

A Sleeve Device using Electrical Impedance for Coaching Jump Shots in Basketball

Kazuma Takaishi¹, Hayato Saiki¹, Masakazu Hirokawa², Modar Hassan¹ and Kenji Suzuki¹

Abstract—The amount of force and the timing of force application are necessary training skills in basketball free-throw practice. Coaches cannot readily assess the shooter's motion and provide instructions because the throwing motion is performed in a short time, and because the applied force cannot be directly observed by a second person. In this work we propose a wearable device that measures the wearer's force control during throwing based on electrical impedance and acceleration measurement of the forearm, and provides feedback such that the wearer can adjust their motion appropriately. Temporal features of the electrical impedance and acceleration measured during throwing are determined experimentally to differentiate between experts and beginners. Using these features, we propose a training system for force control using the proposed device and verify its effectiveness in free-throw training.

I. INTRODUCTION

Throwing a basketball is a whole-body movement accomplished by transferring kinetic energy to a ball through the kinetic chain at the joints of the lower limbs, trunk, and upper limbs. In ball games, the appropriate throwing motion is required to ensure accuracy in the velocity and trajectory of the ball [1]. To improve the success rate of basketball jump shots, a technique to rotate the ball in the direction opposite to the throw must be learned. This technique reduces the horizontal force of the ball when it hits the board or the ring, thereby increasing the possibility of scoring. Correct hand movements such as wrist warping and finger releasing are necessary to apply a rotational force to the ball [2] [3] [4]. In this sense, a free throw is the result of a series of chronological movements by the wrist and fingers, respectively, and the temporal characteristics of each of the involved body segments must be understood to acquire such a kinematic chain [5] [6]. Excessive force during the throwing motion affects the shooting success rate. Beginners expend more force during the execution of this movement than experts, and excessive muscle activation reduces performance accuracy. Therefore, beginners must learn to apply an appropriate amount of force at the correct time [7].

For contact-type hand motion measurements, a typical method is to obtain the finger joint position information using only inertial sensors [8]. Inertial measurements are

not limited by the measurement range or environment which makes them more suitable than camera-based methods. However, inertial sensors may inhibit shooting motions due to attachment of the sensors to the finger joints.

Kinematic and bioengineering methods are primarily used for coaching motor-skill acquisition. An example of a kinematic method is a system that measures and coaches the acceleration and angular acceleration of the back of the hand during shooting [9]. However, information that can be provided to the player includes the position of the ball when it is grasped and the timing of ball release, where feedback regarding the overexertion of force (on the wrist joint) during shooting cannot be provided readily.

Bioengineering methods include systems that measure and use surface ElectroMyoGraphy (EMG) potentials of the upper arm and forearm for coaching [10]. The system supports skill acquisition by measuring the surface EMG of the learner's forearm and coaches the learner using the difference in timing by comparing with the EMG of a skilled player.

Biological information can be obtained via electrical impedance [11] [12]. In electrical impedance measurement, an alternating voltage is applied to the measurement target, and the electrical impedance is measured from the current flow based on Ohm's law [13] [14]. Because electrical impedance measurements use the alternating voltage from an external power supply as the input, they feature a greater effective power and higher stability than surface EMG measurements, thus allowing obtaining highly reproducible biological information. For example, a technique exists for measuring hand motion during a ball throw that requires fewer electrodes, thus improving the time response, and reduces the sensitivity to deformation in the cross-section of the measurement site [15]. This method confirms the change in electrical impedance via wrist flexion and the tendency of electrical impedance to decrease with increasing load applied to the hand. Hence, we infer that the hand motion and force during the throwing motion can be measured based on the acceleration of the arm and electrical impedance measurement at the wrist.

The objectives of this study are to propose and investigate a coaching method for basketball free throws based on force control using arm acceleration and electrical impedance measurement at the wrist. In addition, to realize a wearable system for coaching, we propose the following design requirements for the device: (1) does not interfere with the throwing motion for measurement; (2) possess a temporal resolution of 30 Hz or higher; and (3) provides real-time

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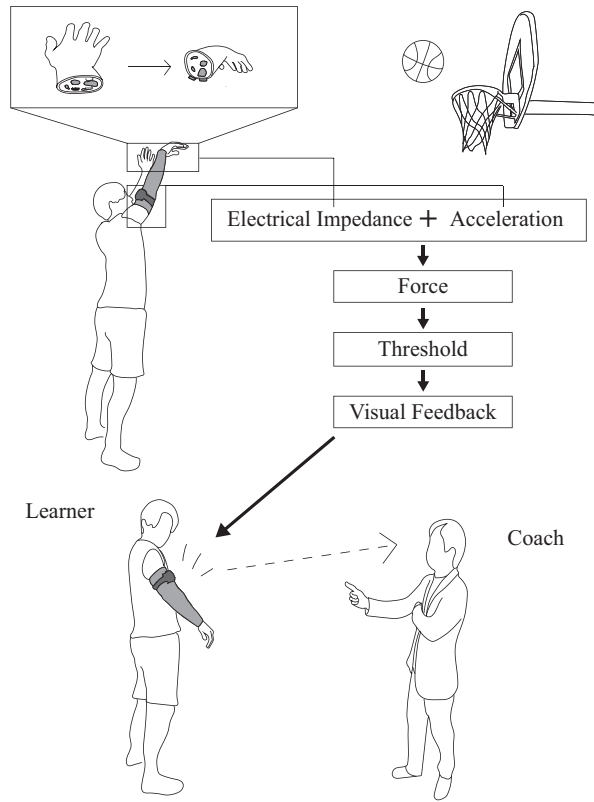


Fig. 1: System Overview

feedback to the user.

II. METHODOLOGY

A. Biomechanics of Ball Throwing Motion

An overview of the proposed coaching method is presented in Fig. 1. The device attached to the wrist measures the electrical impedance of the two electrodes to calculate the force overexertion during shooting. When the specified threshold is exceeded for the electrical impedance of the wrist and the acceleration of the upper arm, a Light-Emitting Diode (LED) on the device emits light to notify the learner of overexertion.

Hand motion in basketball shooting involves the flexion of the wrist and fingers to generate the force needed to launch the ball. The flexion of the wrist and fingers is accomplished by contracting the flexor digitorum, flexor carpi radialis, ulnar carpal flexor, and palmaris longus muscles, which are attached to the humerus via tendons. During contraction, the cross-sectional area of the muscles on the humeral side increases, whereas the cross-sectional area of muscles on the wrist side decrease. These muscles are attached to the bone via tendons, and the contraction of skeletal muscles attached to the bone causes the tendons to contract, thus resulting in flexion motion. All these tendons pass through the wrist, and the external shape of the wrist changes as the tendons stretch and contract. Thus, the cross-sectional area and external shape of the wrist muscles change with the flexion of the wrist and fingers.

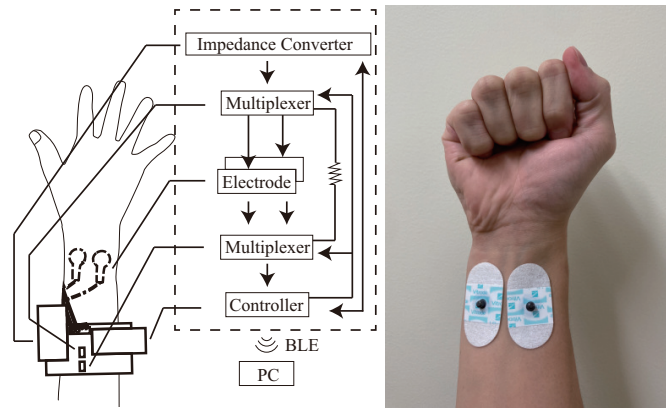


Fig. 2: Overview of the electrical impedance measurement setup on the wrist.

B. Electrical Impedance Measurement

In this study, we measure the internal structure and external shape of the wrist, which change with wrist and finger motion, based on electrical impedance. To measure electrical impedance, two electrodes were placed near the tendons involved in wrist flexion, as shown in Fig. 2. As the external shape changes are caused by tendon expansion and contraction, placing electrodes near the tendon allows one to measure electrical impedance changes that accompany the external shape changes.

C. Coaching method

In general, the throwing motions of beginner players are more wasteful and forceful than those of experienced players. Experienced players exert force on the ball at a timing in accordance with elbow extension during ball release. Meanwhile, beginners apply the force earlier than skilled players relative to elbow extension, which is referred to as *overexertion*. In this study, we aim to support the acquisition of force control skills by teaching the timing of force application. We attached acceleration sensors to the upper arm to detect elbow extension. The time difference between the elbow extension motion and the start of the change in the muscle cross-sectional area was calculated based on the electrical impedance of the wrist, and the timing of applying force to the elbow extension was calculated. The appropriate timing was derived by comparing the timing of the beginners and experts. If the timing of applying force to elbow extension exceeds a threshold value, then visual feedback is provided to the learner.

III. SYSTEM OVERVIEW

The configuration of the developed system is illustrated in Fig. 2. The device comprises two electrodes, two multiplexers, an impedance converter, a controller, and a $1\ \Omega$ resistor. The device was worn on the upper arm and the electrodes were attached to the wrist.

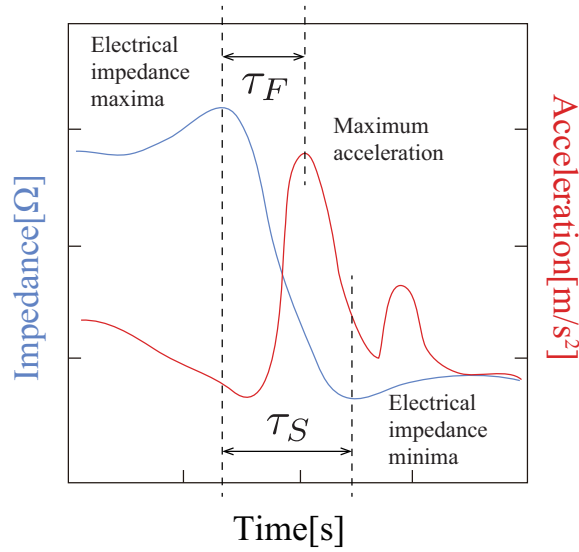


Fig. 3: Overview of two types of timing factors

A. System Configuration

The electrical impedance between the two electrodes attached to the wrist was measured, and the acquired values were transmitted from the microcontroller to a PC via Bluetooth Low Energy (BLE) communication. An adhesive gel electrode (Dispo-electrode F Vitroad, NIHON KOHDEN, Tokyo, Japan) was used. A multiplexer (ADG1404 Analog Devices) was used to switch the channel between the two electrodes and a 1 kΩ resistor for calibration.

The impedance converter (AD5933 Analog Devices) comprised a frequency generator and a 1 MSPS 12bit Analog-to-Digital (A/D) converter. The frequency generator can output excitation voltages of up to 100 kHz with a resolution of 0.1 Hz. The impedance measurement range was from 100 Ω to 10 MΩ. In a previous study [11], researchers discovered that an excitation voltage of 40 kHz was the most suitable for gesture recognition. Therefore, in this study, we measured the electrical impedance of the wrist using an excitation voltage of 2 V peak-to-peak at 40 kHz. To calibrate the impedance converter by measuring the impedance of a known resistor before the measurement, a 1 kΩ carbon electrical resistor was connected between the two multiplexers, as shown in Fig. 2.

A microcontroller (Arduino Nano 33 BLE Sense) was used to control the multiplexer and impedance converter using I2C communication with a clock frequency of 400 kHz. A built-in inertial sensor (LSM9DS1) was used to measure the angular velocity of the forearm to detect shooting motion, and the results were sent to a PC via BLE communication.

A 3.7 V 110 mAh lithium-ion battery was used, and a case to contain the components above was fabricated using a 3D printer. An arm sleeve was used to attach the case to the upper arm to prevent the case from interfering with the shooting motion.

B. Measurement Procedure

An overview of the procedure for measuring the electrical impedance and acceleration is shown in Fig. 4. For calibration, a resistance value similar to the impedance of the measurement target at the wrist is desired [11]. Therefore, a 1 kΩ resistor was used for calibration in this study. After calibration, an excitation voltage was applied between the electrodes using an impedance converter. The impedance converter acquired 1024 data points and calculated the discrete Fourier transform. The computed real and imaginary components were sent to the microcontroller to calculate the impedance. Additionally, acceleration was measured along the three axes via a built-in inertial sensor. A moving average filter with five intervals was applied to the electrical impedance and acceleration measurements. Based on the results, the average absolute values of the acceleration data for the three axes were calculated to determine the motion of the entire arm. Subsequently, the time of maximum and minimum values of electrical impedance were recorded, i.e., $T_{EI_{max}}$ and $T_{EI_{min}}$, and time of maximum acceleration was recorded $T_{ACC_{max}}$, for each shooting. Based on these timings, we introduce two forms of time difference, as illustrated in Fig. 3. The time difference between the maximum and minimum electrical impedance (τ_s : snap time) and the time difference between the maximum of the electrical impedance and the maximum of the acceleration (τ_f : force application time) as shown in (1) and (2).

$$\tau_s = T_{EI_{max}} - T_{EI_{min}} \quad (1)$$

$$\tau_f = T_{EI_{max}} - T_{ACC_{max}} \quad (2)$$

The microcontroller then sends the acquired electrical impedance, acceleration measurement results, τ_s , and τ_f to the PC via BLE communication, and repeats the measurement. The impedance converter is calibrated only once.

IV. EXPERIMENTS

A. Relationship between surface EMG potentials of forearm and electrical impedance of wrist

The purpose of this experiment was to measure the surface EMG potentials of the forearm and the electrical impedance of the wrist during shooting and to clarify the relationship between the EMG potential and electrical impedance.

Male basketball players were recruited to conduct the experiment. A wireless EMG measurement system, Trigno (Delsys), was used to measure the surface EMG potentials. Two EMG sensors were attached near the radial carpal flexor muscle, which operated via wrist flexion; one sensor was attached near the long radial extensor muscle, which operated via wrist extension; and one sensor was attached at the back of the hand. The developed device was attached as shown in Fig. 5 for the experiment, which was conducted in an indoor sports facility. The participants shot from the free-throw line (4.6 m from the board of the basketball goal) toward the goal (height of 3.05 m).

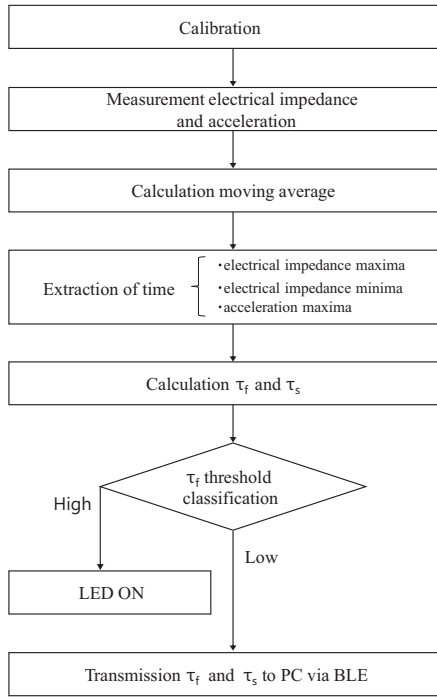


Fig. 4: Overview of the algorithm to generate feedback for the coaching method

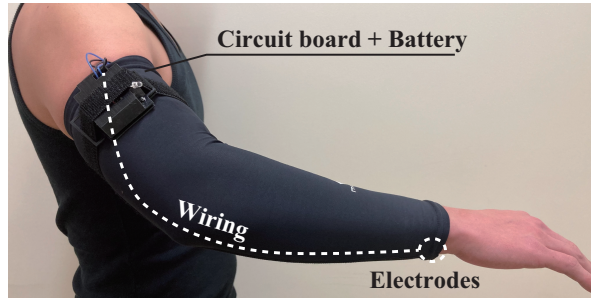


Fig. 5: A participant wearing the developed device

First, the participant was instructed to grasp the basketball near the chest and hold it with the knees bent. Next, the experimenter commenced the measurements and instructed the participants to shoot. After 10 repetitions, the experimenter instructed the participant to intentionally shoot with excessive force, which was performed 10 times. Subsequently, the experimenter instructed the participant to intentionally over-relax and shoot, which was performed 10 times.

The acceleration and electrical impedance of the upper arm were measured at 175 Hz, the surface EMG at 1.8 kHz, and the acceleration and angular acceleration of the IMU sensor built into the wireless EMG system at 74 Hz. The angle of wrist flexion relative to the forearm was calculated from the data of the IMU sensor built into the wireless electromyography system to estimate the wrist flexion motion.

Fig. 6 shows a sample of the results of the electrical impedance, surface EMG, wrist flexion angle, and acceleration when the participant shot with normal force (no

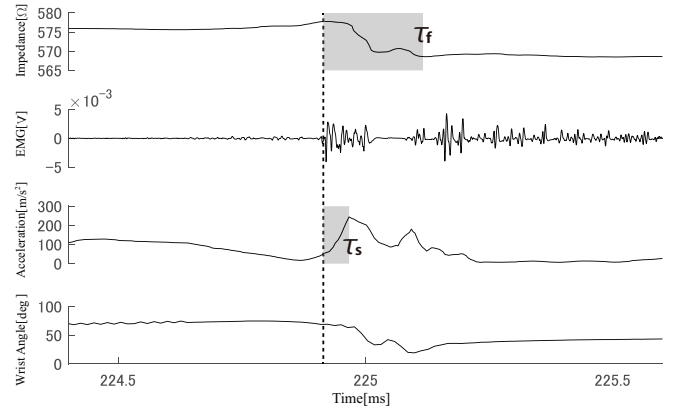


Fig. 6: Electrical impedance and EMG during throwing motion

TABLE I: Force application time

Participant	Force application time [ms]
relax	46.40±23.47
normal	49.20±11.86
stress	62.80±6.78

overexertion or over-relaxation). The dashed line in the figure represents the time at which the electrical impedance reached its maximum value. The mean and standard deviation of τ_f were calculated from the results of the electrical impedance and acceleration, and the results were classified into normal shooting, forceful shooting, and relaxed shooting, as shown in Table. I. Based on Fig. 6, changes in the electrical impedance at the wrist, the generation of surface EMG potentials at the forearm, the wrist flexion motion, and the acceleration at the upper arm were observed with hand motion during shooting. Comparing the temporal changes in electrical impedance and surface EMG, we observed that the surface EMG was generated when the electrical impedance began to decrease. A comparison of the temporal changes in the electrical impedance and wrist flexion angle showed similar temporal changes.

Additionally, we observed that τ_f was greater for the intentionally overexerted shots than for the intentionally over-relaxed or normal shots, as shown in Table. I.

B. Impedance measurement at the wrist during shooting

The purpose of this experiment was to clarify the differences in force between novice and expert shooters. Three expert male basketball players and three beginners were recruited to conduct the experiment using the developed Device, as shown in Fig. 5.

As mentioned in Section IV.A.1, the experimenter started the measurement and instructed the participants to shoot

TABLE II: Time of force applied by an expert and a beginner

Participant	Success Rate[%]
expert	75.6 \pm 11.1
beginner	48.9 \pm 14.4

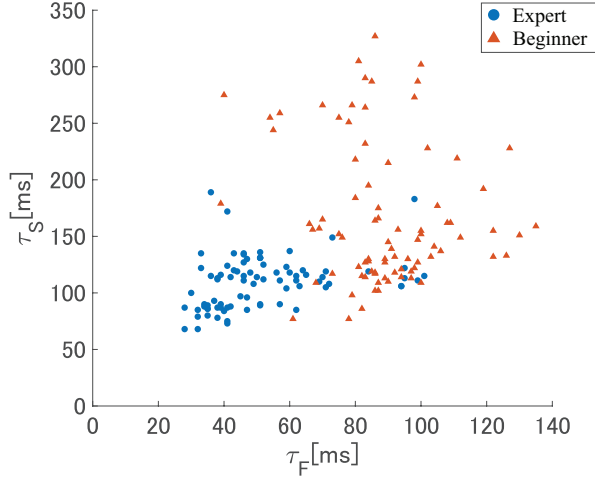


Fig. 7: Scatter plot of electrical impedance measurement during ball throw by expert and beginner players

from the free-throw line toward the goal. Immediately after shooting, the participants verbally answered whether the shot was successful or unsuccessful based on their own judgment before visually confirming the results of the shot. This procedure was repeated 30 times.

The success rates of skilled and novice players are listed in Table. II. Additionally, τ_s and τ_f were calculated and classified into those of skilled and novice shooters, and the results presented in a scatter plot are shown in Fig. 7. Figure 8 shows the difference between beginner and expert players in terms of τ_S and τ_F . In both cases, statistically significant differences were observed (Welch's t-test). The observed effect size d was large for both cases (τ_S : $p < 0.001$, $d = 0.96$, τ_F : $p < 0.001$, $d = 0.96$). Additionally, the variance in the novice shooter results exceeded that of the expert shooters.

C. Coaching experiment

The purpose of this experiment was to evaluate the coaching of force application time using the developed system. A beginner male basketball player was recruited for the experiment using the developed device, as shown in Fig. 5. Here, τ_f was calculated for each shot, and when the time exceeded 80 ms, the LED on the device emitted light to indicate overexertion. The threshold values were set based on Fig. 7 in Section IV.B.

First, the experimenter explained the relationship between τ_f and overexertion to the participant and notified them that the emission of the LED light indicated overexertion. Subsequently, as in Section IV.B.1, the participant responded regarding the throw success immediately after each shot based on their judgment. After each shot, the participant was

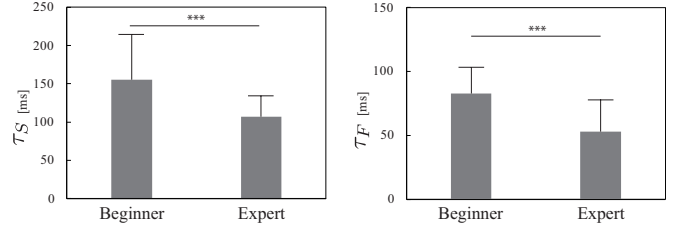


Fig. 8: Difference of τ_S and τ_F between beginners and experts

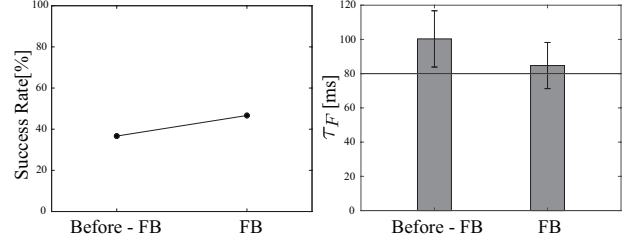


Fig. 9: Success rate and electrical impedance with and without visual feedback from wearable device.

provided visual feedback regarding the overexertion of the previous shot. This procedure was repeated 30 times.

The results of τ_f and the success rate of shooting with and without feedback on overexertion are shown in Fig. 9. The results showed that the proposed coaching method decreased τ_f and increased the shooting success rate.

V. DISCUSSION

A. Relationship between surface EMG potentials of forearm and electrical impedance of wrist

The comparison between the temporal changes in electrical impedance and surface myopotentials confirmed that the electrical impedance began to decrease when the myopotentials were applied. This was speculated to be due to the change in the cross-sectional area of the wrist caused by forearm muscle contraction. Therefore, we can conclude that measuring the electrical impedance of the wrist allows us to measure the shape change of the wrist associated with the contraction of the radial carpalometacarpal flexor muscles. In addition, comparing the time variations of the electrical impedance with the wrist flexion angle, the results showed that the electrical impedance either increased or decreased with changes in the wrist flexion angle. This may be due to changes in the cross-sectional area of the wrist muscle caused by wrist flexion. These results suggest that the electrical impedance of the wrist changes with the contraction of the radial carpalometacarpal flexor muscle and the flexion of the wrist during throwing. As shown in Fig. 6, muscle activity occurred twice during the throwing motion. This is speculated to be due to the overexertion generated in the wrist to release the ball and stabilize the wrist posture after the release.

As shown in Table. I, τ_f was larger in the case of the intentionally overexerted shot than in the cases of an intentionally

over-relaxed shot and a shot performed normally. This can be attributed to the fact that the timing for applying force during the throwing motion advanced due to overexertion; consequently, the time at which the electrical impedance of the wrist began to decrease in relation to the time of the peak acceleration of the upper arm advanced. This suggests that the calculated τ_f can be used to detect overexertion during throwing motion.

B. Wrist electrical impedance measurement during shooting

Our experimental results showed that novice players exhibited longer τ_f than skilled players (Fig. 7). This implies that the difference between the τ_f of a skilled person and that of a novice can be detected, and that a coaching method can be designed based on τ_f to improve the skill of novice players. In addition, a comparison of the τ_s values of novice and expert players showed that the variance was smaller among the expert players. Since τ_s is the time from the onset of wrist force to the end of the wrist-bending motion during the ball release, the result indicates that the wrist-bending motion for ball release by the skilled players was stable from the time at which the wrist force was applied to the time at which the wrist was bent.

C. Coaching experiment

As shown in Fig. 9, the proposed coaching method reduced τ_f , whereas the presented feedback reduced overexertion. In addition, the shooting success rate increased by 10 % after the instruction was provided. Reduced overexertion may be related to more stable force transmission to the ball and improved shooting stability. These results indicate that a coaching method based on wrist electrical impedance can potentially support skill acquisition during basketball throwing motion.

VI. CONCLUSION

We proposed a device that teaches the correct timing of force application to a ball based on electrical impedance measurements of the wrist during the throwing motion. A comparison of electrical impedance and surface EMG values showed that the electrical impedance changed with muscle contraction and wrist flexion. A comparison of the electrical impedance of the wrist and the acceleration of the upper arm of novice and expert players showed that beginner players tended to overexert their shots. Additionally, the beginners' overexertion during the throwing motion was reduced by providing visual feedback on force application time using a wearable device. The results indicated that coaching based on the measurement of electrical impedance at the wrist during the throwing motion is viable to support skill acquisition.

In this study, coaching was performed based on the force application time. However, increasing the number of indicators used for coaching, such as the time at which the force is extremely weak, may enable a wider variety of kinematic information to be taught and further support beginners' acquisition of skills. In addition, although we focused on shooting from a free-throw line in this study,

teaching shooting from different distances and in various situations, such as during a game, is desirable. In the future, we intend to develop a coaching system that measures electrical impedance during the throwing motion in various situations and teaches the appropriate level of force based on distance.

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