3	1653.96	1640.42	**1767.91**	1434.73	1691.44	1637.69	123.81
4	**1771.03**	1549.72	1381.62	1694.44	1440.39	1567.44	164.74
5	**2146.90**	2116.71	2067.77	1961.57	1689.24	1996.44	185.59
6	**1803.07**	1582.37	1659.16	1712.48	1707.18	1692.85	80.75
7	1529.36	2009.34	1684.28	**2215.38**	1687.03	1825.08	279.56
8	**2314.53**	2215.16	2255.77	2179.40	2126.08	2218.19	71.93

This computer-intensive technique, introduced by Efron and Tibshirani [17], allows estimating the sampling distribution of a statistic of interest (b_j and a_j) without specific assumptions about the form of the population, such as normality and equal variance hypotheses. To this end, the procedure for the statistical treatment was as follows:

1. A sample with replacement of size *n* is drawn from the elements of the sample ***S*** as an estimate of the population ***P***, denoting $X^* - = \{(x_{i1},y_{i1}),\dots,(x_{i8},y_{i8})\}$ the bootstrapped pairs obtained from ***S***, in which x_i is the age and y_i is the measured maximum impact force, for example.

2. This procedure is repeated a large number of times (*R*) to obtain the empirical distribution of the coefficients fitting the model and saving it from each bootstrap sample.

Table 3. Estimates for equation (1) – results. Dependent variable: maximum impact force [N].

Independent variables	Marginal expertise effects	Marginal age effects
x_1	**485.34***** (5.94)	**148.44***** (8.32)
x_1^2	**–22.34*** (1.93)	**–2.39***** (–2.57)
Adjusted R^2	0.95	0.99
F-statistic	**78.44*****	747.60
Bootstrap replications	5000	5000

Notes: the t-values are into brackets; statistically significant at: *p = 0.10; ***p = 0.01.

3. Lastly, the average of the bootstrappedb$^*_j$ coefficients is computed from the expression,

$$\bar{\beta}_j^* = \hat{E}^*(\beta_j^*) = \frac{\sum_{b=1}^{R} \beta_{jb}^*}{R} \quad (8)$$

To test for the significance of the bootstrap statistic, it is necessary to calculate the bootstrap estimated standard error, defined as,

$$s\hat{e}^*(\beta_j^*) = \sqrt{\frac{\sum_{b=1}^{R} (\beta_{jb}^* - \bar{\beta}_j^*)^2}{R-1}} \quad (9)$$

The analogous expressions (8) and (9) were also calculated for the coefficients a_1 and a_2 from population model described in equation (4).

RESULTS

Table 2 presents the maximum impact force measured in five trials for all the subjects. For instance, the first and second athlete presented the highest maximum impact force which was observed in the second trial, and so on.

Additionally, from the anthropometric data and Table 1, a negative correlation (R = –0.25) was observed between the age and the standard deviation of the subject's performance. This indicates that the expertise accumulated over the years may exert a stabilising effect. Table 3 presents the estimates for the model specified in equation (1), in which the maximum impact force is the dependent variable.

As expected, the signs of the coefficients are according to the hypothesis stated in this study and render all statistically significant at a conventional level of probability. The F-statistic indicates that the model is globally significant at 0.01 percent level. Additionally, the high goodness-of-fit

Table 4. Estimates for equation (4) – results. Dependent variable: maximum impact force [N].

Age and expertise comparison		Age and height comparison		Expertise and height comparison	
Independent variables	**Estimates**	**Independent variables**	**Estimates**	**Independent variables**	**Estimates**
Age	**1.19***	Age	**0.69****	Expertise	**0.55***
	(1.88)		(2.46)		(1.90)
Expertise	–0.53	Height	**0.49****	Height	**0.71*****
	(–0.80)		(2.55)		(5.00)
Adjusted R^2	0.69	Adjusted R^2	0.82	Adjusted R^2	0.64
F-statistic	**9.86***	F-statistic	**19.38*****	F-statistic	8.03
Bootstrap Replications	5000	Bootstrap Replications	5000	Bootstrap Replications	5000

Notes: the t-values are between brackets; statistically significant at: *p = 0.10 level; **p = 0.05; ***p = 0.01

measure (R^2) indicates that the model can accurately predict the individual behaviour with only two variables.

Both variables age and expertise present statistically significant correlation with the maximum impact force. However, this dependence manifests itself in a quadratic form, in which a decreasing effect is present and dictates the behaviour of the maximum impact force. Table 4 presents the estimates for the population model specified in equation (4).

When the age effect upon the maximum impact force is controlled for expertise or height, its significance and positive influence remain. Because the magnitude of these estimated coefficients are measured in standard deviations, evidence was found that age is the main influence on the athlete's performance when controlling expertise and height (Table 3). Figure 3 was obtained based on the coefficients estimated from the sample and are presented in Table 3. In this graph, is possible to observe how the maximum impact force progresses according to variations in age and expertise.

DISCUSSION

Cinematography

The first study employing cinematography was conducted by Nakayama [3], using a 16 mm motion picture camera at 64 frames per second. The films were obtained from a distance of 8 m against a calibrated background with 10 cm marks. In the study, an athlete performed *tameshiwari* on two boards using a straight punch. The maximum impact force was initially estimated as approximately 1668 N calculated in an arbitrary contact time of 1/100 s, but it was later recalculated to be 6867 N on a more realistic contact time of 1/64 s.

The second study was conducted by Walker [4] to acquire the velocity of a reverse punch for one subject. Assuming that the mass of the striking arm is 10% of the body mass, and the contact time estimated by Nakayama the maximum impact force was calculated as an average of 4900 N. The main disadvantage of cinematography is that the results are highly dependent on the quality of the movies. If the movie is not clear, is difficult to determine the position of the markers clearly, and consequently, it introduces a substantial error in the determination of the velocity and acceleration. Additionally, the process of differentiation can also introduce round-off error compromising the accuracy of the results.

Force plate

A limited amount of literature has been published using this method. Voigt [8] employed a triaxial force plate to acquire the maximum impact force in a reverse punch for 10 experienced subjects. The results range from 2345 N to 4866 N with an average of 3334 N. Dworak et al. [9] experimented with 21 subjects executing a reverse punch on a triaxial force plate covered with a shock absorbing the material. The subjects presented different degrees of expertise, i.e., the group of the subject consists of beginners and advanced practitioners. Their results indicated that the maximum impact force generated by the left and right limbs are statistically significant at %5 probability.

The average impact forces for the right and left limbs are approximately 1800 N and 1600 N,

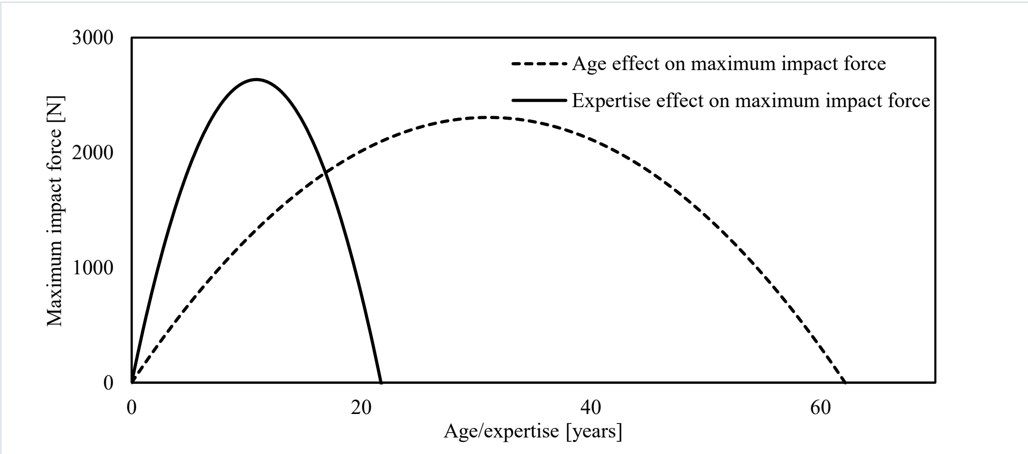

Figure 5. Correlation between the age and the maximum impact force and the expertise and the maximum impact force.

respectively. Considering all trials, the maximum impact force ranges from 1260 N to 2160 N, independent of the limb. Gulledge et al. [10] employed 12 expert subjects to acquire the maximum impact force of a reverse punch aimed at a padded force plate fixed to the wall. The average maximum impact force exerted by the fist was 1450 N.

The main disadvantage of the studies employing this method and these settings is the rigidity of the whole target/measurement system. While all the studies employing this method use a force plate with its surface covered with some damping material, the fact that the force plate is fixed to the wall drastically increases the rigidity of this measurement apparatus. In addition to that, the force plates are already rigid, which increases the total rigidity of the system even further. As a consequence, the subjects can become afraid of being injured by punching such stiff apparatus, and therefore do not perform the karate techniques at full power. Also, an over-rigid apparatus is prone to provide unrealistically high values for the impact forces.

Accelerometry

Some researchers have investigated the maximum impact force using this method. Schwartz et al. [12] used accelerometers set at a sampling rate of 12.8 kHz and mounted at the centre of mass of a dummy's head to acquire the acceleration caused by a reverse punch executed by 14 experienced subjects. The representative result presented in the study estimated the average maximum impact force as 3021 N. The acceleration value acquired in the study was 44 g where g = 9.81 m/s^2. This study considered the effective mass involved in the reverse punch as 4 kg to estimate the maximum impact force for all cases involving the accelerometry method.

Chiu and Shiang [13] employed 12 experienced subjects (8 males and 4 females) to perform reverse punch aiming at a target instrumented with a tri-axial accelerometer set at a sampling rate of 1000 Hz. The range for the maximum impact forces is from 1687 N to 2119 N and from 942 N to 1530 N for males and females, respectively.

The advantage of this method is that the acceleration can be obtained instantaneously, eliminating errors generated during the calculation of the associated kinetic variables (displacement and velocity) like in the case of cinematography. There are, however, some problems with this approach. First, the accelerometers can affect the way the punch is executed because the wiring may complicate the movement of the upper limbs. Second, the impact involved in punching a fixed target can generate artefacts in the output signal because of the mass of the accelerometer itself. Third, mounting the accelerometer is complicated, and the mounting method can affect the results.

In general, accelerometers mounted directly on soft tissue are prone to produce results which do not reflect the amplitude of the actual acceleration of the segment, as stressed by Nigg & Herzog [24]. Unfortunately, because none of the studies details of how the accelerometers were mounted, it is difficult to evaluate the accuracy of the results, or to interpret the extent to which the measured acceleration corresponds to the acceleration of interest.

Strain gauges

Only one short report was published by Girodet et al. [16] using strain gauges to measure the maximum impact force of a reverse punch. In this study, the maximum impact force was acquired directly on an instrumented punching board. The study recruited only one subject which generated a maximum impact force of 1745 N. It is important to emphasise that the accuracy of the results is highly dependent on the calibration process. For this kind of movement, it is important to employ not just a static calibration but also to include a dynamic calibration.

The range for the maximum impact force acquired in this study, 1310.82 N – 2314.53 N, which employed the same method, is consistent with most of the results presented in this section. Additionally, the average value for all trials, 1812.01 N, is similar to most of the results found in the literature. This is a strong indicator that the methodology employed in this study is adequate for this kind of biomechanical analysis.

Effect of the variables on the maximum impact force

Previous studies already found evidence that expertise is a crucial factor for performance, i.e., athletes with more expertise perform significantly better than beginners [2, 24, 25]. As expected, this study also found that expertise plays an important role in the athletes' performance. However, expertise does not contribute positively to the maximum impact force indefinitely, i.e., it has a critical point after which the contribution to the maximum impact force is negative.

From the results exposed in Table 2 and the calculations from equation (2), it is concluded that the critical expertise point is 10.89 years, whose maximum performance associated is 2614.08 N. In addition to the expertise effect from equation (3), it is concluded that the first year of expertise renders 485.34 N of additional maximum impact force.

When the typical athlete has already undergone 12 years of regular training, the impact force increases by $[485.34 - 2 \times (22.34) \times (12)] \approx -50.92$ N, because of the decreasing marginal effects. Thus, after 12 years of expertise, one additional year of the expertise implies a decreasing effect of approximately 51 N, on average, on the maximum impact force generated by the athletes in the population.

Because the majority of the studies are focused on the mean and median of years of training, according to the estimated effect described previously, and in accordance with equation (3), the effect of an additional year of training when the individual has 7.7 years (sample mean) of expertise is 141.80 N of additional impact force.

Similarly, the second variable, i.e., age also affects the maximum impact force. This effect was already expected because biological functions on the human body, which affect the capacity to perform athletically, decreases with age [21, 22]. For this variable, the turning point was calculated as 31.07 years and the maximum impact force associated is 2306.02 N. In this case, it was found that after a critical point of 31 years, i.e., when the individual turns 32 years old, the diminishing effect is $[148.44 - 2 \times (2.39) \times (32)] \approx -4.43$ N.

In conclusion, when the rate of change of the two variables is analysed is possible to verify that the expertise has a faster effect on the maximum impact force than the age. These effects can be identified in Figure 3.

CONCLUSIONS

This direct measurement enabled the subjects to perform the reverse punch naturally and without the fear of injury involved in punching a force plate. Also, this measurement technique did not change the inertial mass or the rigidity of the punching board, and this is crucial to acquire accurate results for the maximum impact force.

It was found that age and expertise directly affect the maximum impact force as documented in the literature. However, these influences have a critical point of which they have a decreasing effect on the maximum impact force. The critical point for the age is 31 years old and, the critical point for the expertise is 11 years of lifetime training. After these critical points, the karate athlete would be advised to search for ways to compensate for the decreasing marginal effects, such as nutrition or complementary practices under the guidance of a professional.

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REFERENCES

1. Funakoshi G. Karate-Do Kyohan. The Master Text. Tokyo: Kodansha International; 1973
2. Lenetsky S, Nates RJ, Brughelli M et al. Is effective mass in combat sports punching above its weight? Hum Mov Sci 2015; 40: 89-97
3. Nakayama M. Dynamic Karate: Instruction by the Master. Tokyo: Kodansha International; 1966
4. Walker JD. Karate strikes. Am J Phys 1975; 43(10): 845-849
5. Feld MS, McNair RE, Wilk SR. The physics of karate. Sci Am 1979; 240(4): 150-158
6. Wilk S, McNair R, Feld M. The physics of karate. Am J Phys 1983; 51(9): 783-790
7. Blum H. Physics and the art of kicking and punching. Am J Phys 1977; 45(1): 61-64
8. Voigt M. A telescoping effect of the human hand and forearm during high energy impacts. J Biomech 1989; 22(10): 1095
9. Dworak LB, Dziewiecki K, Maczynski J. Characteristics of kinematics and kinetics of strokes in karate - biomechanical approach. ISBS – Conference Proceedings Archive 2005; 109-112
10. Gulledge JK, Dapena J. A comparison of the reverse and power punches in oriental martial arts. J Sports Sci 2008; 26(2): 189-196
11. Viero FT. Analise cinetica do soco no karate em postura natural e avancada [master's thesis]. Florianópolis City, Santa Catarina State: Universidade do Estado de Santa Catarina, Centro de Ciencias da Saude e do Esporte; 2011 [in Portuguese]
12. Schwartz ML, Hudson AR, Fernie GR et al. Biomechanical study of full-contact karate contrasted with boxing. J Neurosurg 1986; 64(2): 248-252
13. Chiu H, Shiang T. A new approach to evaluate karate punch techniques. ISBS - Conference Proceedings Archive 1999; 61-64
14. Aguiar de Souza V. Analise de impacto e risco de lesoes no segment superior associadas a execucao da tecnica de gyaku tsuki sobre makiwara por praticantes de karate do estilo shotokan. MA thesis. Porto Alegre, Rio Grande do Sul: Universidade Federal do Rio Grande do Sul, Departamento de Engenharia Mecanica; 2002 [in Portuguese]
15. Emmermacher P, Witte K, Hofmann M. Acceleration course of fist push of gyaku-zuki. ISBS – Conference Proceedings Archive 2005; 844-847
16. Girodet P, Vaslin P, Dabonneville M et al. Two-dimensional kinematic and dynamic analysis of a karate straight punch. Comput Methods Biomech Biomed Engin 2005; Suppl 1: 117-118
17. Efron B, Tibshirani RJ. An Introduction to the Bootstrap. Boca Raton: Chapman & Hall; 1993
18. Hofmann M, Witte K, Emmermacher P. Biomechanical analysis of fist punch gyaku-zuki in karate. ISBS – Conference Proceedings Archive 2008; 576-579
19. Gallaher DM. 3D analysis of punching technique: reverse vs. lead (gyaku tsuki vs. oi tsuki) [master's thesis]. Chico: California State University; 2013
20. Aguiar de Souza V, Viero FT, Marques AM. Weight distribution in karate stances: a comparison between experimental and postulated values. Arch Budo 2015; 11: 351-358
21. Bosco C, Komi PV. Influence of aging on the mechanical behavior of leg extensor muscles. Eur J Appl Physiol Occup Physiol 1980; 45(2-3): 209-219
22. Tanaka H, Seals DR. Invited review: dynamic exercise performance in masters' athletes: insight into the effects of primary human aging on physiological functional capacity. J Appl Physiol 2003; 95(5): 2152-2162
23. Nigg BM, Herzog W. Biomechanics of the musculo-skeletal system. Chichester: Wiley & Sons; 2007
24. Cesari P, Bertucco M. Coupling between punch efficacy and body stability for elite karate. J Sci Med Sport 2008; 11(3): 353-356
25. VencesBrito AM, Rodrigues Ferreira MA, Cortes N et al. Kinematic and electromyographic analyses of a karate punch. J Electromyogr Kinesiol 2011; 21(6): 1023-1029
26. Dictionary of Sport and Exercise Science. Over 5,000 Terms Clearly Defined. London: A & B Black; 2006
27. Martens R. Successful Coaching. London: Human Kinetics; 2004

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EDITORIAL NOTE

The article is an example of holding on the paradigm of discussing the results of a specifically studied phenomenon. Out of concern for raising the methodological value of publications and providing the reader with the expanded knowledge about the phenomena from the borderline or with the perspective of other martial arts (combat sports) we are recommending papers concerning taekwondo [28-32].

However, the most important of the prospect of the mission the *Archives of Budo* [33-35], and the *Czestochowa Declarations 2015: HMA against MMA* [36] is promoting the health values of martial arts (and combat sports) in the global science space. Conventionally, the global science space is associated with the ability to provide the latest scientific knowledge through prestigious electronic scientific journals [37]. It is about journals being evaluated in the most prestigious scientific literature databases. The peer review procedurę is guaranteed and the possibility of tracking.

RECOMMENDED REFERENCES

28. Wąsik J, Czarny W, Małolepszy E et al. Kinematics of taekwon-do front kick. Arch Budo Sci Martial Art Extreme Sport. 2015; 11: 23-29
29. Wąsik J, Shan G. Kinematics of the turning kick – measurements obtained in testing well-trained taekwon-do athletes. Arch Budo 2015; 11: 61-67
30. Ortenburger D, Wąsik J, Góra T. Selected dimensions of the self-esteem and a kinematic effect of the intentional target at taekwondo athletes. Arch Budo Sci Martial Art Extreme Sport 2016; 12: 117-121
31. de O Goulart KN, Corgosinho RF, Rodrigues SA et al. Correlation between roundhouse kick and countermovement jump performance. Arch Budo 2016; 12: 125-131
32. Wąsik J, Ortenburger D, Góra T. The kinematic effects of taekwondo strokes in various conditions the outside environment. Interpretation in the psychological aspect and perspective of application in sport, health-related training and survival abilities. Arch Budo 2016; 12: 287-292
33. Kalina RM, Barczyński BJ. Archives of Budo – dialogue about the personal safety and action worth the man. Arch Budo 2008; 4(4): 1-3
34. Kalina RM, Barczyński BJ. Budo – a unique keyword of life sciences. Arch Budo 2009; 5(5): 117-119
35. Kalina RM, Barczyński BJ. Archives of Budo Science of Martial Arts and Extreme Sports – A reason for this new branch journal. Arch Budo Sci Martial Art Extreme Sport. 2013; 9: 1-9
36. Kalina RM, Barczyński BJ. Long way to the Czestochowa Declarations 2015: HMA against MMA. In: Kalina RM (ed.) Proceedings of the 1st World Congress on Health and Martial Arts in Interdisciplinary Approach. 2015 Sep 17–19; Czestochowa, Poland. Warsaw: Archives of Budo; 2015: 1-11
37. Barczyński BJ, Kalina RM. Science of martial arts – Example of the dilemma in classifying new interdisciplinary sciences in the global systems of the science evaluation and the social consequences of courageous decisions. Procedia Manufacturing; 2015; 3: 1203-1210