Experimental Analysis of Japanese Martial Art Nihon-Kempo

by Tetsuzo Kuragano & Saburo Yokokura, Meisei University, Hino-City, Tokyo, Japan

Abstract

With a male, adult subject, this study measured the punch force and kick force of the Japanese martial art Nihon-Kempo, the movements of the dominant (right) arm, leg, and the movements of the legs using timed synchronization. Using an electromyogram (EMG), the relationship between the variation of punch force and the variation of the electrical potential of the muscles were examined. It was observed that when the punch force was at maximum, the electrical potential of the muscles was not at maximum. The relationship between the variation of the punch force and that of the ground reaction force was experimentally analyzed. The variation of punch force based on time progression was examined. The theoretical punch force values were calculated by establishing a differential equation for a fist with a glove and a target load cell to assure the validity of our experimental equipment. This second order differential equation was transformed into two first order differential equations. Using the Runge-Kutta methods, the two first order differential equations were solved simultaneously. The calculated results were compared with the experimental data. It was found that the theoretical solutions corresponded to the experimental data. Therefore, it has been recognized that the experimental equipment functioned reliably. For the kick, it was examined that the velocity of the heel and toes became maximum around the halfway point in the kick's trajectory and hit the target load cell while reducing in velocity. It is supposed that the trial subject began the kicking motion and aimed at the target load cell while experiencing a reduction in velocity of his heel and toes due to his leg reaching maximum extension. The force of the kick, about 4500 N, was roughly 2.8 times stronger than that of the punch.

Keywords: punch force, EMG, differential equations

Introduction

Previous studies examining martial arts have tended to focus on descriptions of movements without involving biomechanical analysis and reporting data. Those measuring movement data of martial arts usually failed to report equipment used to measure movement. Nishimitsu (2008) described the effectiveness of Nihon-Kempo protectors of headgear, plastron (breast plate), and crotch, and the effectiveness was described from a subjective point of view without specific data reported. A study by Sawayama & Doya (1968) described punching techniques subjectively, and the experimental methods of gathering the punch force and motion were not described. Zako (2003) conducted a study on Nihon-Kempo examining how and when throwing should start, but experimental methods used to analyze the throwing techniques were not given. Zako (2006) also reported a study covering Nihon-Kempo history.

A study on a Shaolin kung fu punch was reported as well (Yoshihuku, Ikegami, & Sakurai, 1985) in which the punch force, the velocity of the elbow, and that of the wrist of the dominant right arm while the fist hit the target were measured, and the kick force of the right leg and the velocities of the knee, heel, and toes were also measured in the study. However, the experimental method used to measure the punch and kick force, and the velocity of the arm and leg were not given. A study on various martial art punch and kick forces was conducted by Yoshihuku (1986) - reporting the non-dominant punch, roundhouse kick, and combination of punch and kick. There were 37 subjects of Shaolin kung fu with the ranking of 1, 2 and 3 dan (black-belt degree), 7 subjects of Karate with 1 dan, 3 subjects of Nihon-Kempo with 2 dan, and 3 groups of untrained subjects involved in Yoshihuku's study. However, only the Shaolin kung fu roundhouse kick and the combination of punch and kick were measured. The punch and kick forces of the various martial arts were not compared, and the experimental method and equipment were not described at all.

In addition, a study on punch motion in martial arts was reported by Yoshihuku and Ikegami (1984). In their study, the body parts used for punching were classified according to the Shaolin kung fu system. The mechanism of punch force was described from the biomechanics point of view, but the experimental method of punch force gathering and the equipment used were not reported.

Further, a study about the punch force of Kickboxing, Karate, and Nihon-Kempo was published (Yoshihuku, 2008). The experimental equipment used in the study was a homemade cantilever equipped with a strain gauge and an oscillograph to record the gathered data. The experimental equipment calibration, data gathering, and visual presentation methods, however, were not shown. A conventional high-speed camera shooting at the rate of 250 frames per second was used. But the objective of using this was to examine the motion of the trial-subject, not to collect the motion data. A punch force comparison of Kickboxing, Karate, and Nihon-Kempo was made using the same equipment. The comparison outcomes may be correct, but the absolute force measurements may not be correct, because the punch forces were described as estimated values.

Nihon-Kempo is a traditional Japanese martial art that consists of movement components known as punch, kick, twisting joints, throw, and throttle. The purpose of this study concerning Nihon-Kempo experimental analysis was to examine the relationship between punch force and ground reaction force by the legs, the relationship between kick force and ground reaction force by the leg, and time elapsed punch force variation from the biomechanics point of view using one subject while showing the properly arranged experimental equipment. The study was also intended to establish data collection and processing methods for future studies. Hopefully, the values of the punch and kick force obtained in this study would be able to be compared with those using the same experimental method and equipment in the future.

Method

Participants

One male, adult participant was involved in the study. The participant was 26 years old, weighed 88kg, and was 173 cm tall. He was a 2nd degree black belt of Nihon-Kempo and a former champion of the Self-Defense Forces of Japan.

Instruments and Data Collection

A piezoelectric three-component force sensor 9068 manufactured by Kistler Instrument AG, Winter Thur, Switzerland was used to gather the punch and kick force as a target load cell. This force sensor was set as shown in Figure 1 letter A.

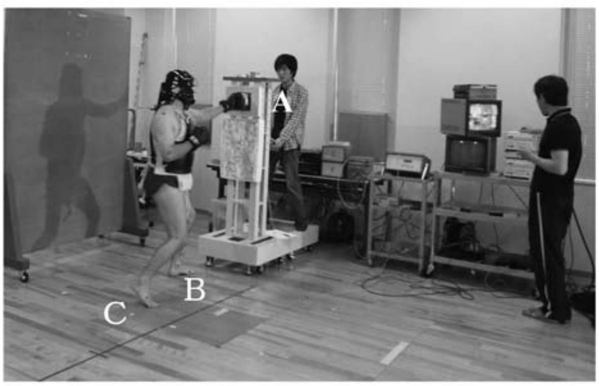

Figure 1. Image of experiment and apparatus
The subject is taking the range of the target load cell A using his left arm, prior to punching it using his dominant right arm.

In this image, the subject was taking the range of the target load cell prior to punching it using his dominant right arm. A 30-mm thick silicon rubber plate was placed over the force sensor to protect the fist from injury. The manufacturer of the silicon rubber was Shinetsukagaku Co. Ltd., Japan. Its specific gravity was 1.3, rubber hardness was 40 degrees, tensile strength was 30 kg per square centimeter, and elongation was 180 percent. An eight-ounce glove manufactured by Kuzakura Co. Ltd., Japan was worn to protect the fist from injury. The silicon rubber plate would reduce the punch and kick force. The glove would also reduce the punch force.

Two piezoelectric multi component force plates 9287B/BA, manufactured by Kistler, were used to collect data of the ground reaction force caused by the behavior of both legs. The force plates were set as shown in Figure 1 letters B and C. The electromyograph sensors were manufactured by Biometric Ltd., Switzerland. The sensors, used to measure the timing of the electrical potential of the individual muscles when they were tense, were attached to the middle of the deltoid, middle of the trapezius, at the 50% position of the triceps, middle of the pectoral major, and at the 80% position of the antebrachial flexor and antebrachial extensor. The signals from force sensor, force plates, and EMG sensors had a sampling frequency of 1 kilohertz. The motion of the shoulder, elbow, and wrist and that of the hip, knee, heel, and toes were captured by placing adhesive white markers at the articulation joints of the right arm and leg when punching or kicking, then filmed using a high-speed video system, HSV-500, model ST-549J, manufactured by NAC Corp., Japan at the rate of 125 frames per second.

Data Visualization

The force data from the force sensor and the force plates and the electrical potential data from the EMG sensors were visualized as graphs using a Trias software system manufactured by DKH Corp., Japan. Captured motion data were visualized as graphs using a Frame-Dias software system manufactured by DKH Corp., Japan. The main purpose of using a Frame-Dias software system was to collect the motion data every 0.008 seconds and then visualize them as graphs. This system also has a function to calculate the velocity and acceleration using Lagrange's polynomial numerical differentiation.

Data Analysis

The experimental data from the Frame-Dias software system and the Trias system were compared with theoretically calculated data to assure the reliability of the instruments. The velocity and acceleration data from the Frame-Dias software system were compared with the values calculated by our computer program using Lagrange's polynomial numerical differentiation. This comparison assured that the data from the Frame-Dias software system were accurate. The force data from the Trias software system were compared with the theoretically calculated data. In order to calculate theoretically, a mathematical model shown in Figure 8 was established using a fist with a glove and the piezoelectric force sensor as a target load cell. A differential equation which was the second law of Newton was set for this mathematical model. This differential equation was a second order ordinary differential equation. Therefore, it was divided into two first order differential equations to be solved by using Runge-Kutta methods.

The Runge-Kutta methods were numerical computation methods used to solve first order differential equations through successive approximation. Initial conditions have to be given to solve first order differential equations. All solutions are numerical particular solutions after computation. To set the initial conditions, the values from the experimental data were used; then, these first order differential equations were solved simultaneously. The solutions for these simultaneous first order differential equations were two numerical particular solutions, which were, in our case, velocity and acceleration as a function of time, which was an independent variable. These solutions were later compared with the actual experimental data to assure that the experimental equipment was functioning reliably.

Results and Discussion

In this section, the relationship between the punch force of the dominant right arm and the ground reaction force by the legs, and the relationship between the kick force of the right leg and the ground reaction force are described. Also, punch force variation, theoretical analysis of the punch force, and a comparison of the punch and kick force are described.

Punch Force and Ground Reaction Force by the Legs

In Figure 2, time was set to the horizontal axis and the punch force and the ground reaction force were set to the vertical axis, and the relationship between the punch force and the ground reaction force of both legs using time elapse is illustrated. The punch process movement was as follows. First, the left leg was lifted a little. Then, the right leg was used to push off the floor. Because of this motion, the ground reaction force to the left leg became zero, and the ground reaction force to the right leg increased. This phenomenon is shown as line 1 in Figure 2. Then, the left leg landed and the weight of the body shifted to it. The ground reaction force for the right leg became zero. The total weight of the body was then on the left leg. This situation is seen as line 2 in Figure 2.

The fist with a glove hit the target load cell and the punch force became maximum. This phenomenon is shown as line 3 in Figure 2. The ground reaction force to the left leg increased, shown as line 4 in Figure 2. The second maximum of the punch force was examined, shown as line 5 in Figure 2. From this phenomenon, it was supposed that the fist with a glove was moved forward by the ground reaction force. Both legs were pushing off the floor, however, it was observed that the left leg pushed off more than the right leg, as noted along lines 4 and 5 in Figure 2.

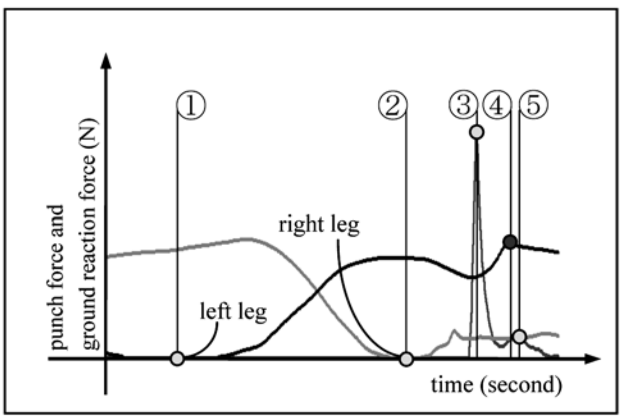

Figure 2. Punch force and ground reaction force through time

Kick Force and Ground Reaction Force by the Leg

When kicking was performed, the total weight of the body was loaded to the left leg and a kick forward to the target load cell was strongly applied. The target load cell was kicked by the trial subject, with the sole of the foot and then thrust forward after contact. This motion is shown in Figure 3. The vertical thick lines in Figure 3 were time synchronized. In this way, the kick and ground reaction force values could be compared at the same moment in time, which was the moment of contact with the target load cell.

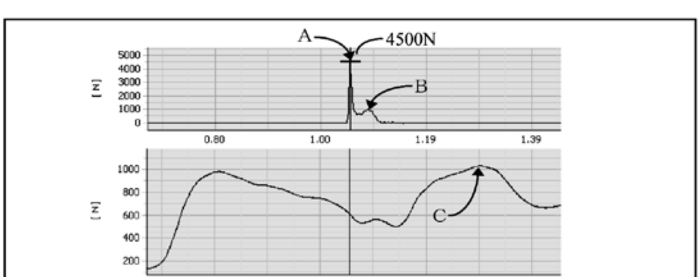

Figure 3. Kick force and ground reaction force

The kick force showed a maximum value of about 4500 N. This is point A in Figure 3. Thereafter, the kick force disappeared rapidly. However, there was a secondary spike in the kick force, which became maximum at point B, shown in Figure 3. This was caused by thrusting the right foot forward after the initial contact. At this point, the trial subject supported himself only on the toes of his left foot. This is shown at point C in Figure 3. The value showed about 1000 N. The weight of the trial subject was about 88 kg. Therefore, the values from the Trias system are reasonable.

The positional data of the hip, knee, heel, and toes were collected using a high-speed video system at the rate of 125 frames per second. To collect the motion data, white adhesive markers were stuck to the hip, knee, heel, and toes. This is shown in Figure 4 (a). In Figure 4 (b), velocity of heel and toes was set to the vertical axis and time elapsed was set to the horizontal axis. In Figure 4 (c) kick force was set to the vertical axis and time elapsed was set to the horizontal axis. The velocity of the heel and toes was at maximum around the halfway point of the kick trajectory. The trial subject hit the target load cell while reducing his velocity. When the kick force was at maximum, the velocity of the heel and toes showed about 1 m/s. This is shown by time synchronized vertical thick lines in Figure 4 (b) and (c). From this, it was assumed that the trial subject began the kicking motion and aimed at the target load cell while experiencing a reduction in the velocity of his heel and toes as his right leg extended.

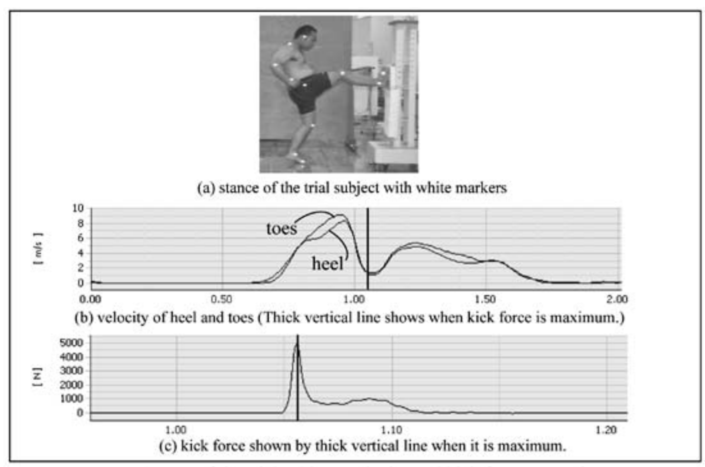

Figure 4. Stance of the trial subject, velocity and kick force at maximum

Nihon-Kempo Punch

Punch force variation based on time can be observed as occurring in three stages in Figure 5. Punch force was set to the vertical axis and time elapsed was set to the horizontal axis. The first stage was the period between time A, when the fist hit the target load cell, and B when the punch force was at its maximum. At time A, when the fist with a glove hit the target load cell, the velocity of the fist with a glove was about 2.6 m/s. At time B, the punch force was maximum at about 1600 N (Yoshifuku, 2008) and the velocity of the fist was about 2 m/s. The period between time A and B was 0.008 seconds.

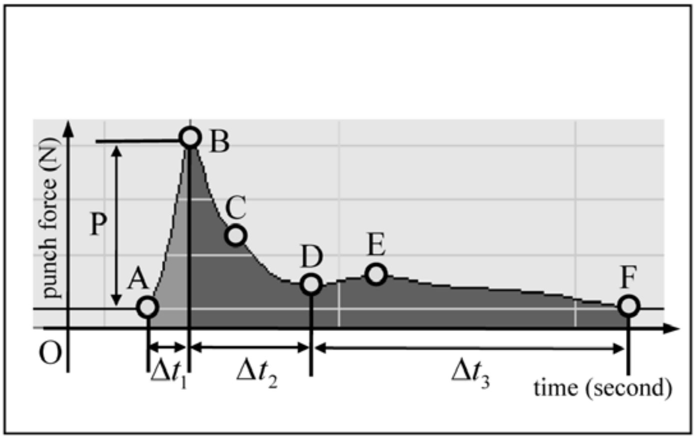

Figure 5. Time based punch force variation

By examining the time synchronized vertical thick lines on the EMG graphs shown as Figure 6 (b), (c), (d), (e), (f), (g) and (h), it is noted that the deltoid was active, but the biceps, triceps, antebrachial flexor, antebrachial extensor, trapezius, and pectoral were not active.

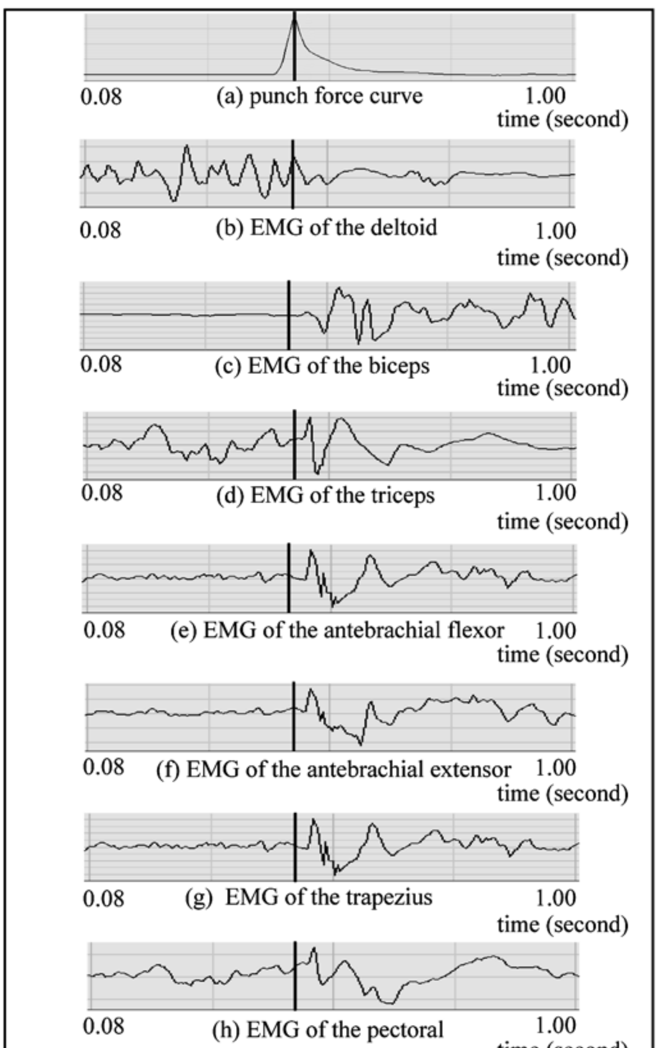

Figure 6. Punch force curve and EMG of corresponding muscles when punch force is maximum

The second stage was the period between the time B and D as shown in Figure 5. At the time B the punch force was maximum, and at the time D the punch force was minimum. At the time C in Figure 5, which corresponds to (a) in Figure 7, the triceps, antebrachial flexor, antebrachial extensor, trapezius, and pectoral became tense. The electrical potential of these muscles showed a surge. This is observed by examining the time synchronized vertical thick lines on the EMG graphs shown as Figure 7 (d), (e), (f), (g) and (h). The punch force at the time C showed about 800 N.

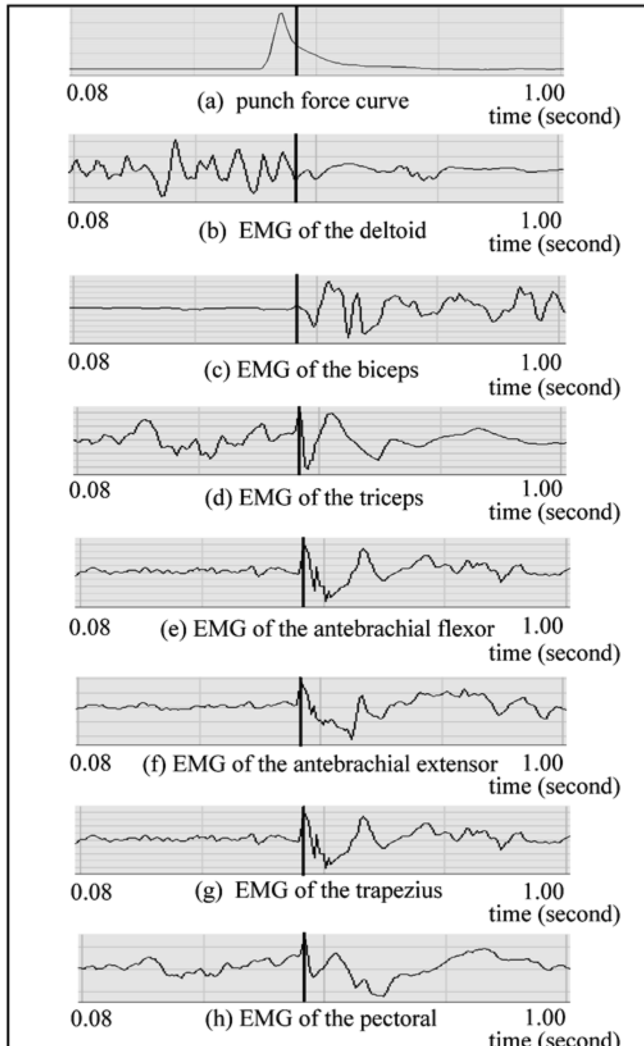

Figure 7. Punch force curve and EMG when electrical potentials of corresponding muscles are maximum

The third stage was the period between the time D and F as shown in Figure 5. After the time D, the punch force increased again. At the time E, punch force became local maximum, which is shown as line 5 in Figure 2. It was assumed that this was caused by the left leg's pushing off the floor, shown as line 4, in Figure 2. At the time F, the punch force became zero. During the period between the time E and F, the fist with a glove was on its return trajectory, but the punch force still remained. It was assumed that the reason for this was the residual reacting force of both legs from the floor.

Punch force variation with time elapsed can be briefly summarized by using Figure 5. During the first stage, Δt_1, the fist with a glove hit the target load cell and the punch force became maximum. During the second stage, Δt_2, the punch force did not decrease rapidly while maximizing muscle activity, as examined by the time synchronized vertical thick lines on the EMG graphs shown in Figure 7 (d), (e), (f), (g) and (h). During the third stage, Δt_3, the punch force was slightly increased again by the left leg pushing off the floor.

Theoretical Solutions and Experimental Data

The theoretically calculated solutions were compared with the experimental data to assure the reliability of the experimental equipment, as described in the following paragraphs. A fist with a glove and a target load cell to measure the punch force were used to establish a mathematical model. These are shown in Figure 8.

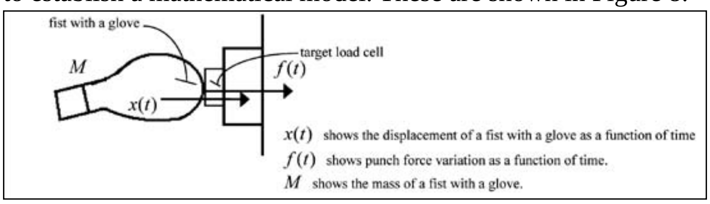

Figure 8. Fist with a glove and target load cell

A differential equation was set for the mathematical model shown in Figure 8 and was expressed as Eq.(1). This is the second law of Newton.

$$M\frac{d^2x}{dt^2}(t)=f(t) \tag{1}$$

where M was the mass of the fist with a glove and $f(t)$ was a variation of punch force. The letter t was an independent variable that shows time. M was decided by using Matsui's table (Yokoi, Shibukawa, & Ae, 1986), which indicated a fist as being about 1.8 percent of body weight. Thus, for our 88 kg subject, a fist was valued at 1.58 kg. Adding the weight of a glove of 0.23 kg, M was valued at 1.81 kg.

The portion $\frac{d^2x}{dt^2}(t)$ was acceleration of M, and also the second derivative of $x(t)$ which was the displacement of the fist with a glove. Since Eq. (1) was a second order ordinary differential equation, it was divided into two first order differential equations to be solved by using the Runge-Kutta methods. For this, the new dependent variable y was introduced for the independent variable t, and $y(t)$ was expressed as Eq.(2).

$$y(t)=\frac{dx}{dt}(t) \tag{2}$$

Then, Eq. (2) was expressed as Eq.(3).

$$\frac{dy}{dt}(t)=\frac{d^2x}{dt^2}(t) \tag{3}$$

Next, Eq. (1) was transformed into two first order differential equations as shown in Eq. (4).

$$\left.\begin{aligned}\frac{dy}{dt}(t)&=\frac{1}{M}f(t)\\ \frac{dx}{dt}(t)&=y(t)\end{aligned}\right\} \tag{4}$$

The Runge-Kutta methods were applied to the two first order differential equations shown in Eq.(4). Punch force through time $f(t)$ in Eq.(4) was expressed as a quadratic function using the experimental data from A, B, and C in Figure 5. The time at the position A shown in Figure 5 where the fist with a glove hit the target load cell was set to zero. At this time, the punch force $f(t)$ given from the Trias software system was 0.9 N, the velocity $\frac{dx}{dt}(t)$ and acceleration $\frac{d^2x}{dt^2}(t)$ of the fist with a glove given from the Frame-Dias software system were 2.6 m/s and -81.1 m/s^2 respectively. These values were set as initial values to solve the differential equations shown in Eq.(4). Then, the differential equations were solved simultaneously using the Runge-Kutta methods. The solutions are shown as a velocity curve and an acceleration curve in Figure 9 (a) and (b) respectively. The solution value for velocity, $\frac{dx}{dt}(t)$, with t being 0.008 seconds, was 1.99 m/s., and the solution value for acceleration, $\frac{d^2x}{dt^2}(t)$, with t being 0.008 seconds, was -76.50 m/s^2. Corresponding experimental data given by the Frame-Dias software system were 2.00 m/s and -72.65 m/s^2 respectively. The corresponding experimental data were plotted in Figure 9 (a) and (b) respectively. This showed that the experimental values roughly correspond to the theoretical values. Therefore, the velocity and acceleration values from the Frame-Dias software system and the punch force from the Trias software system are reliable.

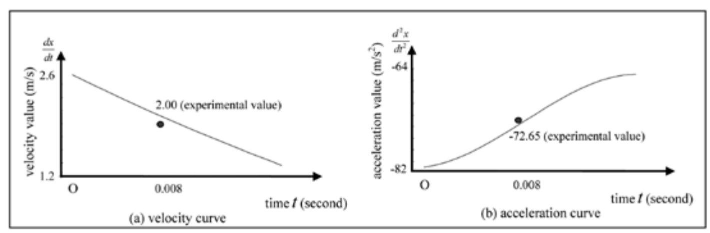

Figure 9. Velocity curve and acceleration curve of the differential equations solved by using the Range-Kutta methods

The Comparison of Nihon-Kempo Punch and Kick

The dominant right arm punch force was compared with the dominant right leg kick force. When punch force was compared with kick force, kick force showing about 4500 N was roughly 2.8 times greater than punch force showing around 1600 N. When the kick force was examined, it is seen that the kick force was sharper than that of the punch. The punch force remained after the maximum value as described in the previous Nihon-Kempo punch section, but the kick force disappeared soon. This shows the heel and toes return quickly after kicking. There is no residual force as found in punching.

References

Nishimitsu, T. (2008). Examination of technique improvement in Nihon-Kempo: History of Nihon-Kempo and required attention of instruction. *Ashiya University Bulletin, 2*, 63-72.

Sawayama, K., & Tsuchiya, H. (1968). Characteristic of Nihon-Kempo, *Physical Education Journal, 12*(5), 68-75.

Yokoi, T., Shibukawa, K., & Ae, M. (1986). Body segment parameters of Japanese children. *Research of Physical Education: Japanese Society of Physical Education, Health and Sport Sciences, 31*(1), 53-66.

Yoshihuku, Y. (1986). Impact forces of various kinds of fighting techniques II. *Japanese Journal of Sports Science, 5*(8), 572-577.

Yoshihuku, Y. (2008). *Science of the strongest martial arts*. Tokyo: Fukushodo Publishing Co. Ltd.

Yoshihuku, Y., & Ikegami, Y. (1984). Punch motion in martial arts. *Japanese Journal of Sports Science, 3*(3), 188-198.

Yoshihuku, Y., Ikegami, Y., & Sakurai, S. (1985). Energy flow from the trunk to the upper limb in TSUKI motion of top-class players of Shaolin Kung Fu. In B. Jonsson (Ed.), *Biomechanics X-B* (pp. 733-737). Campaign, IL: Human Kinetics.

Zako, T., (2003). Nihon-Kempo, fist technique, and punch examination. *Kansai University Bulletin, 52*(4), 89-160.

Zako, T., (2006). Examination of wrestling technique of Nihon-Kempo. *Physical Exercise Culture Forum, 1*, 63-68. ■