Chosen aspects of physics in martial arts

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Abstract

Background: All activities performed by a human being depend on physical phenomena. A human body is a biomechanism which is affected by different forces. The body as well as its parts can move with various velocities and can obtain different energies. That is why practicing martial arts, punches, kicks, jumps or doing other exercises to achieve strength follow the same rules.

Material/Metods: The aim of the research was to analyse a simple punch forward (in the Taekwon-do terminology: Ap Joomuk Jirugi). Research on kinematics and kinetics of some chosen movements in Taekwon-do ITF was made with the BTS Smart Morion Capture system used for three dimensional movement analysis. A 17-year-old competitor measuring 175 cm and weighing 70 kg was analysed in the laboratory of Motoric Diagnostics in the Academy of Physical Education of Katowice.

Results: Up to 20% of the cycle the fist speed is a little higher than 0. Between 20–50% have negative speed. After going beyond 50%, the speed is rapidly rising to reach the maximum power of 86%. The maximum speed 6.184±0.534 m/s. Afterwards rapid decrease in speed is observed.

Conclusions: Minimal theoretical time of a person's reaction to an attack is about 0.2 sec and practically it is 0.4 sec. The time for the punch to reach its goal is 0.1 sec. This fact can suggest that it is not possible to defend against a punch. On the other hand we know that people can defend themselves against an attack. Apparently it appears that it is not worth doing anything because we have no chances, but it is an argument to practice martial arts and self-defence. The trainings give a person faith in his or her own strength, they teach how to recognize the opponent's abilities, how to stand to decrease the body part susceptible to attack and how to make the distance longer (which also increases the time of a potential attack). They also teach how to concentrate the attention and energy as well as how to predict the opponent's movement and how to surprise him or her.

Key words: taekwon-do • power test • ap joomuk jirugi • time of reaction • harm energy

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Background

Taekwon-do – a Korean martial art based mainly on punches and kicks.

All activities performed by a human being depend on physical phenomena. A human body is a biomechanism which is affected by different forces. The body as well as its parts can move with various velocities and can obtain different energies. That is why practicing martial arts, punches, kicks, jumps or doing other exercises to achieve strength follow the same rules.

The sight of a person breaking a pile of boards or another hard object with his or her bare hand or foot can be associated with special or supernatural skills and predispositions. One of the characteristic features for **Taekwon-do** is its Theory of Power [1–3], which consists of the following factors: mass, acceleration, equilibrium, concentration and breath control. The first two factors are typically physical values but the others may also be described in physical categories. Equilibrium is connected with placing correctly the centre of gravity of a person. Concentration is, in other words, the focus of a punch. This association with optics is justified due to the resemblance between the focus of light and the focus of the force during performing a punch.

Breath control can be described with mechanics of gases. Therefore, physics can help us to master fully and consciously the elements of martial art.

First biomechanical descriptions of techniques included in the Far East martial arts can be found in the 70s. They were carried out by physicists [4,5].

In this research they describe kinematic aspect of punches and analyze the process of breaking hard objects with bare fists. With the use of a stroboscope they recorded moves and analyzed them to calculate their velocity, acceleration, time of strike. Physical analyses were an attempt to know physical aspect of punching and interaction with the target, i.e. wooden boards. This research was continued during next years [2,6,7] and there were attempts to describe the dynamic theory of punches and more accurate calculation of punches' kinematics. Among other things, maximum velocities of different punches executed by karate fighter were measured.

Table 1. Maximal speed of selected techniques.

Technique	Max speed [m/s]
Front forward punch	5.7–9.8
Side kick	9.9–14.4

In the MIT, USA measurements were made to determine time of execution chosen techniques in Taekwon-do [2].

Table 2. Time of selected techniques.

Technique	Time [s]
Front forward punch	0.03
Side kick	0.1

Material and Metods

The aim of the research was to analyze a simple punch forward (in the Taekwon-do terminology: **Ap Joomuk Jirugi**). The following questions were asked:

1. How can separate phases of the punch be classified?
2. At which moment does the punch have the biggest speed?

Ap Joomuk Jirugi – simple front forward punch.

The answers to these questions can contribute to the choice of a better, more effective method to perform this kind of punches in self-defense and to win the **power tests** event in Taekwon-do ITF.

Power test – a sports event in Taekwon-do ITF.

Research on kinematics and kinetics of some chosen movements in Taekwon-do ITF was made with the BTS Smart Morion Capture system used for three dimensional movement analysis. A 17-year-old competitor measuring 175 cm and weighing 70 kg was analysed in the laboratory of Motoric Diagnostics in the Academy of Physical Education of Katowice. He was informed about the aim of the research and he agreed to take part in it voluntarily.

Results of Research

Figure 1 presents typical changes of the fist speed in the following percentage of the movement cycle, 100% standing for the entire arm extension. Up to 20% of the cycle the fist speed is a little higher than 0. Between 20–50% have negative speed. After going beyond 50%, the speed is rapidly rising to reach the maximum power of 86%. The maximum speed is 6.184±0.534 m/s. Afterwards a rapid decrease in speed is observed. The measurements of punching forward time showed that time of a single punch is about 0.03–0.05 sek. [2,8].

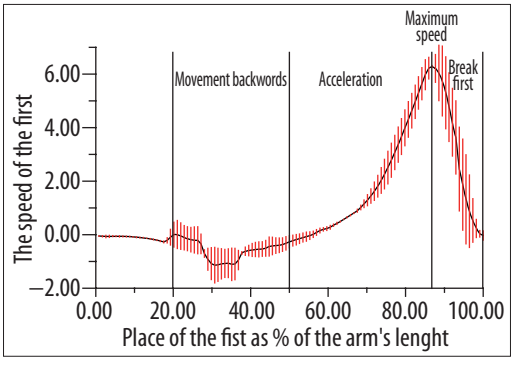

Figure 1. Average speed of the hitting fist in reference to the place of the fist scaled in% of the arm's length for the technique gunnun so bandae ap joomuk jirugi.

Discussion

Let's consider a punch to the opponent's head. We suppose that the weight of the attacker is 70 kg, so the weigh of his arm is about 3.92 kg (the arm 3%; the forearm 1.7%; the hand 0.9% of the total body weight) and the weight of the head is about 5 kg. According to the graph, the maximum speed is obtained with 86% of the arm bend v ≈6.2 m/s. The initial kinetic energy of the arm is:

$$E_{kp} = \frac{m_r v^2}{2} = \frac{3{,}9kg \cdot (6{,}2\frac{m}{s})^2}{2} = 75J$$

Two masses (fist and head) after punching will be moving with velocity:

$$v' = \frac{m_r v}{m_r + m_g} = \frac{5kg \cdot 6{,}2\frac{m}{s}}{5kg + 6kg} = 2{,}8\frac{m}{s}$$

After the punch the kinetic energy of the set consists of the energy of the arm and the energy of the opponent's head:

$$E_k = \frac{(m_r + m_g)v^2}{2} = \frac{(3{,}9kg + 5kg) \cdot (2{,}8\frac{m}{s})^2}{2} = 35J$$

So, the **energy to harm** the opponent's body is $E_k - E_{kp} = 40J$

All the changes and phenomena taking place in the surroundings are registered by our senses, whose sensibility, or the time necessary for us to realise the phenomenon, is the treshold of human perception. This treshold is estimated more or less to be 1/16–1/18 sec (0.05–0.06 sec) and is biologically constant for every human being, whose physiological and psychological time is set according to this constant. It is, in other words, the treshold of the frequency of changes registered by a human being. The eye registers 18 stimuli per second (as an impression of separate impulses), the ear hears a sound of over 16 vibrations per second (till this border separate vibrations are not perceived as a sound). The beginning of performing a simple movement takes at least 1/12 sec because of the limit of frequency of nervous impulses in the muscles. If we count the minimal time of realizing the presence of the stimulus (0.05 sec), the minimal time of choosing the adequate reaction (0.05 sec) and the mininmal time of beginning the movement (0.08), together it gives about 0.18 sec as the minimal theoretical **time of reaction** of the opponent [2]. In practice it can be longer.

Table 3. Theoretical reaction time.

The minimal time of realizing the presence of the stimulus	0.05 s
The minimal time of choosing the adequate reaction	0.05 s
The minimal time of beginning the movement	0.08 s
Total	**0.18 s**

Performing an attack or defence movement with the appropriate speed allows us to hit the opponent in the time shorter than his or her time of noticing the movement and reacting. The time of performing most techniques of Taekwon-do by an advanced competitor is shorter than the average time of a person's defence reaction, which is in practice about 0.2–0.4 sec (to compare: a blink takes about 1/10 sec). The data presented above prove that it is important to pay particular attention to predicting the opponent's movements and to maintain a proper distance and concentration during the fight.

Time punch ~0.05 s	<	Teoretical time reaction ~0.18 s

The speed of the hitting fist shows so called „movement backwards", which is characteristic for Taekwon-do, visible between 27–40% of the cycle. The maximum speed obtained when the movement is performed in 86% gives us information that also in this place the power of the hit is the biggest, according to the formula $F = m \cdot \frac{2\Delta v^2}{s}$ (3). The hitting power estimated when the movement was performed in 87% with the maximum speed equals F=420 N, but a mistake of only 5% of the movement cycle gives us the power of F=194 N. It means that the precise moment of hitting the target is very important. One of the events in Taekwon-do is power breaking, which consists of breaking boards and one of the tests consists of breaking the boards with a fist. Measuring the distance precisely gives the competitor 50% of success in this event.

Harm energy – difference in energy before the strike and after the strike.

Obviously, the appropriate position of the hand is also important. If we look at the formula describing the pressure on one unit of the surface $p = \frac{F}{S}$, we will see that the smaller the surface on which the hand touches the target at the moment of impact, the bigger the pressure [9]. It is clear that the stress of the body is directly proportional to the power and inversely proportional to the surface on which the power operates. In consequence, if we maintain the same power of the impact and the smallest surface of the attacking tool, the stress which causes damage will be the bigger.

Conclusions

More than half of the energy of the hit is destined to cause damage. If we decrease the surface of the attacking tool and in consequence increase the pressure on the target, this energy will be bigger. The martial art tradition aims at achieving ethic and technical perfection and its goal is to maximize the effectiveness. The fight between David and Goliat shows that a surprise can highly affect the fight and it proves how much can depend on just one blow. Sometimes one punch or kick can determine the result of the match and sometimes it can decide about a person's life [10].

Time of reaction – time of performing an action which is the answer to an external stimulus.

Minimal theoretical time of a person's reaction to an attack is about 0.2 sec and practically it is 0.4 sec. The time for the punch to reach its goal is 0.1 sec. This fact can suggest that it is not possible to defend against a punch. On the other hand we know that people can defend themselves against an attack. Apparently it appears that it is not worth doing anything because we have no chances, but it is an argument to practice martial arts and self-defense. The trainings give a person faith in his or her own strength, they teach how to recognize the op-

ponent's abilities, how to stand to decrease the body part susceptible to attack and how to make the distance longer (which also increases the time of a potential attack). They also teach how to concentrate the attention and energy as well as how to predict the opponent's movement and how to surprise him or her.

That is why putting this theory in practice in the gym hall can bring measurable effects and increase of our abilities to win.

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