Original Article

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Conception of effective mass and effect of force – measurement of taekwon-do master

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Abstract

Background: Engagement of mass during a strike in martial arts and its relation to generated force is one of the factor, deciding on the success of an athlete. The aim of this study was to calculate the quantitative portion of effective mass of a athlete who execute striking techniques, by registering a force of strike and time of its contact with a sensor (target). *Material and methods:* Black belt taekwon-do (International Taekwon-do Federation) master (age 32 years, body mass of 60 kg, height of 160 cm) performed three types of techniques for three times; roundhouse kick, front kick, side kick and straight punch. His target was a shield mounted on force plate MC 12-2K with amplifier GEN5. Acceleration data was obtained by mounting wireless IMU sensor manufactured by Noraxon attached to a lateral side of a foot. *Results:* The highest force was registered for side kick (2406.9 ± 299.8 N), and the lowest for front kick (2008.6 ± 284.8 N). The shortest time of contact with a target had roundhouse kick (0.026 ± 0.010 s), while the longest front kick (0.119 ± 0.052 s). The highest effective mass was achieved by front kick (44%). The highest effect of force coefficient was obtained by roundhouse kick. Other techniques with much lower values seems to be push-like movements. *Conclusions:* During strike, a crucial factor for its effectiveness lies in its destructive power. It does not only depend on generated force and engaged mass, but also on contact duration. Proposed quantitative indicators could be beneficial during preparation of an athlete to sport competition. Correctly calculated effective mass allows to measure force in a training environment.

Keywords: martial arts, biomechanics, force plate, acceleration, effective mass

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INTRODUCTION

Maximal force of a strike depends on many factors; distance, speed and proper coordination of certain segments of the body [1,2]. Determining a strike force for uniformly shaped block of mass is a simple product of its mass and acceleration [3]. In this example, effective mass is equal to its whole mass. However, human body is not homogenous block. It is composed of tissues with their unique elasticity and deformity. These factors could decrease the force of a strike, as some force could be dispersed through tissues involved in the kinematic chain [4]. Therefore, while executing a strike in combat sports, we do not use a whole mass of striker, but some percentage of it. Effective mass is a term commonly used in sport science, referring to a degree of mass involved in a strike. It is used in a sports when there are strikes and mass put behind it involved such as baseball, golf, tennis etc. [5]. It was suggested, that the more body segments sportsman can involved into executing a motion, the higher is potential effective mass use [6,7]. What is interesting, there is no linear correlation between effective mass and total mass of a sportsman's body [8]. This suggests that well-trained and experienced martial artists could achieve higher effective mass by proper muscle contraction right before a contact with a target [9]. Moreover, getting proper effective mass value is crucial, as sole maximal velocity or acceleration did not guarantee high force values behind a strike [3].

Equation of dynamics are used for determining effective mass in combat sports [5,8,10] are based on a simple models of the principle of conservation of momentum. It assumes, that given mass (i. e. mass of a fist) strikes a target with known velocity and transfers all momentum into a target. It results in target displacement with registerable velocity. Assessments of effective mass and calculations based on regression equations [11] confirms, that tested martial artists obtained higher effective mass values than those estimated from mass of body segments, confirming importance of technique and coordination of kinematic chain during the stroke [12]. Moreover, another flaw of that assessment method is that effective mass could differ depending on the mass of a target. Theoretically, this model seems to be proper, but it does not explains fully transfer of momentum during a hit executed by an athlete [13]. That was a reason why we decided to assess effective mass with use of classical The Principle of Newton's Second Law:

$$\mathrm{M_e} = \frac{\mathrm{F_{max}}}{\mathrm{a}} \quad (1)$$

where M_e –effective mass, involved in a strike; F_{max} –maximum force with which strike was performed; a – maximal acceleration before a contact with a target.

Important factor affecting a total amount of force transferred into an object is a time of contact. If a time of contact is short, we consider it as a strike, if its longer we consider it as a push. In a physics, there is a term for impulse force. Its definition says that it is a vector Impulse is the product of the force affecting an object over certain duration [3,14]. In practice it is easier to register maximal force value and a time of contact with a target. Therefore, to show a specificity of acting force, we compute coefficient E_F (Effect of force), which is proportion of maximal force of a strike to its time of contact according to a proposed formula:

$$\mathrm{E_F} = \frac{\mathrm{F_{max}}}{\mathrm{T_{contact}} \cdot 100} \quad (2)$$

where E_F –effect of force; F_{max} – maximum force with which strike was performed; $T_{contact}$ – contact duration time.

To avoid very large values of Ef, we decided to multiply time by 100, for better presentation of the results.

The aim of this study was to calculate the quantitative portion of effective mass of a athlete who execute striking techniques, by registering a force of strike and time of its contact with a sensor (target). Applicational aim of this study is to form a recommendations for coaches and practitioners in order to optimize technical parts of techniques executions and training methods. Teaching faster, stronger and more accurate strikes is a key for sport competition and self-defense.

MATERIALS AND METHODS

Subject

This study was conducted with one participant. He is black belt taekwon-do (International Taekwon-do Federation) master in age was 32 years with body mass of 60 kg and height of 160 cm. He won Polish Championships twice and obtain bronze medal in European Championships.

Protocol

Participant did 10 minutes of warm-up and then performed three types of techniques for three times; roundhouse kick, front kick, side kick and straight punch. His target was a shield mounted on force plate MC 12-2K with amplifier GEN5. The size of plate was 300 mm x 400 mm x 78 mm. Force plate can register forces up to 18000 N with sampling frequency of 880 Hz. Device was connected to computer and data was acquired using MR 3.18 software provided by Noraxon. Acceleration data was obtained by mounting wireless IMU sensor manufactured by Noraxon, synchronized with a force plate. Sensor was attached to a side of a foot, near lateral malleolus. All techniques were executed with the right limbs, which is participant's preferred side of the body. Techniques were performed from sport stance. The range from was adjusted by participant. Shield was placed on the height corresponding to a middle strike zone, which corresponds to a height of his torso. Participant was instructed to start striking on his decision after we informed him that capturing process started. After each technique capture session stops and we prepare software for another one, which did not last more than 2 minutes. Participant ought to strike the fastest and hardest he can.

Statistical analysis

Raw data was exported in a form of data frames accessible for further computation. Maximal values of force and acceleration were determined using program written by authors in python programming. Using scipy library for python programming language, peak values of signal for each technique was determined alongside a time of its occurrence. Then time of contact was extracted manually from analyzing signals manually firstly from the graphs then comparing it from video synchronized with captured data. Mean and standard deviation was computed from obtained data. Effect of force was computed using Microsoft Excel 365.

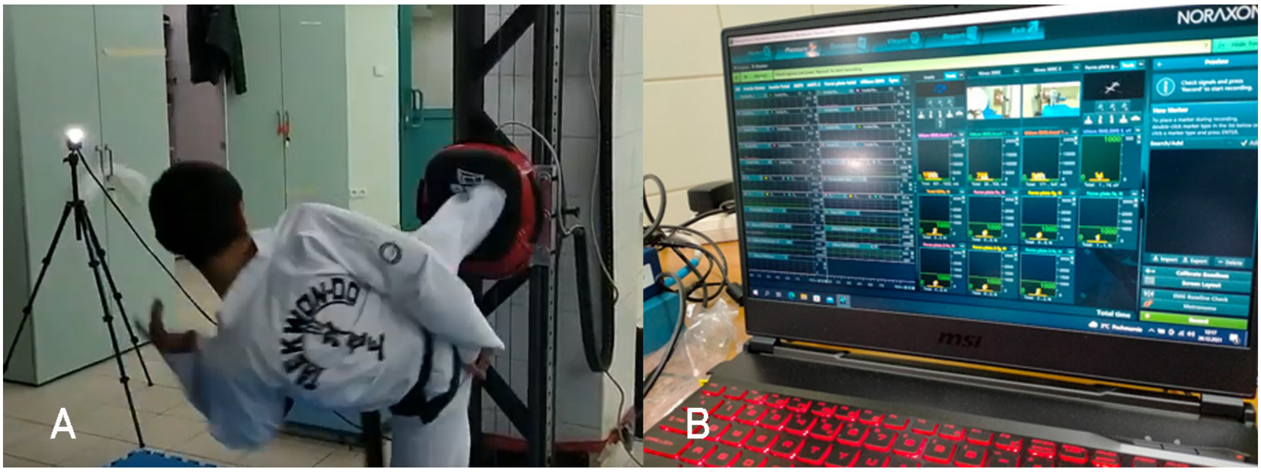

Figure 1. Illustration presents setup with authorship apparatus for assessing striking force. A – example of executing side kick, B – software interface on the computer.

Ethics

The Human Subjects Research Committee of the host University scrutinized and approved the test protocol as meeting the criteria of Ethical Conduct for Research Involving Humans (Ethics Committee at the Jan Dlugosz University, number KE-O/4/2022, date 21.03.2022). All subjects in the study were informed of the testing procedures and voluntarily participated in the data collection.

RESULTS

Avarage values of registered kinematic indicators are presented in table 1. The highest force was registered for side kick (2406.9 ± 299.8 N), then for roundhouse kick (2330.7 ± 71.2 N) and the lowest for front kick (2008.6 ± 284.8 N). Force registered for straight punch was almost twice lower as those for kicks (1184.4 ± 55.5 N), but acquired higher maximal acceleration of 140.4 ± 5.1 m/s^2. The shortest time of contact with a target had roundhouse kick (0.026 ± 0.010 s), while the longest front kick (0.119 ± 0.052 s). Figure 2 shows an example of force of a strike, registered by force plate. The whole contact lasts no more than 0.2 s. After body contacted the force plate, there is a phase of receiving a force up to its maximum value, then at deceleration and slow retraction of a body from a force place, there is a decrease in registered values until they got to zero. Effect of force coefficient for studied techniques are presented in a figure 3. It shows overwhelmingly larger value for roundhouse kick, as its duration of kick is much lower, without such gap in registered force.

Table1. Avarage values of registered kinematic variables.

Technique	a [m/s^2] x ± SD	F_{max} [N] x ± SD	$T_{contact}$ [s] x ± SD	M_e [kg] x ± SD
Straight punch	140.4 ± 5.1	1184.4 ± 55.5	0.093 ± 0.023	8.4 ± 0.1
Front kick	64.3 ± 9.8	2008.6 ± 284.8	0.119 ± 0.052	26.1 ± 2.7
Side kick	106.3 ± 7.7	2406.9 ± 299.8	0.106 ± 0.048	22.6 ± 1.4
Roundhouse kick	115.8 ± 11.3	2330.7 ± 71.2	0.026 ± 0.010	20.6 ± 2.5

a – acceleration; F_{max} – maximum registered force; $T_{contact}$ – duration of contact; M_e- effective mass; x – average; SD – standard deviation

Figure 1 shows proportion of effective mass calculated accordingly to a formula 1. Despite the highest registered values for side kick, the values of effective mass was highest for front kick with 44% of participant's body mass. The less percentage value of 14.1% was for straight punch.

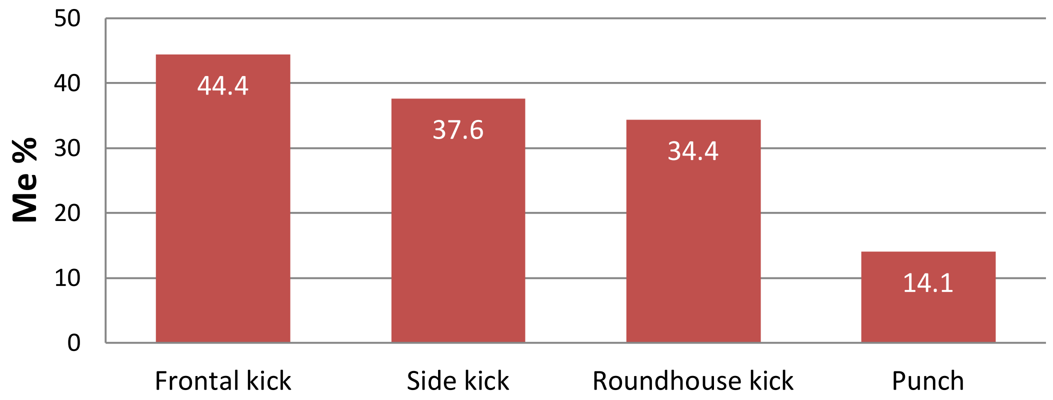

Figure 1. Percentage of participation of effective mass in chosen techniques.

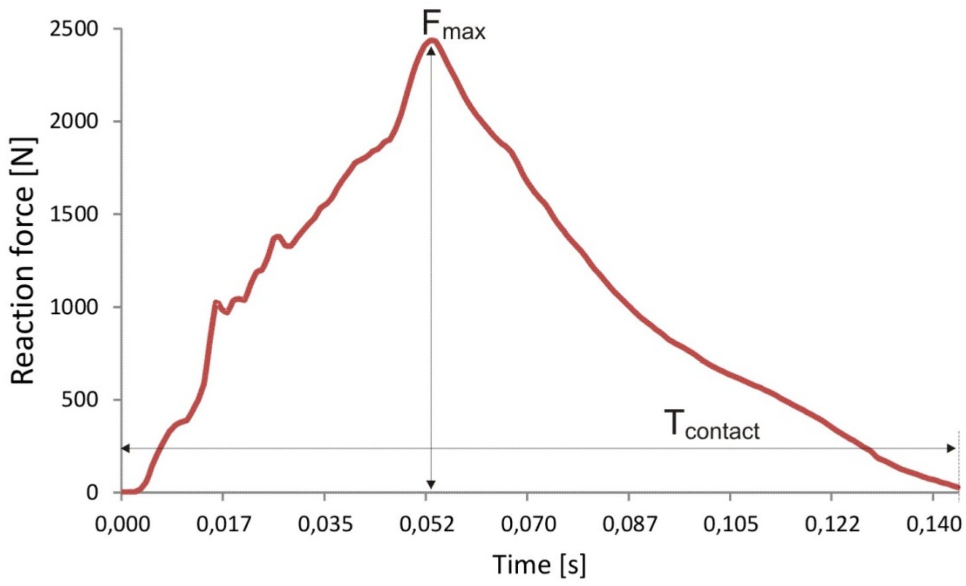

Figure 2. Graph presenting force registration on force plate during a strike.

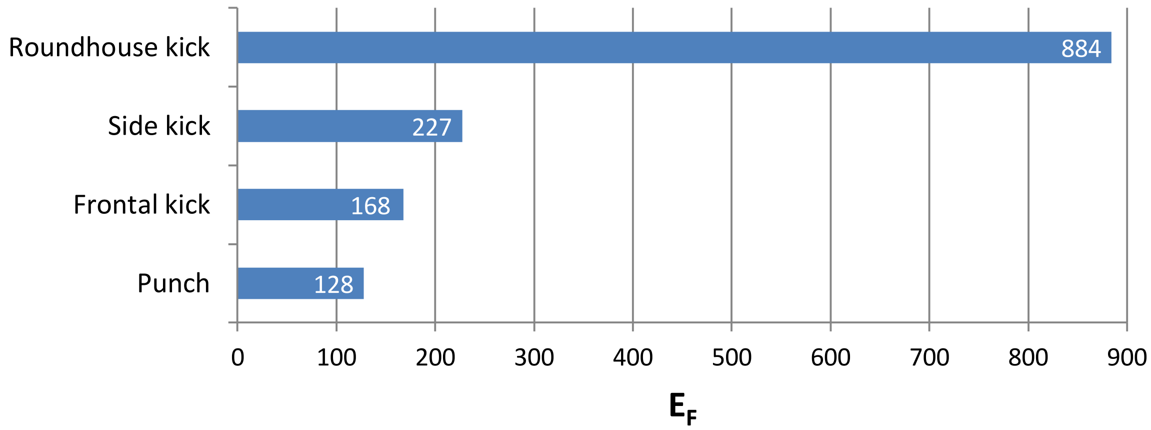

Figure 3. Graphical presentation of E_F coeficient depennding o type of strike.

DISCUSSION

Conducted experiment shows that lower limb techniques have higher percentage value of effective mass. It is not surprising, as in theoretical, model division of human body, mass of the lower limb is about 20% total body mass (thigh is 14.2%, shin is 4.3% and foot is 1.4%), while upper limb is only 5% (2.7% is arm, 1.6% for forearm and 0.6% for hand) [15]. It could be assumed, that engagement of rest of the body mass for presented techniques is: 24% for front kick, 17% for side kick, 14% for roundhouse kick and 9% for straight punch.

It shows that considerable amount of effective mass is allocated beside used limb. According to The Principle of Newton's Second Law, force is proportional to a mass [16]. Therefore, for increasing strike force it is crucial to engage the highest possible mass of body to execute a motion.

The highest acceleration was registered for straight punch technique. Small mass of this body part may be a main reason for this. The results confirms observations from practice. Upper limbs techniques are faster and have lower inertia than lower limb techniques. This is important knowledge during preparation, training sessions, tactics and strategy during sport competition. Similar trends have been found by researchers in other combat sport for example in fencing [17,18].

During strike, a crucial factor for its effectiveness lies in its destructive power. It does not only depend on generated force and engaged mass, but also on contact duration. Proposed coefficient E_F shows relation between maximum force to duration of a contact with a target. It a good representation of characteristics of each technique. It this experiment, roundhouse kick obtain high force value and the shortest contact duration. It informs as, that that it can have the highest effect of force (similar to a hammer striking a nail). Other kick shows much lower E_F values, with characteristics more similar to push-like movements.

Obtained results allows to assess strike in quantitative way, which was expressed by qualitative, intuitive assessment by coaches and other expert until now. Proposed quantitative indicators could be beneficial during preparation of an athlete to sport competition. Correctly calculated effective mass allows to measure force in a training environment.

This is a primary study, that validates presented conception. Further research with group of participants will allow to confirm this findings and set more approximate values for specific techniques. Presented reasoning is another step to better understanding factors affecting the kinematic of strikes. This results could set a path for further research in this field and serve as a reference results for other scientists.

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