Evaluation System For Straight Punch Training: A Preliminary Study

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Abstract. The punch is one of the major components of martial art that is related to kinematic indicators and impact forces. However, the impact forces of punching postures have not been fully investigated. Therefore, the aim of this research is to propose a new system to measure the acceleration and force created by the punch and monitor practitioners' stances during the punching process. A study was conducted in which six participants (3 females and 3 males) participated with at least 1 year of experience. Each participant performed 5 straight punches with the fist rotation and 5 straight punches without the fist rotation. Force was measured from the load cell, acceleration from an accelerometer, and stance was monitored via a motion analysis module using a computer. The experimental results from the proposed system showed that the hand acceleration and punch forces correlated strongly with an average acceleration of 28.3 m/s2 (without rotation) and 29.9 m/s2 (with rotation) producing an average force of 107.5 N and 139.9 N, respectively. These results show that the punching velocity had a great impact on the punching forces. The experiments also proved that the system can use to monitor the force, acceleration of the punch, and also the posture of practitioners when doing punches.

Keywords: Martial art, straight punch, motion tracking, accelerometer, load cell, MediaPipe.

1. Introduction

There are many kinds of martial arts in the world nowadays that develop for many years with their own philosophy and style [3]. For example, Karate, which is an oriental art of self-defense, improves physical fitness and mental discipline in its practitioners and gained considerable popularity during the punch is a key to the development of practitioners in martial art. The punch in a martial art is used to create physical damage to an opponent. The right technique will lead to big damage. Besides that, having more knowledge of punching will improve tactical advantage, and score points against an opponent [7]. There are four types of basic punches which are the most often used attack form in martial art. They are straight punch, lunge punch, reverse punch, and jab punch [7]. Among these, the straight punch has the longest range and tends to be the most powerful. Straight punching techniques require the use of the entire body to apply optimum force for a very short period. So, to obtain more force at impact, the movement of the punch is needed to be considered [7]. From the normal fight stance, the attacker athlete must follow steps such as (1) lowering the center of mass of the whole body while extending the stance, (2) lunging towards the opponent, and (3) then extending the punching arm forward, executing the punch in the open unguarded part of the opponent's abdomen [5]. This punch is done based on the combination of a series of bodily movements, called the twisting of the hips and shoulder rotation. The kinematic movement of the straight punch technique is shown in the figure below:

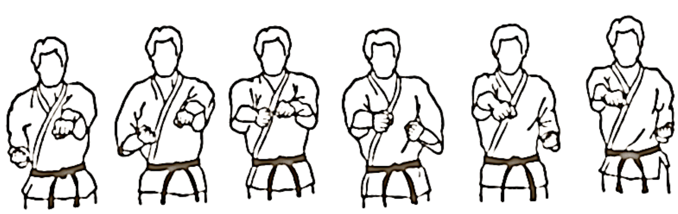


Fig 1. Straight punch technique.
Source. Choku-zuki (Straight Punch). 1 July 2018, https://bom.so/IXfGR2

In the research of Rathee et al. [16] the parameters of breaking a wooden board of two athletes have been studied. In this study, the deformation energy (DE) is the energy calculated in joules determined by the loss to deformation in the case of inelastic collision (show equation [1]):

$$D.E. = \frac{1}{2}((m_1 \times m_2)/(m_1 + m_2)) \times V_c^2 \quad (1)$$

Where:

- m_1 is the mass (kg) of the wooden board
- m_2 is the mass (kg) of the arm of the punching participant.
- V_c (ms^{-1}) is the velocity of the punch upon impact.

Based on the equation, DE will be increased by mainly the velocity of the punch. So the athletes have to train to increase the velocity of the punch if they want to create a bigger force. It means that the posture of the athletes also has to consider reducing the way they punch. Also, performing correct standing and movement is very important for the force to effectively impact and analyze the kinematic characteristics of punch type.

The assessment of the straight punch technique is very difficult because it is related to many factors such as motor characteristics, the technique of the athletes, tactics in combat, the psychological status of the athletes, and related methods [12], [13], [15], [17]. In fact, there is some research related to the relationship between punching force and postures [8]. Smith et al. [14] have proven that the force power of the punches is dependent on the athletes' skills. To measure the force, there is some measurement system has been developed to monitor them such as using a water-filled heavy bag [12], force plate [11], strain gauge-based measuring systems [7], [5], and an accelerometer-based measuring system. For example, in research [12], they use a punching bag with an embedded strain gauge to measure the force or use the BTS-3 boxing training simulator system in another research [6]. Suwarganda et al. [16] captured punching movement using 6 infrared Motion Analysis cameras and a Kistler force plate. Jacek Wasik et al. [16] applied reflective markers on fists to collect the punching kinematic data. However, these existing systems mainly focused on measuring and analyzing force. They do not focus on whole punching activities to find the reason to create the force in order to improve punching techniques. Hence, developing a new system that would meet the requirements of martial art disciplines was necessary.

The goal of our research is to propose a new system to detect punching stances, attacking acceleration, and punch force of karate practitioners for straight punch technique using instrumentation conducted by combining motion detection, an accelerometer, and a force measurement system using load-cell together. The system can evaluate the straight punch technique and give real-time feedback information to practitioners and instructors. Therefore, it will provide coaches and learners with a better understanding of the mechanics of the body in performing the straight punch technique as well as be used for training purposes and for technique evaluation.

2. Materials and Methods

2.1. Apparatus

The system architecture is presented in Fig. 2 In this diagram, the measuring system includes three parts as acceleration sensor to measure the acceleration of the hand movement, a force plate to measure the force, and the motion analysis to do pose detection. The motion analysis system uses Mediapipe Pose Detection algorithm [9] to detect the punch's angles.

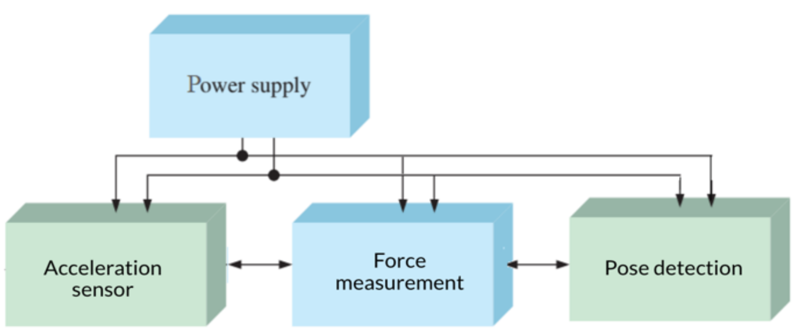


Fig 2. Punch evaluation system diagram

Punching force measurement

For the punching force analysis of this system, two steel plates is cut to have a size of 20x15x0.4 cm and the 100-kg load cell was placed in between them to detect the force applied on the steel platform. The load cell after being modified had a sampling rate of 80 Hz. The load cell is placed in the middle of two platforms so that when the sensor receives the punching force, the load cell deforms and thereby obtains the punching force without deforming the contact surface. With the selected steel plate thickness of 0.4cm, deformation of the steel surface for punching forces less than 5kN will not occur. However, to ensure the safety of athletes, a pad with 3.0cm thickness and a size of 20x15cm is placed on the surface of the steel plate to reduce the direct impact of steel on the hand bone structure when punching. This will not reduce the measured punch force but only slow down the force acquisition by a negligible amount of time. The model of the load cell punching board is presented in Fig. 3. The photo of the load cell punching board respectively is shown in Fig. 4:

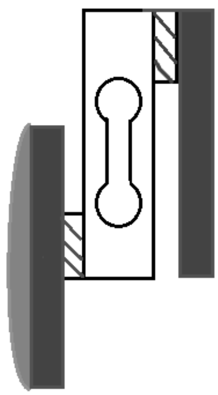
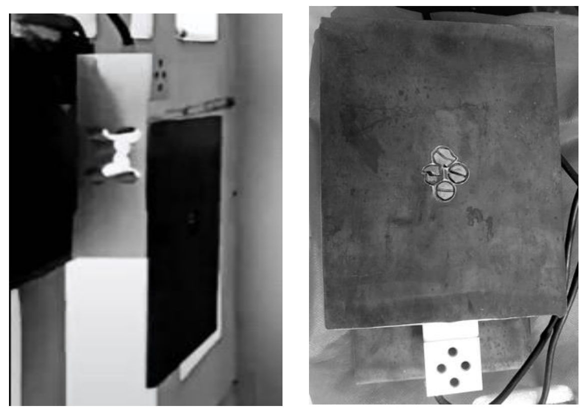


Fig 3. Load cell punching board's model



(a) Side-face (b) Front face

Fig 4. Load cell punching board.

After securing the module and attaching it firmly on the wall, the entire load cell system was calibrated with and without the foam padding using overloads known masses. The setup of the loadcell calibration is shown in Fig.5, we set up a simple pendulum test that acts as the fist of a straight punch. First, we fixed the load cell on a vertical plane, then hang the pendulum which is placed parallel to the plate of the loadcell board. The center of mass of the pendulum is lined in the center of the load cell. Second, we pulled the pendulum up to a known angle then release it and redo the experiment 5 times for each angle to take average value results. Repeat the calibration process with the other angle and other pendulum's mass. The main data obtained from the system were their punch's acceleration and the punch force displayed and recorded on the computer screen.

The impact force of the pendulum is determined by:

$$F_{Impact} = [(2kmgl(1 - cosX)]^{1/2} \tag{2}$$

where m is the mass of the pendulum (kg), g is gravity acceleration (m/s^2), l is length odd wire(m), X is angle between the wire and vertical axis. The results of the load cell calibration is shown in Fig. 6.

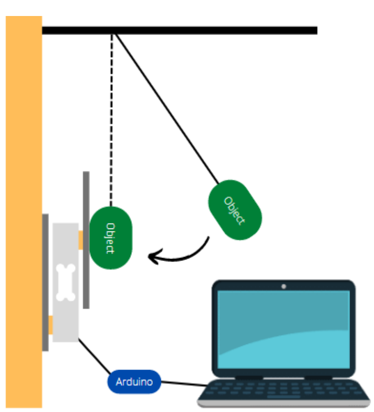


Fig 5. Calibration setup of the load cell

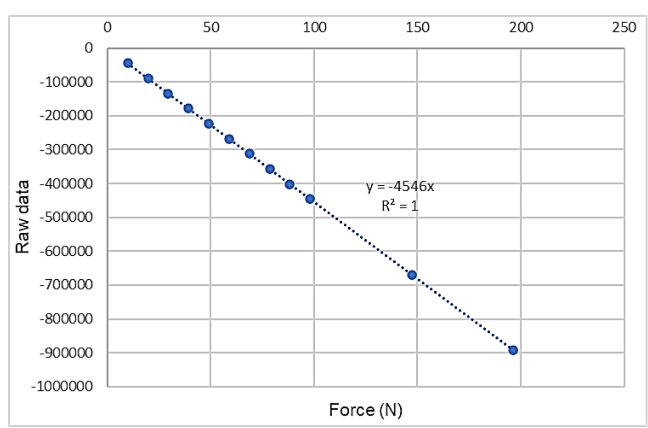


Fig 6. Calibration curve of the load cell

Punching acceleration measurement

For the punching acceleration detection module, a tri-axial accelerometer was attached to the wrist of the subject to identify punch timing and measure the impact acceleration of the punch. The acceleration sensor used in this module is MPU6050 with a sampling rate of 1000 Hz. It's a 6-axis Motion Tracking chip that combines a 3-axis gyroscope, a 3-axis accelerometer, and a Digital Motion Processor (DMP). The accelerometer was then implanted in a small box with a size of 3x5x2 cm for convenience. Acceleration signals from the accelerometers were sent to the computer for analysis via a Bluetooth module. The acceleration measurement module is shown below:

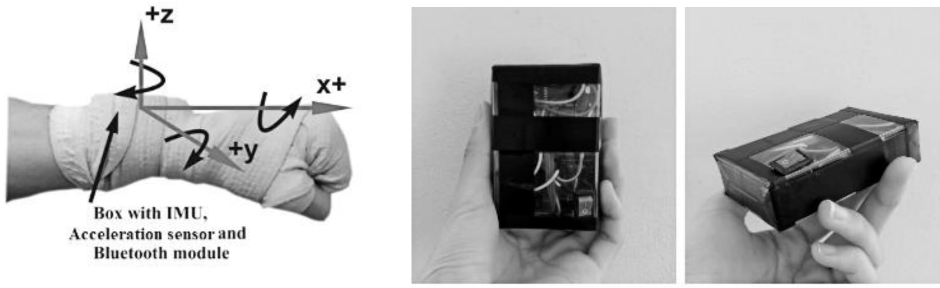


Fig 7. Accelerometer module attached to the wrist

Motion analysis module

For the motion analysis module, a smartphone's camera stabilized by a tripod was used to record videos of the punching process. A program was built with the support of MediaPipe [9] library for analyzing motion through these videos. MediaPipe is mainly focusing on data processing and building ML solutions across platforms [9]. Unfortunately, it is impossible to train MediaPipe-pose on a custom dataset. The training phase is usually done by TensorFlow. We just downloaded the trained model, then coded the get_angle function to get the magnitudes of joint angles of the arm in the punching motions and visualized the results.

Fig 8. Pose detection's result

2.2. Subjects

Six subjects (3 males, and 3 females) from the Bach Khoa Martial Art club were selected for this study. Table 1 shows the characteristic of the participants in the experiment. These subjects' experience in training ranged from 1 year to 3 years. All participants received and signed the informed consent form when joining these experiments.

Table 1. Participants' information

Subject	**Height (m)**	**Weight (kg)**	**Experience (year)**
1	1.76	63	1
2	1.78	67	3
3	1.62	55	3
4	1.63	51	1
5	1.59	50	1
6	1.75	62	1

The average height of male participants is 1.77±0.10 m and the average weight is 65±1 kg. The average height of female participants is 1.61±0.20 m and the average weight is 64±1 kg. Each participant was asked to punch the target in a testing sequence with straight punch techniques. The punches were performed from the normal standard stance with two parallel feet remaining in contact with the ground throughout the duration of the punches.

2.3. Experimental Protocol

After a proper warmup, participants were asked to perform straight punches with and without the fist rotation.

Five repetitions of each punch were recorded and analyzed. For all participants, throughout the experiment, the punching hand was the right hand and both legs remained parallel and in contact with the ground. After completing the punch, participants remained in their final positions. Participants were allowed to repeat the punch if the punch had been improperly performed. The experiment's setup was arranged as in Fig. 9:

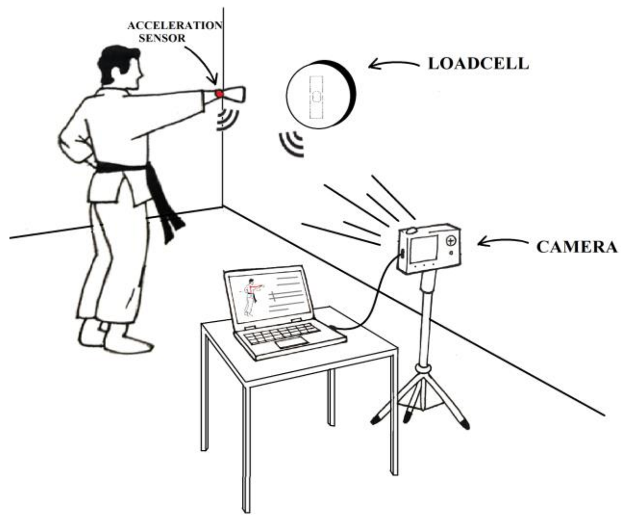


Fig 9. Experiment setup

For the setup of the straight punch's measuring system, we connected the accelerometer and the load cell punching board to two computers via Bluetooth to display and record the results. The main data obtained from the system were their punch's acceleration and the punch force acted on the punching board. The accelerometer was fixed to the participant's gloves and the punching pad was attached vertically to the wall with the height adjusted to suitable for each subject. As the punch impacts the punching pad, it causes the steel plates to compress and produce an output voltage. This voltage unit is then converted to Newton when recording and analyzing data.

The motion analysis system used high-speed cameras to record the subject's movement. The camera was placed perpendicular to the plane of the subject's punch.

3. Result

3.1. Punch Acceleration

Measured data was accumulated to dataset X. Every sample has 2 columns (x-axis acceleration and angular acceleration) which have the graph as shown in the figure 10 and figure 11. At both graphs, the horizontal axis represents time (ms) and the vertical axis represents the magnitude of acceleration.

Fig 10. Acceleration result's graph without rotation

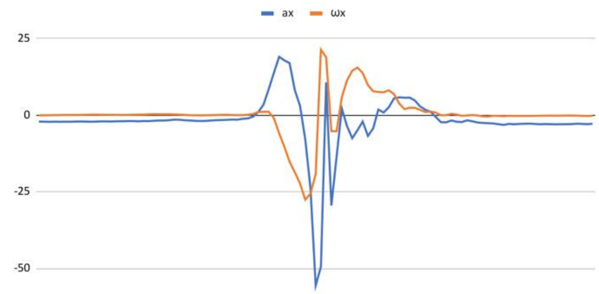


Fig 11. Acceleration result's graph with rotation

3.2. Punch Force

Tests were conducted to check the experimental values when punched with both types of punches which are straight punches with and without rotation. After checking the force trend generated by these punches, both punches were tested for achieving maximum average acceleration. Table 2 shows the values of force versus average acceleration performed by each participant. Table 3 shows the tests conducted to calculate the maximum acceleration that can be attained by both these punches.

Table 2. Average acceleration and corresponding forces

Force without rotation		Force with rotation	
Acceleration	**Force (N)**	**Accelearation**	**Force (N)**
20.6	76.4	25.1	111.9
26.3	136.6	28.4	168.3
21.4	80.2	27.8	115.6
20.0	65.5	22.3	80.8
20.6	73.7	19.6	90.1
25.6	104.6	26.3	132.6

Table 3. Maximum attainable acceleration (m/s^2) of both punches

No	Without rotation	With rotation
1	22.4	26.2
2	27.2	31.7
3	23.3	30.7
4	20.6	23.3
5	21.1	21.1
6	26.8	28.2

3.3. Punch Angles

After conducting the punching test, we built a program using MediaPipe [9] to estimate the angle between the arm joints when punching. In this study, we performed three angles estimation: elbow angle in the preparation position, the angle between arm and torso, and elbow angle when punching out. Table 4 below shows the diverse angles measured by the program by 6 different people punching, combined with corresponding forces and acceleration.

Table 4. Punching angles corresponding to maximum acceleration and force

No	Angles	Acc. with rotation	Force with rotation	Acc. without rotation	Force without rotation
1	(84; 84; 178)	26.2	111.9	22.4	76.4
2	(86; 92; 178)	31.7	168.3	27.2	136.6
3	(92; 86; 176)	30.7	115.6	23.3	80.2
4	(82; 84; 168)	23.3	80.8	20.6	65.6
5	(82; 80; 170)	21.1	90.1	21.1	73.7
6	(84; 86; 176)	28.2	132.6	26.8	104.9

4. Discussion

4.1. Comparison of Punch acceleration

As shown in table 3, the maximum attainable accelerations of punches with rotation are higher than those without rotation. It shows that the straight punch without the fist rotation can attain a maximum acceleration of 28.3 m/s2 while the one with rotation could attain an average high acceleration of 29.9 m/s2. This small difference in acceleration shows that both punches attain almost the same average high acceleration.

4.2. Comparison of Punch force

The values obtained in Table 3 and Figure 9 shows that the force generated by the punch with rotation is higher than the one without rotation when punched at the same acceleration. At all accelerations, the force of a straight punch with rotation is higher than the one without a fist rotation. This is completely consistent with the analysis in Daicu's study [2] when calculating the force generated by a straight punch with fist rotation and in the research of Bremer [1] when calculating the force of wrist rotation during a straight punch.

4.3. Comparison of Punch acceleration

From the data in Table 4 of the angles measured by different punchers, it was shown that there will be an impact on the force and acceleration of the punch with different arm positions. Specifically, the experiment was done with Angle1, Angle2 angle of around 90 degrees, and Angle3 angle of approximately 180, which will give the strongest punching force.

5. Conclusion

In this paper, we have presented a new measuring and monitoring system to evaluate the straight punch techniques. Our proposed system could give an evaluation of the punch techniques and real-time feedback information to athletes and coaches. The results getting from this system could be extremely valuable in characterizing each subject's technique, and in designing training programs as well as developing competitive strategies. In the future, we hope to improve the accuracy and feedback speed of our system to provide a better user experience. We also want to obtain more quantitative results by testing the system in a larger population and applying this approach not only in martial arts but also in other army training programs.

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