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# Development of a smart Kendo sword and assessment of grip pressure of Kamai stance and Kote cut

Kwangyul Jeong*, Franz Konstantin Fuss, Bernd Fuernschuss, Yehuda Weizman

*School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Melbourne VIC 3083, Australia*

**Abstract**

A Kendo bamboo sword was instrumented with customized grip pressure sensors for right and left hand. The grip pressures were tested in the Kamai stance and during the Kote cut. In the Kamai stance, the grip pressure of the left hand was on average 6-7 times greater than the one of the right hand. In the pre-impact phase of the Kote cut the pressure distribution was similar to the Kamai stance. During the impact period, the grip pressure of both hands increases dramatically and the grip pressure of the right hand is 12% greater in the left hand. The smart Kendo sword is a useful tool for assessing the pressure distribution and feeding it back to the Kendoka.


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*Keywords:* Kendo; shinai; instrumented sword; grip pressure; Kamai; Kote cut

## 1. Introduction

Kendo is one of the most ancient martial art forms in Japan meaning ‘the Way of the Sword’ [1]. It is a full contact fight using bamboo swords (Shinai) and protective armour (bogu) (Figure 1). The basic stance (Kamai) exhibits the left foot at the rear and the right foot at the front; both feet are pointing forward, and both hands hold the grip surface of the Shinai (right hand on top of left hand) (Figure 1). According to the competition rules, scoring two points is required for winning a match. Scoring a point in a kendo competition is defined as an accurate strike or thrust against a point-scoring target of the opponent's armour resulting in physical contact with the correct part of

* Corresponding author. Tel.: +61 3 9925 6123; fax: +61 3 9925 6108.
*E-mail address:* s3467405@student.rmit.edu.au


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the Shinai. The competitor has to demonstrate high fighting spirit, correct stance and posture, and continuing awareness (Zanshin) (Figure 2). The four point-scoring targets are as follows [2]:

- Men-bu, the top or sides of the head protector (sho-men and sayu-men);
- Kote-bu, a padded area of the right or left wrist protector (migi-kote and hidari-kote);
- Do-bu, an area of the right or left side of the armor that protects the torso (migi-do and hidari-do);
- Tsuki-bu, an area of the head protector in front of the throat (tsuki-dare) [2].


Fig. 1. (**a**) Kendo gear; Photo courtesy © Ballarat Kendo Iaido & Judo club, reproduced with kind permission; (**b**) snapshot of a Kendo competition (the right Kendoka scores a kote cut), Photo courtesy © University of Melbourne Kendo club, reproduced with kind permission.

Kendo training includes a lot of practices of repetitive scoring motions to improve speed and accuracy of the attack. One of the keys to increase the speed lies in the capability of the practitioner to propel his/her body forward by using the left foot. The accuracy of striking targets depends on the grip position and power. The term '*power*' refers to the speed and force of a sword strike. These two skills are commonly focused on and have been, for most of the kendo practitioners, lifetime challenges [3].

The aim of this research is to develop an innovative smart Shinai for assisting Kendokas in maximising their training. The instrumented equipment is designed to optimise Kendo training to make it easier and more efficient. This will help facilitate the learning of kendo techniques with improvement of performance in competition.

Learning the 'Way of Sword' is not necessarily the most natural thing in the world. Kendo practitioners require many years of training, with appropriate sensei's (coach) guidance, to learn the footwork and how to properly grip the sword. Prolonged incorrect posture leads to slow performance development and even to injuries. It is often quite challenging to detect these problems and to correct them efficiently.

The most common difficulties experienced by Kendokas are: *incorrect grip position and insufficient grip power*. Grip position and power are important for accurately striking a target. Incorrect grip posture leads to difficulties in executing a technique; loss of accuracy of the cut; and to shoulder and wrist injuries. Furthermore, the standard fighting position requires an adequate grip power and pressure distribution across the two hands when holding the sword (Shinai). Therefore, the research intends to measure the grip pressure on both left and right hand. Good left hand position and power are some of the most important basics in kendo. The practitioners should be able to hold the Shinai correctly with appropriate forces in right and left hand.

## 2. Design and method

### *2.1. Design rationale*

The smart Kendo sword is intended to improve the grip force and pressure distribution of Kendokas, specifically if their training workload of gripping and forcing the sword is high. Kendokas have to train the ideal hand pressure distribution and power to maximise their grip technique. Kendokas who need to correct their pressure distribution would also benefit from extra pressure and force when gripping the Shinai. Therefore, the Shinai was equipped with two sensors, one for each hand (Figure 2).


Fig. 2. Top view of Shinai instrumented with sensors for the right (SRH) and left hand (SLH).

### *2.2. Electronics*

Instead of using FSR, FlexiForce or similar off-the-shelf sensors for pressure measurements, an in-house developed pressure platform was applied. These low-cost but highly accurate sensors were made of a conductive piezo-resisitive cellular polymer (Rmat *Fa*, RMIT material code), with aluminium foil electrodes taped to the polymer (Figures 2 and 3). The electrodes surrounded the grip of the sword, leaving a small area on the top of the grip surface uncovered. This area is in contact with the webbing between thumb and index. The reason why this area was left blank is because any impact force on the tip of the sword when hitting an object would add further compression to the sensor, which should not be confused with the actual grip force and therefore should not be measured. The electrodes are connected with wires to the circuit and microcontroller (Figure 3). The Teensy3.1 (LLC, Sherwood, Oregon, USA) used for the project is a 32 Bit Arduino-compatible microcontroller running at a sampling rate of 9600 bits per second. The microcontroller code was developed with Arduino Software (Arduino, Ivrea, Italy). With a delay function, the data recording frequency was set to 50 Hz. The measurement circuit (Figure 4) comprises of the Teensy3.1, the two sensors and two reference resistors (4.7kΩ) to reach the highest possible resolution of the sensors. The power of 3.3 Volts was supplied via the Teensy3.1

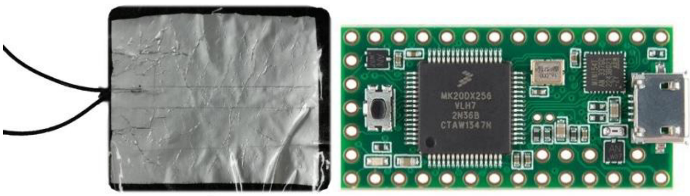

Fig. 3. Sensor and Teensy microcontroller

### *2.3. Experimental procedure*

Two different experiments were realised in this project. The first one utilised the standard combat stance without hitting a target (Figure 8a). An experienced Kendoka (holding a 5$^{th}$ Dan and numerous championship titles) gripped and held the Shinai for five seconds in the Kamai (normal stance) followed by releasing the grip for five seconds. This procedure was repeated 45 times and recorded in three measurements (15 tests each). The second experiment explored the attack stance with hitting a target (Figure 8b,). The Kendoka applied grip force to the sword for five seconds force hit the target once, followed by releasing the grip for 5 seconds. This procedure was also repeated 45 times and recorded in three measurements.

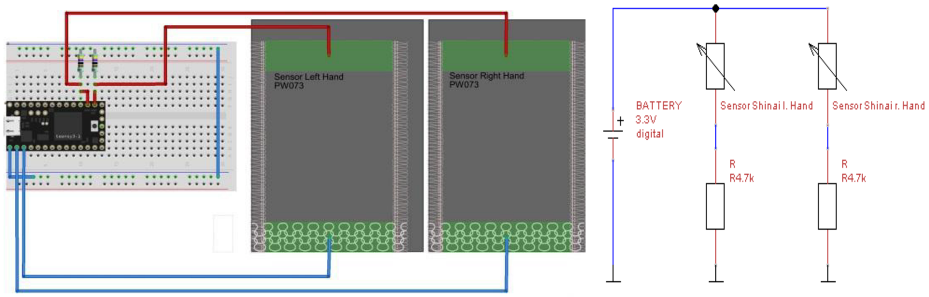


Fig. 4. Circuit diagrams with the Teensy 3.1, the reference resistors (4.7 kΩ) and the smart sensors for the left and the right hand.

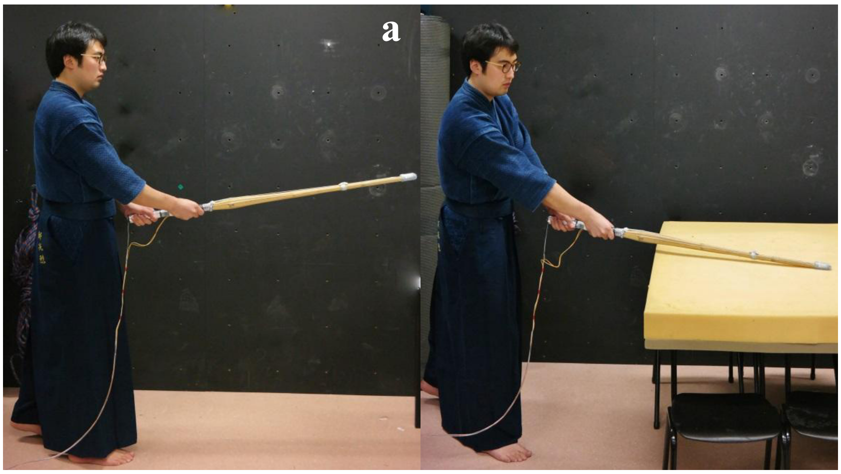


Fig. 5. Kendoka experimental positions for testing the grip force; (**a**) Kamai stance without hitting; (**b**) grip in the Kote Cut (hitting the wrist).

### *2.4. Data processing*

The voltages measured by the microcontroller were converted to the resistances and conductances of the two sensors from

$$R_{sensor} = \frac{V_{in} \cdot R_{ref} - V_{ref} \cdot R_{ref}}{V_{ref}} \tag{1}$$

where *R* and *V* denote the resistance and the voltage, respectively; and the suffixes *in* and *ref* refer to the *in*put voltage (3.3 V) and the resistance of, and voltage drop across, the *ref*erence resistors (Figure 4). The conductance was converted to pressure based on the calibration function determined by [4]. As the pressure was distributed non-uniformly over the entire sensor area, the pressure was expressed as a percentage, normalized to the maximum pressure measured.

Right- and left-hand data were compared with a correlated t-test for each grip technique, as right- and left-hand data were recorded simultaneously. The grip pressures of different techniques were compared with an independent t-test for the right and left hand.

## 3. Results

In the Kamai stance, the grip pressure of the left hand was on average 6-7 times greater than the one of the right hand (Table 1; Figure 6). The Kote cut exhibited two different stages (Figure 7): the pre-impact period with a pressure distribution similar to the Kamai stance (left hand pressure 4.5-5 times greater than the one of the right hand), and the impact period, during which the grip pressure of both hands increased dramatically. The transition from pre-impact to impact period was defined by the sharp increase of the right hand pressure and a short decrease of the left hand pressure (Figure 7). After this short dip, the pressure of the left hand increased subsequently. In contrast to Kamai and the Kote cut pre-impact period, the grip pressure was 12% greater in the right hand during the impact period than in the left hand.

Table 1. Statistical data of grip pressure.

| Grip pressure | average (%) | standard deviation (%) | minimum (%) | maximum (%) |
|---|---|---|---|---|
| Kamai, right hand | 9.6 | 4.3 | 5.4 | 19.1 |
| Kamai, left hand | 66.0 | 8.4 | 52.9 | 81.5 |
| Kamai, difference (left minus right) | +56.4 | 9.4 | +36.7 | +74.5 |
| Kote cut, pre-impact, right hand | 10.1 | 3.7 | 5.1 | 20.0 |
| Kote cut, pre-impact, left hand | 47.4 | 12.4 | 26.4 | 67.9 |
| Kote cut, pre-impact, difference (left minus right) | +37.3 | 12.7 | +18.1 | +55.0 |
| Kote cut, impact, right hand | 94.6 | 5.3 | 78.1 | 100 |
| Kote cut, impact, left hand | 82.6 | 6.2 | 65.8 | 91.2 |
| Kote cut, impact, difference (right minus left) | +12.0 | 6.4 | –3.5 | +27.5 |

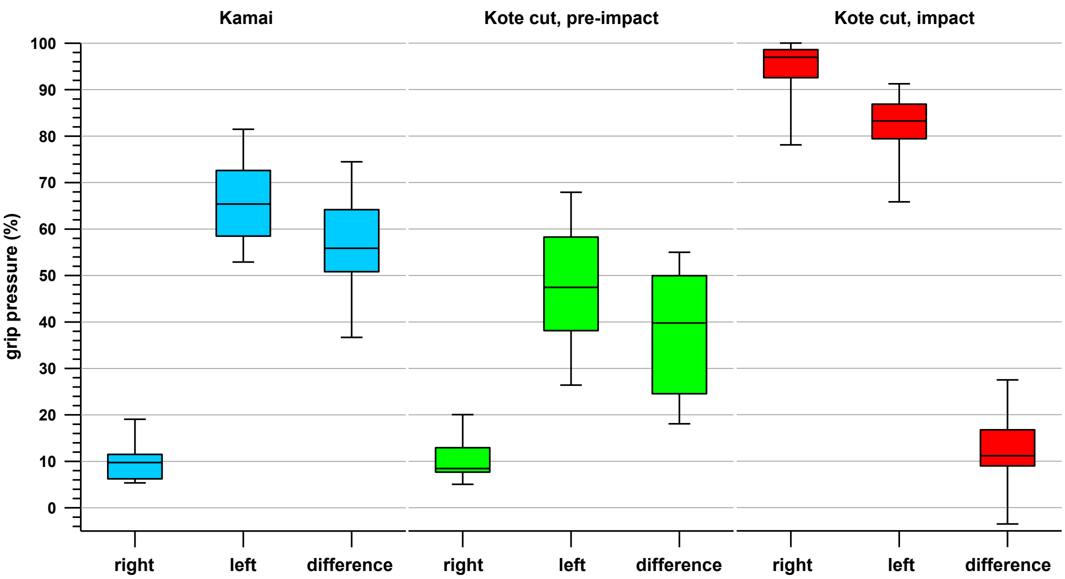


Fig. 6. Box-whisker plot of grip pressures in the Kamai stance, and Kote cut (pre-impact and impact)

Although the difference between right and left grip pressures was highly significant (pairwise t-test, $p<0.0001$), the grip pressure data of right and left hand did not correlate at all (Kote cut, impact phase: $r^2 = 0.16$; Kote cut, pre-impact phase, and Kamai: $r^2 < 0.005$). The pressure difference between the three different grips was highly significant in the left hand (independent t-test; $p < 0.0001$); in the right hand, only the pressure difference between Kamai and pre-impact phase of the Kote cut was non-significant ($p = 0.7$), whereas the difference of the two other grip pressures was highly significant ($p < 0.0001$).

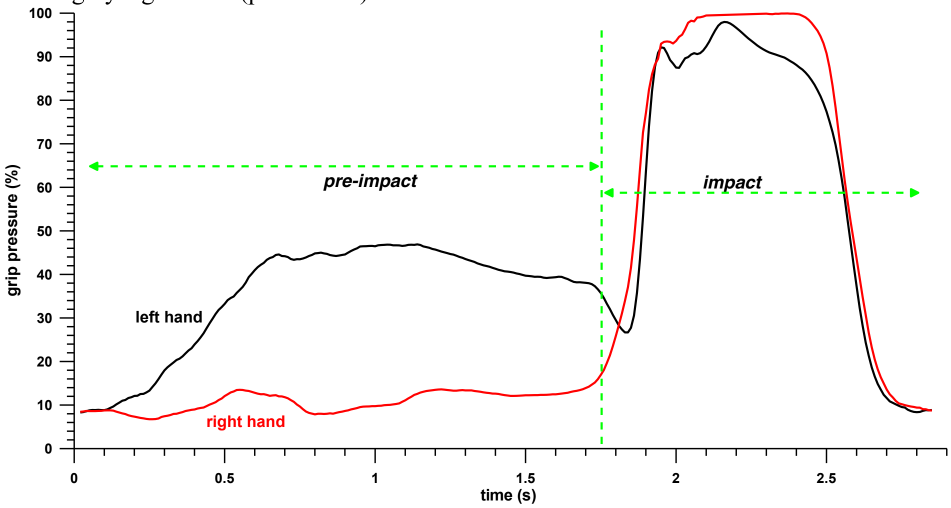


Fig. 7. Pressure (%) against time; Kote cut

## 4. Discussion

To the best of the authors' knowledge, the first instrumented martial arts sword was developed by James et al. [5], equipped with accelerometers. In this study we developed a Kendo sword with instrumented grip areas. We found a clear and statistically significant difference between different gripping techniques, and recorded the pressure transition from pre-impact to impact during the Kote hit for the first time. Care was taken that the impact force was not recorded by the pressure sensors. In the future, the blade of the sword will be instrumented as well, in order to: synchronise the impact with the grip pressure; measure the impact force; and count the number of impacts.

The normal fighting stance (Kamai) requires good balance of the handgrip to allow the player to be able to maintain the stance for long period of time. The theory taught by many kendo instructors recommends that the Kendoka should focus on left hand rather than on the right hand in this stance. However, there has been no scientific proof until now. This makes it difficult for beginners to have an idea of the pressure distribution between left and right hand. These experimental results obtained in this study (left grip pressure 6-7 times greater than right one) coincide with the teaching philosophy of most kendo instructors.

In this study, we reported the grip pressure data of only one subject. However, the participant is a highly experienced Kendoka, holding a 5$^{th}$ Dan degree. Using our instrumented Shinai, ongoing research is conducted on pressure assessment between Kendokas of different Dan grades and experience levels.

## References

[1] D.L.M. Macfarlane, Kendo: its Philosophy, History and Means to Personal Growth by Minoru Kiyota, Journal of the Royal Asiatic Society 7 (1997) 182-183.

[2] International Kendo Federation IKF, The Regulations of Kendo Shiai and Shinpan, International Kendo Federation, . Tokyo, 2006.

[3] G. Salmon, Kendo: A comprehensive Guide to Japanese Swordsmanship, Tuttle publishing, North Clarendon, VT, 2013.

[4] Y. Weizman and F.K. Fuss, RMIT Smart Materials calibration data library; internal report, RMIT University, 2014.

[5] D.A. James, W. Uroda, T. Gibson, Dynamics of swing: A study of classical japanese swordsmanship using accelerometers, in: A. Subic, S. Ujihashi (Eds), The Impact of Technology on Sport, ASTA (Australasian Sports Technology Alliance), Melbourne, 2005.