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Comparison of two boxing training simulators

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Summary

Study aim: the aim of the study was to compare two methods for measuring punching and kicking force and the reaction time of athletes.
Material and methods: both systems were designed to measure and to analyse the mechanical characteristics of punches and strikes delivered by upper and lower limbs to a punching bag. The main difference between both punching bags was the way in which the delivered force was measured. The first method used strain gauges while the second method used accelerometer technology. Both systems consisted of a punching bag with software, attached signal diodes, and either embedded accelerometers or strain gauges. The bags were of different sizes. Acceleration transducers and gyroscopes or strain gauges were placed inside the punching bags, which allowed for measuring dynamics while the bag was struck. The software calculated strike force, the point of force application and its direction, and reaction time. Both systems were tested.
Results: the results of the accelerometer-based method show that the mean relative error of force calculation amounts to 3%. The measurement error of acceleration is less than 1%. The mean relative measurement error of the striking surface on the punching bag is 2%. However, the measurement error of force recorded with the strain gauge-based method is less than 1%. The results show that both systems are similar.
Conclusions: the punching bag having an embedded accelerometer is equipped with more versatile software, which makes the system a good tool for practical application in combat sport training.

Keywords: Accelerometer – Boxing training simulators – Force – Strain gauge

Introduction

In combat sports, tournament results are determined by a number of interrelated factors: motoric characteristics, technique, tactics, psychological features of the athlete, and the refereeing method [4, 5]. The force of a punch or a kick delivered to a punching bag is a crucial element of special fitness [2, 13, 14]. In literature related to the subject, several systems that measure strike force have been described [1, 2, 9, 11]. Pieter and Pieter [11] measured the force of kicks delivered with lower limbs to a water-filled heavy bag. Pędzich et al. [10] used an impact force plate to register the force of leg strikes performed by taekwondo athletes. Karpiłowski et al. [6] and Falco et al. [4] used a strain gauge-based measurement system while Nien et al. [9] used an accelerometer-based measurement system to register strike force. Utilising different measuring methods causes the results to be dependent on the measuring method adopted.

Consisting of a punching bag with an embedded strain gauge, the BTS-3 boxing training simulator system utilised at the Institute of Sport in Warsaw is functional enough to be used in boxing. However, it does not entirely fulfil the diagnostic expectations of taekwondo; hence, the need to develop a new boxing training simulator that will meet the requirements of both sport disciplines.

The aim of the study was to compare two methods to measure punching and kicking force and the reaction time of athletes.

Material and methods

Ethical approval for this study was provided by the Local Ethical Committee, and written informed consent was

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obtained from participants. The study was performed in accordance with the Declaration of Helsinki.

The punching bag with an embedded strain gauge

Until 2013, the measurements of strike force were conducted at the Institute of Sport using a versatile Boxing Training Simulator [6]. The BTS-3 version of the simulator is equipped with a dynamometric punching bag that has an embedded strain gauge (Figure 1). The cylindrical striking surface (L) is 0.5 m, and the outer diameter (D) is 0.48 m. The bag is suspended on a set of stabilizing ropes. Two signal diodes designed for guiding the sequence of executed strikes are mounted on an upper cylindrical section of the punching bag. The dynamometric punching bag is connected with an external integrated strain gauge amplifier equipped with strain gauge bridge power supply sub-assemblies, signal conditioning sub-assemblies, an analogue-to-digital converter, and a USB interface to connect with a computer. The system is managed by means of BTS5v0 specialist software. The punching bag measures resultant reaction force in the plane perpendicular to the cylindrical surface of the punching bag as well as the direction of the force applied during a single punch or kick and the force of consecutive strikes. The punching bag also offers the possibility for a simulated boxing match [6].

The total error in the measurement of the force and time was, respectively, 0.46% and 1.0% [7].

Fig. 1. BTS-3 dynamometric punching bag with an embedded strain gauge

Punching bag with an embedded accelerometer

In 2013, a new diagnostic system BTS-4AP-2K was designed. Its key element comprises a dynamometric punching bag with an embedded accelerometer (Figure 2). It is a long, cylinder-shaped bag (L = 1.8 m; D = 0.42 m; mass = 41 kg) consisting of a stiff inner cylinder and an outer layer to absorb shock. Throughout its length the body of the dynamometric punching bag is solid with a stiff core. The bag's centre of mass is at the midpoint of its height. For measurement purposes, two tri-axial accelerometers mounted on the edge surfaces of the punching bag's inner cylinder base were applied. In addition, using the new BTS6v0 software provides the opportunity to measure strike force in three different dimensions, to compute the location of the point at which the strike is delivered, and to measure the energy of the strike. The use of four signal diodes enabled tests to be conducted in which strikes could be executed with both upper and lower limbs and at different heights permitted in a given sports discipline. After the test is completed, the software generates a standard worksheet that contains measurement results as well as the calculations and analyses of the recorded trials.

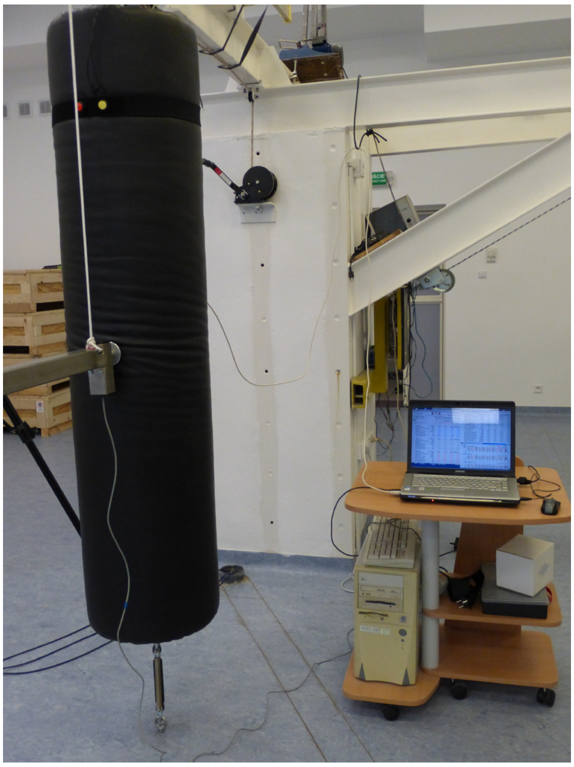

Fig. 2. BTS-4AP-2K dynamometric punching bag with an embedded accelerometer

The worksheet presents the statistics of maximal, absolute, and relative forces of strikes delivered. It also presents force impulse and reaction time for a left and right limb separately as well as for consecutive strikes. The numerical scores of measurements and analyses are available in a text format (ASCII export) for further processing with specialised statistical software.

The method of measuring strike force delivered to a punching bag with an embedded accelerometer

In order to obtain the results of strike force measurements comparable with the previously applied measuring method, a simplified computational model for a planar force system (Figure 3) was applied in which it was assumed that

– a strike force component perpendicular to the punching bag's cylindrical surface will be calculated,
– a strike is momentary, and the displacement of the punching bag's centre of mass until its maximal acceleration is achieved (the punching bag's maximum reaction force to the strike) are negligibly small from the point of view of the accuracy of calculating the force,
– suspension force counterbalances the weight of the punching bag.

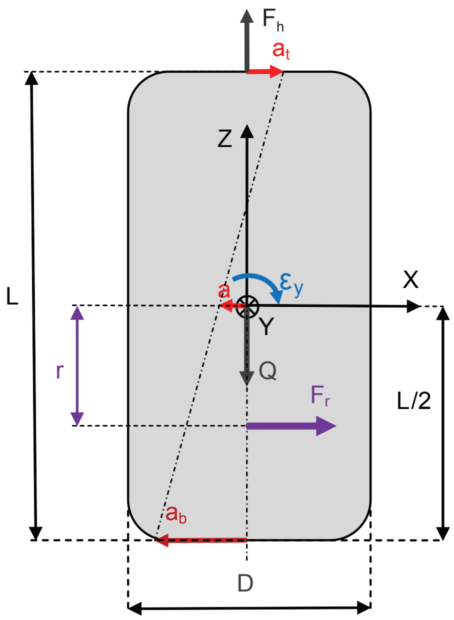

Fig. 3. A simplified, two-dimensional diagram of measured accelerations and forces acting on the dynamometric punching bag having an embedded accelerometer.
F_r – punching bag's strike reaction force, r – distance of the punching bag's reaction force from the punching bag's centre of mass, ε_y – angular acceleration of the punching bag's body against the punching bag's centre of mass in the y-axis, a – acceleration of the punching bag's centre of mass, a_t – acceleration of the punching bag's upper edge, a_b – acceleration of the punching bag's lower edge, L – distance of the punching bag's edge acceleration measurement points, F_h – reaction force of suspension ropes, Q – punching bag's weight force, D – outer diameter

Described with equations (1) and (2) below, a two-dimensional model of the equilibrium of forces and the moments of forces acting on the punching bag was used:

$$F_r*r+\varepsilon_y*J_y = 0 \quad (1)$$
$$F_r+m*a = 0 \quad (2)$$

where: F_r – punching bag's strike reaction force, r – distance of the punching bag's reaction force from the punching bag's centre of mass, ε_y – angular acceleration of the punching bag's body against the punching bag's centre of mass in the y-axis, J_y – moments of inertia against the punching bag's centre of mass, m – the mass of the punching bag, a – acceleration of the punching bag's centre of mass.

The acceleration of movement of the punching bag's centre of mass (a) and the angular acceleration (ε_y) of rotation about the y-axis is calculated on the basis of the measurement results of the horizontal components of the triaxial acceleration of the punching bag's upper and lower edges (a_t and a_b) according to formulas (3) and (4).

$$a = 0.5*(a_t+a_b) \quad (3)$$
$$\varepsilon_y = (a_b-a_t)/L \quad (4)$$

where: a – acceleration of the punching bag's centre of mass, a_t – acceleration of the punching bag's upper edge, a_b – acceleration of the punching bag's lower edge, ε_y – angular acceleration of the punching bag's body about the y-axis, L – distance of the punching bag's edge acceleration measurement points.

The strike force is calculated according to the following formula (5):

$$F_r = 0.5*m*(a_t+a_b) \quad (5)$$

The point at which the strike force is applied to the punching bag's centre of mass is computed using this formula (6):

$$r = J_y*(a_b-a_t)/(L*F_r) \quad (6)$$

The method of executing and measuring test strikes with a dynamometric impact hammer

In order to verify the methods for measuring and calculating used for both types of punching bags, measurements of strike forces delivered with a special dynamometric impact hammer equipped with a strain gauge-based force transducer were performed (Figure 4). The face of the impact hammer was affixed with a single-component force measurement transducer equipped with a light metal spherical cap through which strike force was exerted onto

Fig. 4. The view of the dynamometric punching bag having an embedded accelerometer when delivering test strikes

the dynamometric punching bag. The outer diameter (D_z) of the impact hammer's spherical cap was 64 mm and the radius (r) was 70 mm (Figure 5). The impact hammer was suspended on two parallel ropes at points equidistant from the impact hammer's centre of mass. The impact hammer's longitudinal axis was thus perpendicular to the punching bag's cylindrical surface during impact. Prior to executing a strike, the rope-suspended impact hammer was pulled back away from the punching bag. Next, initial velocity was given to the impact hammer, which was released freely towards the punching bag. Each dynamometric punching bag received from five to eight strikes against different sections of the punching bag's available striking surface. The hammer's force of impact with the punching bag was determined by means of the measuring systems affixed to the impact hammer and the punching bags.

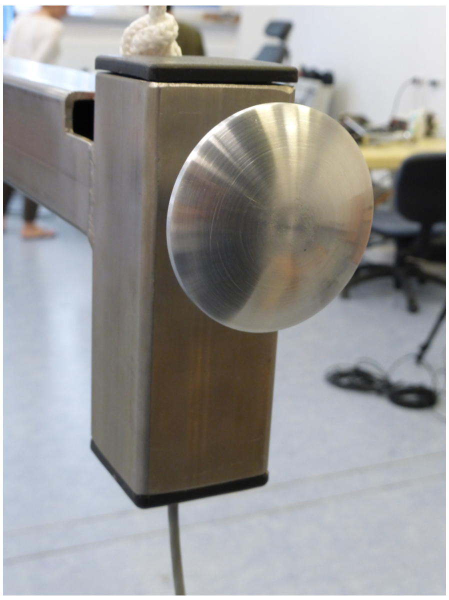

Fig. 5. The view of the impact hammer's spherical face used to deliver test strikes

The force-measuring chains, with which both the impact hammer and the dynamometric punching bag having the embedded strain gauge were furnished, consisted of a force transducer with own vibrational frequency of 160 Hz. The measuring system of the strain gauge amplifier was equipped with a first-order low-pass filter with a cutoff frequency of 300 Hz. Forces were sampled with a 12-bit analogue-to-digital converter with a sampling rate of 500 Hz. The measurement error of force is less than 1%.

The acceleration-measuring chains of the dynamometric punching bag having an embedded accelerometer were equipped with factory-fitted anti-aliasing filters of 780 Hz. Acceleration was sampled at 1000 Hz. The results of acceleration measurements were "smoothed out" with a digital low-pass filter with a cutoff frequency of 200 Hz. The measurement error of acceleration is less than 1%.

Statistical analysis

Pearson's correlation was used to find the relationship between the force recorded with a strain gauge-based impact hammer, the force measured with the punching bag having an embedded strain gauge, and the force calculated based on the accelerations of the punching bag with an embedded accelerometer. In the statistical analyses conducted, the value of $p < 0.05$ was considered significant. All computations were performed with STATISTICA software™ (v. 10.0, StatSoft, USA).

Results

Figure 6 shows the relationships between maximal test strike forces recorded with the measuring systems of the impact hammer and the punching bag having an embedded strain gauge of the BTS-3 system.

Figure 7 shows relationships between maximal test strike forces recorded with the measuring systems of the impact hammer and the punching bag having an embedded accelerometer of the BTS-4AP-2K system.

The accelerometer-based method results show that the mean relative error of force calculation amounts to 3%. The measurement error of acceleration is less than 1%. The mean relative error of calculation the punching place on the boxing bag is 2%. The measurement error of force recorded with the strain gauge-based method is less than 1%. The results show that both systems are similar. However, the accelerometer-based detectors work in a frequency bandwidth of maximum 1000 Hz whereas the strain gauges achieve a maximum of 200 Hz. The measurement data of the accelerometer-based system are filtered with a low-pass filter (200 Hz) in order to eliminate high peaks detected.

Figure 8 presents the relationship between the real strike height measured and the height of strike calculated

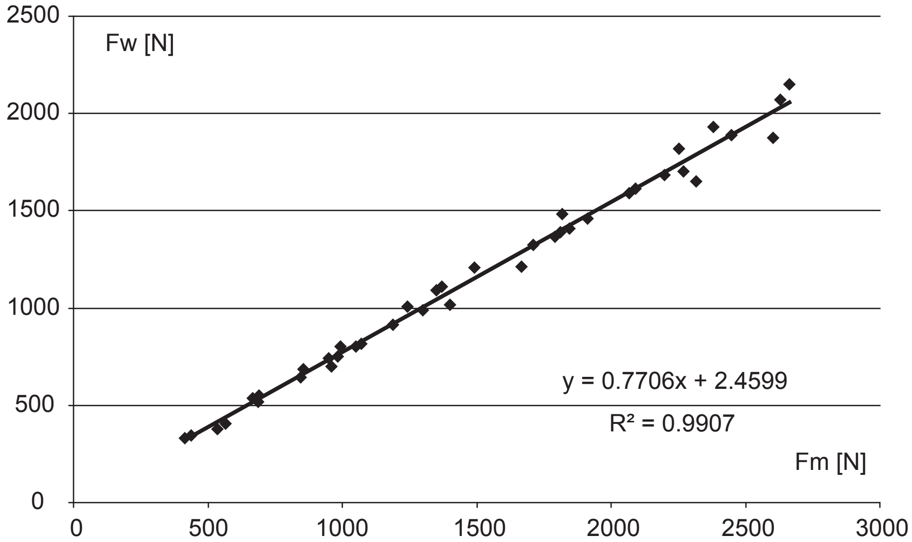

Fig. 6. The relationship between the force of impact (F_m) of the impact hammer and the force measured (F_w) with the BTS-3 system

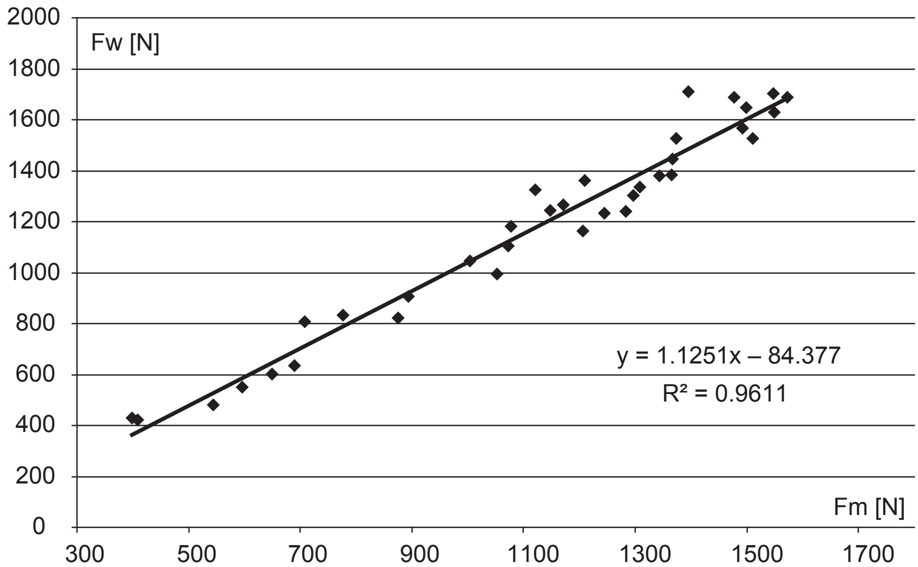

Fig. 7. The relationship between the force of impact (F_m) of the hammer and the force measured (F_w) with the BTS-4AP-2K system

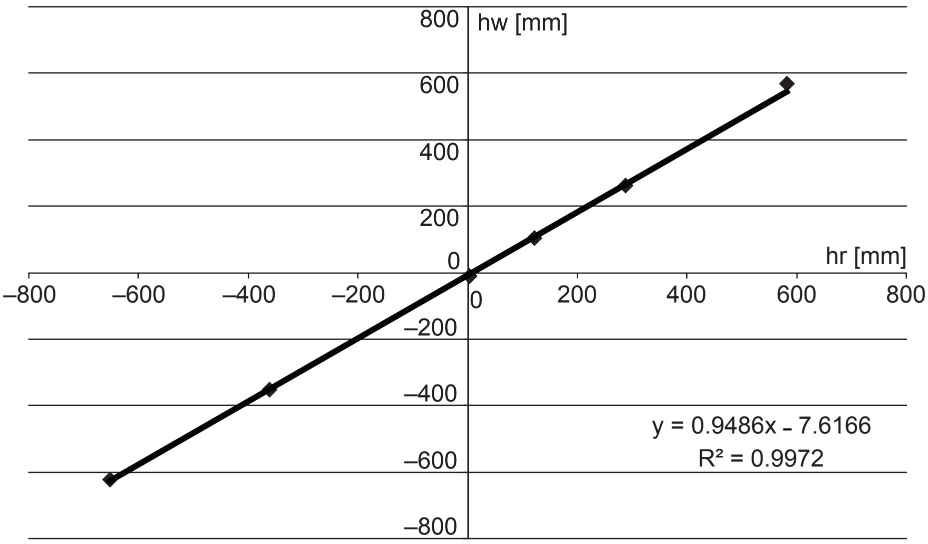

Fig. 8. The relationship between the real strike height measured (hr) and the height of strike calculated (hw) on the basis of the results measured with the BTS-4AP-2K system

on the basis of the results measured with the BTS-4AP-2K system.

Discussion

The aim of the study was to design a new device to measure and to calculate punching and kicking forces in combat sports that could replace the strain gauge-based measurement system formerly used. In the literature, various methods to measure punching and kicking force can be found along with very divergent force values obtained [1, 3, 6, 9–11]. Using a water-filled heavy bag, Pieter and Pieter [12] recorded kick forces ranging from 461.8 ± 100.7 N to 661.9 ± 52.7 N. Balius [1] reported mean impact force of nearly 2130 N while Conkel et al. [3], who used piezoelectric film, measured impact forces up to 470 N. Li et al. [8] observed roundhouse kick forces of 2940 N for males and 2401 N for females. Falco et al. [4] measured the force of Bandal Chagui kicks on a boxing mannequin with piezoelectric pressure sensors mounted on it. They recorded maximal forces of 2089.80 ± 634.70 N. The highest force recorded was 3482 N. The impact forces of delivered kicks were reported at a broad range of 382 N to 9015 N [3, 4, 10–14]. As authors of numerous studies have indicated, however, it is impossible to compare strike forces examined by means of different devices due to their varied firmness and damping parameters of the shock absorbing layer, the accuracy of force and acceleration measurements, and the measuring method: water-filled heavy bag [11], force plate [10], inertial strain gauge-based punching bag [4, 6], or a set of accelerometers [9]. In our study the use of acceleration measurement transducers and angular velocity transducers measuring the dynamometric punching bag's movement enabled the construction of a dynamometric punching bag with a considerably longer cylindrical striking surface (L = 1.8 m) than in the formerly used punching bag with an embedded strain gauge. The mounting of four signal diodes enabled tests to be conducted in which strikes could be delivered with both upper and lower limbs and at different heights permitted for a given sports discipline. Strike forces delivered with an upper limb and recorded with our punching bag having an embedded accelerometer oscillated between 500 N and 2276 N; with a lower limb (Dwit Chagi) they oscillated between 1576 N and 5315 N. The values obtained are consistent with the data available in the literature. Furthermore, the results we recorded with punching bags both with embedded strain gauges and with accelerometers are approximate, thus enabling the comparison of results obtained in earlier studies using the punching bag having an embedded strain gauge.

Moreover, the intensity of training can be controlled more rigorously due to the possibility of setting, e.g., time intervals between consecutive strikes or the sequences of strikes delivered. The bigger punching bag is equipped with more versatile software, which makes it a good tool for practical application in combat sport training.

Conclusions

Due to new construction solutions, the new boxing training simulator system BTS-4AP-2K is sufficiently functional to be used for diagnostics in taekwondo while at the same time offering greater diagnostic capabilities for boxing (punches aimed at the head and chest).

The punching bag having an embedded accelerometer is equipped with more versatile software, thus making the system a good tool for practical application in combat sport training.

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