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DESIGN AND DEVELOPMENT OF AN UPPER EXTREMITY PERFORMANCE ANALYSIS SYSTEM FOR COMBAT SPORTS

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ABSTRACT

The purpose of this study is to develop a training and measurement system based on kinetic and kinematic parameters for combat sports that require upper extremity performance, such as boxing, judo, and karate. This system instantly measures strength, speed, and coordination parameters with cognitive stimuli. The parameters such as force applied against colored cognitive stimuli, reaction time given to stimuli, total training time determined by the coach during the training are saved instantly by the software and reported at the end of the training. As a result, it is ensured to follow sports performance with the kinetic and kinematic data obtained from sports efficiency, develop new training methods suitable for the athlete, determine the training program's effectiveness, and predict injury risk.

Keywords: *Performance, upper extremity, kinetic, kinematic, sport*.

INTRODUCTION

According to specific technical rules that contribute to physical development and aim at entertainment and competition, all body movements made according to specific technical rules are called sports. The physiological, biomechanical, and psychological efficiency required by a sportive activity is called performance [1]. Performance levels depend on internal factors such as age, sex, motivation, genetics, nutrition, health, and external factors such as sportswear, moisture content, height, and suitability [2, 3]. Determining performance is the most important element of sporting success [4]. For this reason, to ensure the improvement of sports performance, training must be in a way that will push the limit of the athlete [5]. By achieving harmonious development of internal and external factors that determine performance, the individual or team achieves the best success [6, 7].

Analysis of the athlete's movements with different methods and techniques reveals quantitative data on the athlete's motor characteristics [8]. Regular recording of these data plays an essential role in developing the athlete's process and planning the increased performance [9, 10]. In the literature, it is seen that there are studies conducted in every field from the anatomical structure of the body of the athlete to the shoe. New products can be designed to improve performance in these studies due to quantitative data evaluation based on measurements [11]. In their study, Perš et al. claimed that the athlete's movement could be examined using biomechanical measurement systems, but these devices are not suitable for studying large-scale motion data during a game because of their limitations. They presented a video-based, computer-aided system as an alternative approach to study large-scale motion data, and in particular, the process of obtaining large-scale motion data [12]. In the study by Harbili and Arıtan, the authors presented the kinetic differences between elite weightlifters by calculating the force, work, and power values applied to the bar during breakout lifting. The study included three elite male weightlifters weighted 56 kg in the 71st World Weightlifting Championships. During the weightlifters' breakout lifts, image recordings were taken with a high-speed camera by marking 18 anthropometric points on the weightlifter and 2 points on the bar. As a result of their study, kinetic and kinematic parameters such as body position, maximal height of the bar, and applied force were collected to determine the technical difference among the weightlifters [13]. Caniberk et al. (2016) realized an analysis system for performing motion analysis outside the laboratory environment to minimize the negative effects such as limitation and inability to observe the physical activities required by the sport. They examined the effects of photogrammetric techniques based on measurement and interpretation of objects from images in determining the athlete's movements based on previous studies. As a result of their research, they designed a system that could analyze the athletes' movements in real-time, examine the techniques of the athletes, and be used by the coaches [14]. In 2018, Koyoma et al. investigated the effects of somatic maturity and training experience on young judo athletes'

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muscle morphology. The study results showed that biomechanical parameters and bilateral asymmetric measurement data affected the muscle morphology of somatic system operation and training experience [15]. The research paper that was published by Busko in 2019 emphasized the importance of measuring response time, as well as the power measurement of the athlete [16].

In this study, unlike the literature, a kinetic and kinematic based measurement system was designed for combat sports branches requiring upper extremity performance such as judo, boxing, and karate [17]. With the developed performance analysis system, cognitive stimuli were included in the training program, and strength, speed, and coordination parameters were measured instantaneously. Analyses were carried out on the force applied by the athlete against the colored cognitive stimuli that can be determined by the coach during the training, the response time is given to the stimuli, the total training time, and so on. The parameters were displayed instantly by the software and reported at the end of the training.

MATERIAL AND METHOD

The block diagram of the designed upper extremity performance analysis system is given in Figure 1. The measurement system consists of six measurement microcontroller circuit boards with force sensors supported by visual stimuli. Red, green, and blue lights are used on each measurement circuit board as a visual stimulus, connected to where the force is applied. In this system, the athlete must watch the red light and knock at the red-lit place according to the coach's predetermined protocol. It aimed to cognitively measure the athlete's selectivity perception by giving the green and blue colors at the same time as the red color. The place where each athlete knocks or kicks is controlled wirelessly by a microcontroller card. A microcontroller controls stimuli, and performance measurement is realized according to the commands from a PC or mobile phone. The athlete's maximum force value and the duration of this movement data are transmitted by each measurement circuit wirelessly to the PC or mobile phone. This way, it is provided to display, report, and store the athlete's performance data instantly by the interface software.

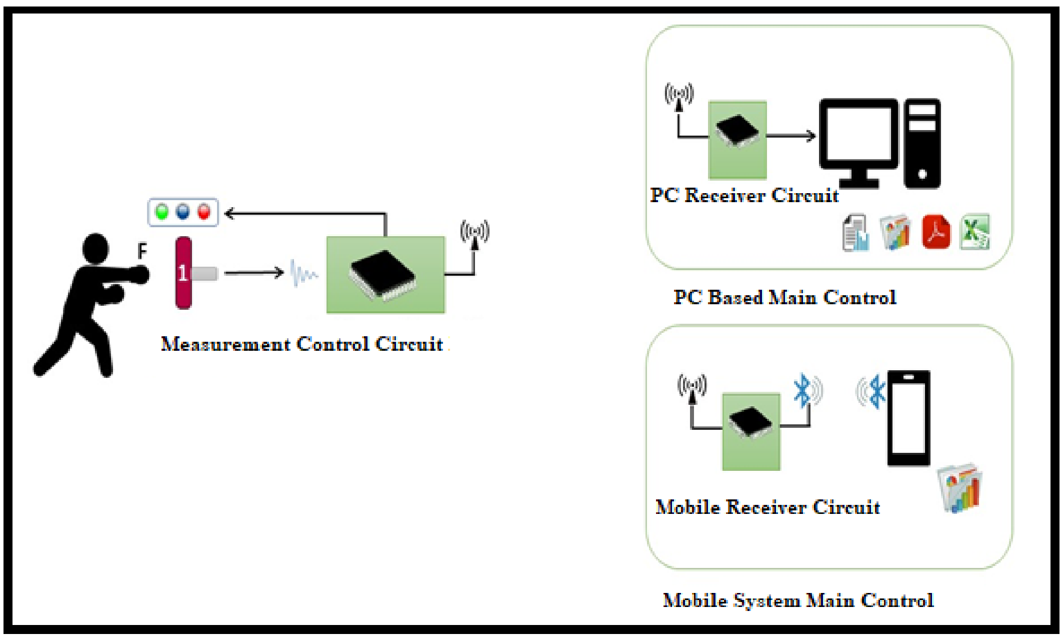

Figure 1. Hardware block diagram of the training measurement system.

Mechanical Design of the Main Measurement System

Figure 2 shows that the Button type sensor was used for single-point force measurement in the main measurement system. The part to be applied force on the measurement unit was covered with an EVA sponge to prevent damage to the athlete's hand. The force applied by the athlete to the boxing mash came directly to the sensor's force application point via the gas piston mechanism. The system was able to move more easily in the piston housing. The measuring unit was mounted to the column-shaped pipe with a pinhole connection at certain angles and heights.

During the training, 6 different stimuli were used for the athlete to apply force to 6 different points. It was determined by the protocols pre-prepared in advance which unit and point of measurement the athlete would apply force during the training. By the protocols, colored light stimuli (red, green, and blue) were given to the athlete, and it is provided that force was applied to the desired red point with the helping of these colors. The force's value applied to the sensor and reaction time was measured by electronic hardware and embedded system software. The measured kinetic and kinematic parameters were sent to the central controller consisting of a computer or a mobile device.

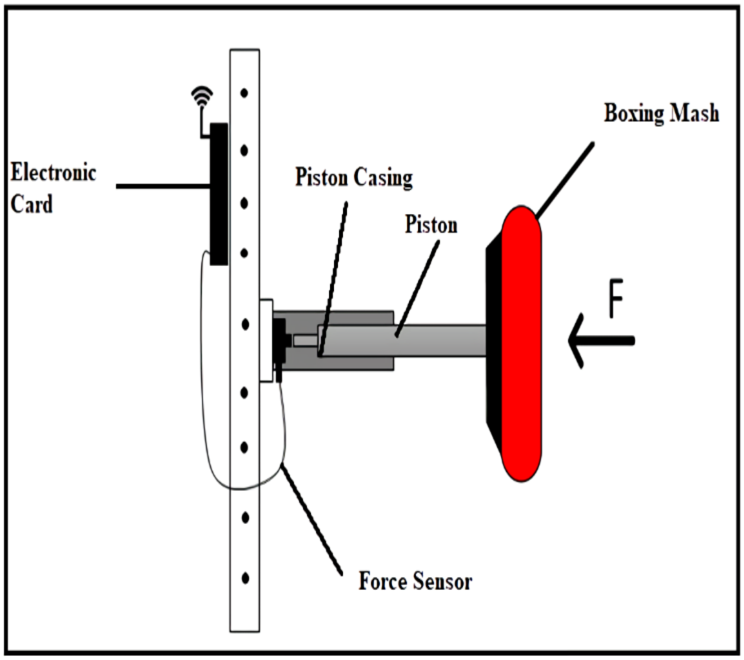

Figure 2. The basic unit of measurement that forms the training measurement system.

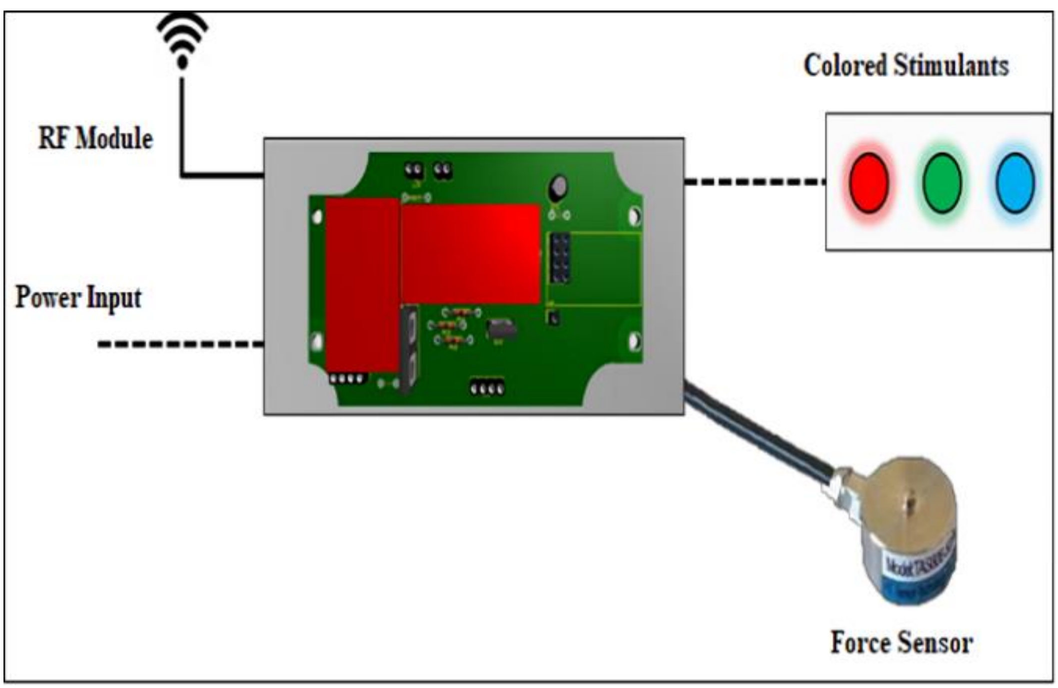

Figure 3. Electronic design of the basic measurement unit.

Figure 3 shows the electronic design of the basic unit of measurement and performance measurement systems. The electronic equipment consists of a microcontroller, wireless communication module, color stimuli, and force sensor. The Arduino Nano board on the ATMega168 controller was used as the controller. To determine the athlete's training based on the stimuli and reaction time, an LED strip was used for the stimuli in three different colors. In this study, to measure the maximum force along with the stimuli, a 200 kg capacity TAS606 of HT, which has different capacities between 5 and 500 kg, is a button-type load cell in the IP66 protection class with a stainless steel body. This sensor has been chosen because of its very small physical size, its suitability for accurate measurement of force in device design, and its linearity characteristic of ± 0.3 in the full measurement range.

Force Sensor Calibration

A calibration process achieved the measurement accuracy of the measurement unit that was used in this study. Figure 4 shows the test setup for force sensor calibration. The 3 mm EVA sponge, which does not affect the applied force, was removed from the box mash in the calibration process. Here, a clamping mechanism was placed between the part to which the force was applied, and the reference force measurement device and an experimental apparatus for taking the measurements was formed. Here, constant power is applied according to DKD-R 3-9 to observe the measuring system's linear response change. Different force values were obtained using the compression mechanism, and force measurements were taken with the system's electronic unit. These measurement values were analyzed with the reference force values, and their accuracy was determined.

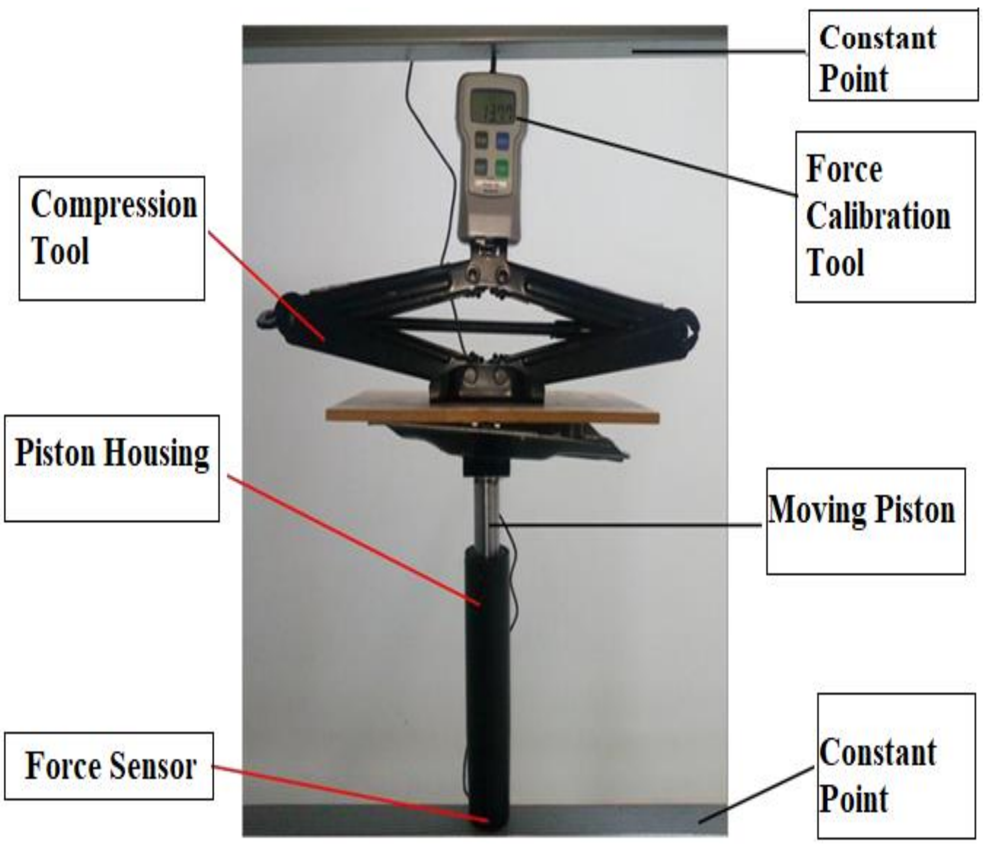

Figure 4. Test setup for force measurement calibration.

The force values obtained from the training device measurement unit were compared with the 500N-capacity SHIMPO FGJN-50, which was the force calibration device. The correlation between the system and the calibration device data was linear, and the regression analysis revealed that the R^2 value was 0.996. The data obtained by the calibration process are displayed in Figure 5.

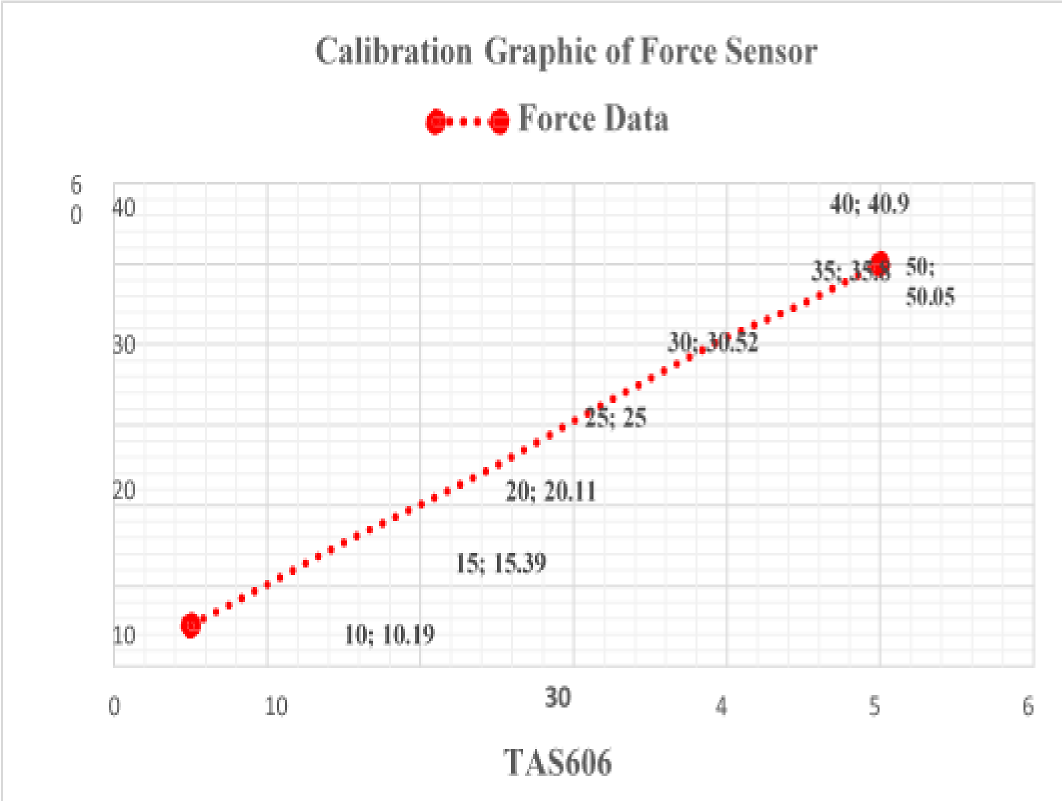

Figure 5. Force sensor calibration chart.

Software Algorithm

Figure 6 shows the flow chart of the software algorithm of the t measurement system. Each measurement unit constituting the measurement system had a microcontroller, peripherals, and input-output connections. The microcontroller has enabled the colors to light up in the box mash according to a certain order according to the commands received from the PC or mobile device. It measured parameters such as the athlete's force to the boxing mash against the light stimulus and sent it wirelessly to a PC or Mobile Device. During the training, data from the main control software were monitored by each microcontroller. After obtaining the data, the microcontroller took the data and matched it with its own identity. The microcontroller sent measurement data compatible with the ID. Otherwise, the microcontroller remained on standby.

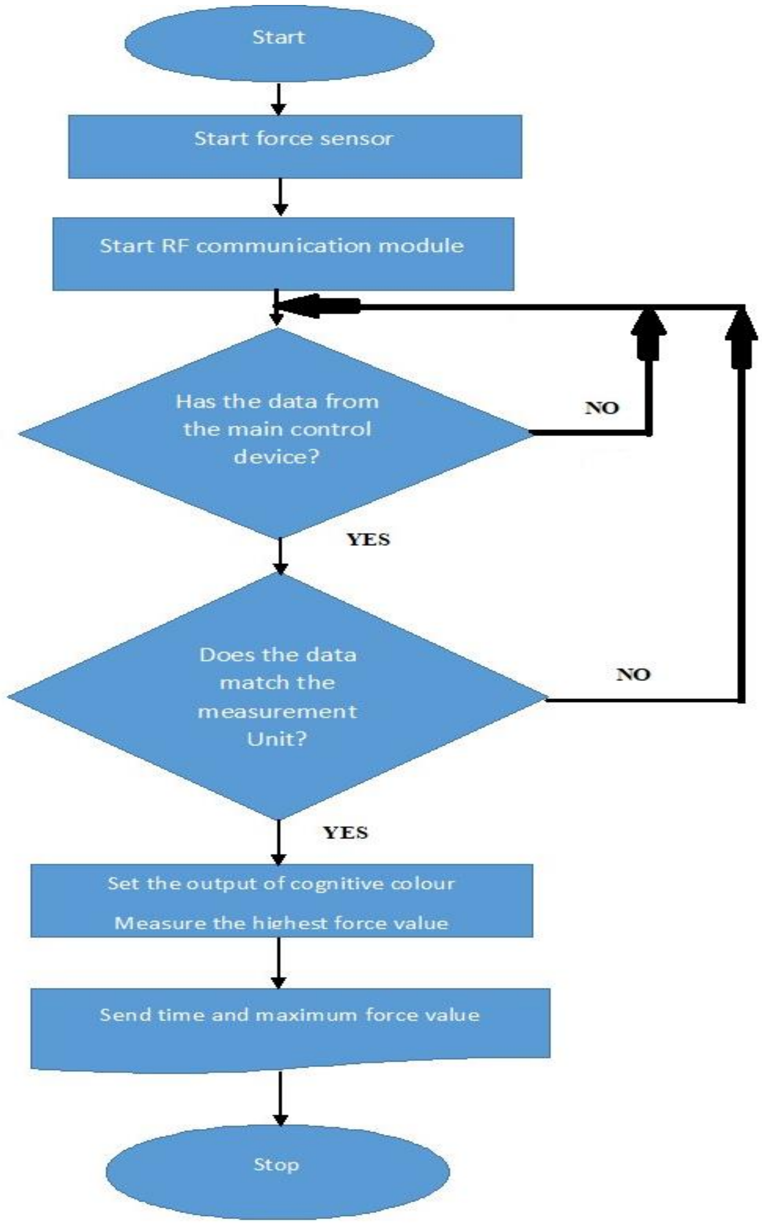

Figure 6. Software algorithm of the training measurement system.

Measurement of Kinetic and Kinematic Parameters

In the developed system, force and reaction time were calculated as the biomechanical parameters. The athlete's maximum force to the boxing mash and reaction time was calculated instantly by the system and sent to the desired main control device, such as a PC or mobile device. The force parameter is of the most important kinetic parameters of the athlete studied in biomechanics. Figure 7 shows the single-strike force curve measured with the TAS606 force sensor. The threshold strength level was used to determine whether the athlete was applying the force predetermined in the program during training. All force data between the athlete's strength exceeding the threshold level (indicated with red dashed line) and the time that this force is withdrawn from the box mash was sampled with the HX711 integrated with a frequency of 80 Hz and recorded instantly. The maximum force value was found from this force data.

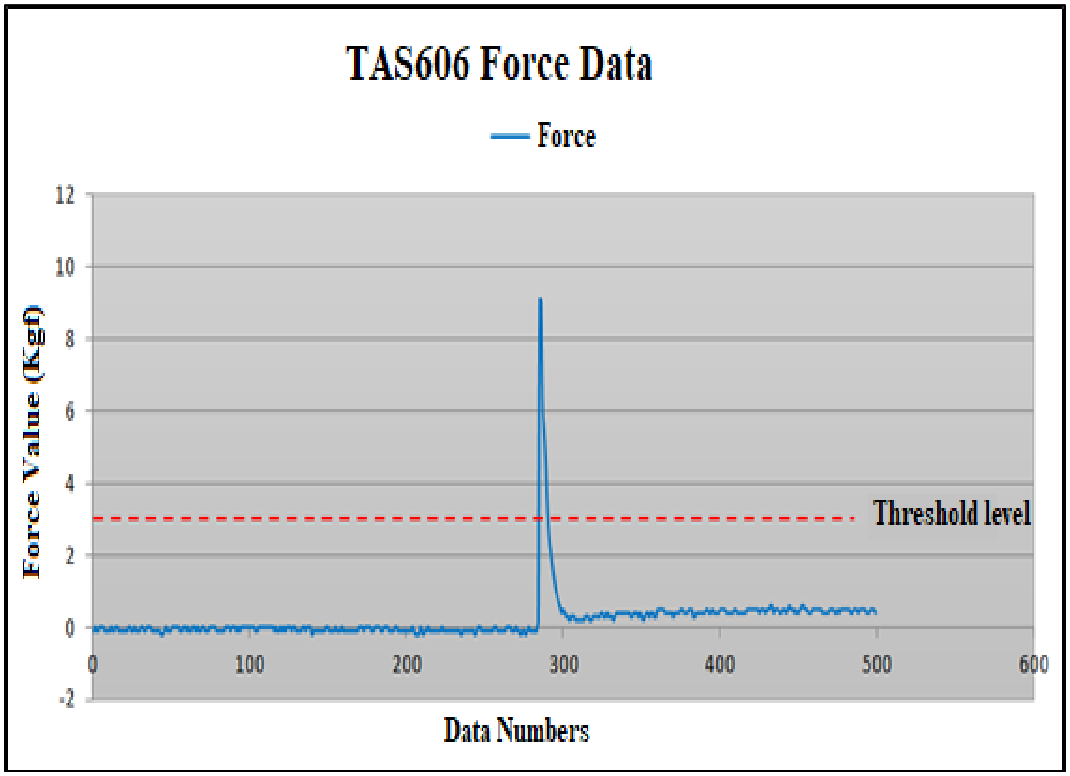

Figure 7. Force Measurement

One of the essential parameters studied in kinematics, another branch of biomechanics, is reaction time. The reaction time shows the functionality of the neural conduction between the athlete's brain and muscles. When a received stimulus is perceived by the athlete and resolved by their brain, it is then sent to the nerves as a stimulant for muscle contraction. Figure 8 shows the calculation of the reaction time.

Color stimuli that could be determined by the user interface software were applied to the athlete during the training, and the time elapsed between receiving the stimulus and applying force as feedback was calculated automatically by the measurement system.

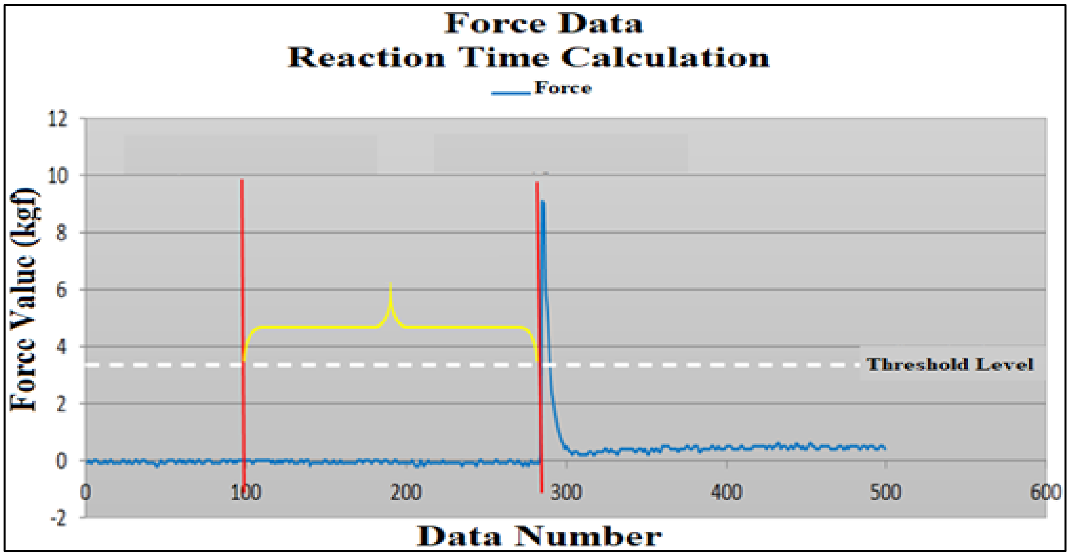

Figure 8. Reaction time calculation.

Training Protocols

In the upper extremity performance analysis system, the athlete's way and order to practice exercise was carried out with the training protocols prepared in the computer and mobile device interface program. Training protocols have been created with one of the colors red, green, and blue or a combination of these. Figure 9 shows a sample training protocol consisting of three different cases, such as cases 1, 2, and 3. Here, the athlete followed the red color and applied the force to the numbered regions by following the red colors in Figure 9a, Figure 9b, and Figure 9c, respectively. In this training example, the athlete followed the red color and applied force to the box mash number 5 in case 1, number 6 in case 2, and number 1 in case 3, respectively. By giving the athlete red, blue, and green colors together, the athlete's selectivity in perception is increased, and his reaction to this situation is measured.

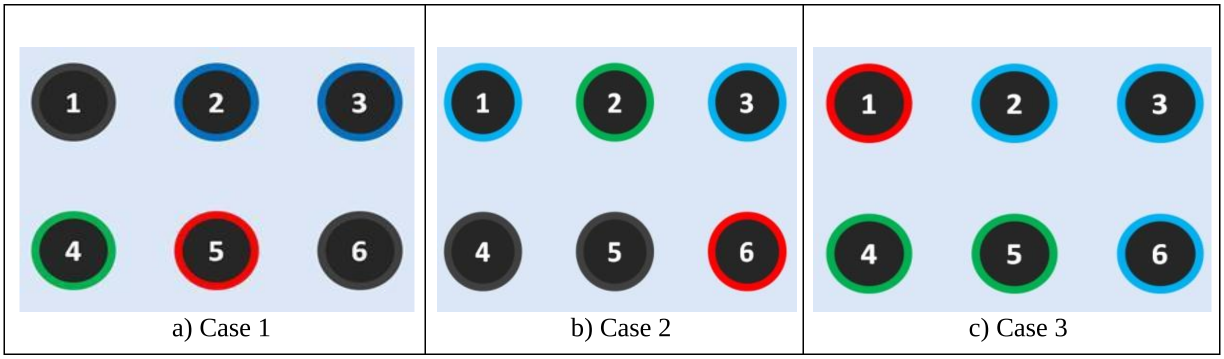

Figure 9. Training protocol cases.

Training protocols must be created in the desired number in computer and mobile device software realized for control and data recording of training and performance measurement systems. After selecting, the desired follow color from among those consisting of red, green, and blue, training protocols may be created according to the coach's request.

RESULTS

Figure 10 shows the training and performance measurement system. The training and performance measurement system consisted of 6 different kinetic and kinematic measurement units. The system was designed to be wall-mounted. According to the athlete's height and upper extremity movement, the system can be adjusted to a certain angle and height by the trainer, up-down, and right-left.

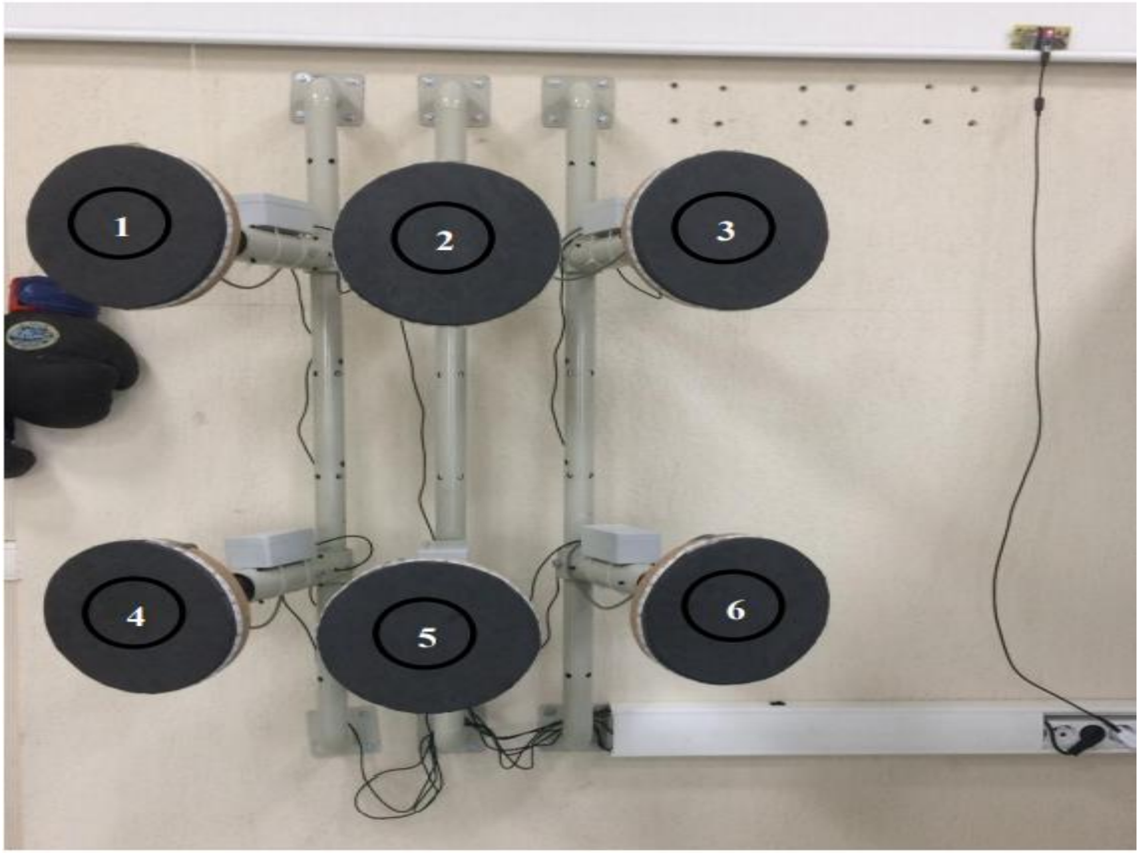

Figure 10. Designed training and performance measurement systems.

Table 1. Technical characteristics of the training and performance measurement system.

Technical Specifications	**Features**
Communication Frequency	2.4GHz ISM
Normal Operation Current	344mA
Communication Type	RF and Bluetooth
Maximum Current	1.4A
Operation Voltage	+ 12V
Number of Stimuli	3
Stimulant Type	Colored Light (Red, Green, Blue)
Communication Distance	250m (in open area)
Dimensions	141x95x55mm
Measurement units	6 units
Maximum Force	2000N (200kg)

With colored stimuli on six different measurement units, the athlete's cognitive ability was tested based on reaction speed. With the protocols created by the coach, the athlete's responses to upper extremity strength and color stimuli during sporting activities were measured as reaction time and sent to the computer software. Table 1 shows the technical characteristics of the training and performance tester.

Computer-Based Performance Measurement System Software

The software developed for the training and performance measurement systems, control of the device, creation of the training protocols, recording and reporting performance data were provided. The kinetic and kinematic parameters such as maximum force applied by the athlete and reaction time after the training protocols sent to the training device were sent to the computer simultaneously via wireless communication. An RF receiver module provided wireless communication between the computer software and the training system. Figure 11 shows the main screen image of the computer software of the training measurement system. In this screen, features such as connection with the training device, access to the previously established training protocols, displaying the training protocols in color, instant display of the data obtained during the training, and displaying this data as a list were added.

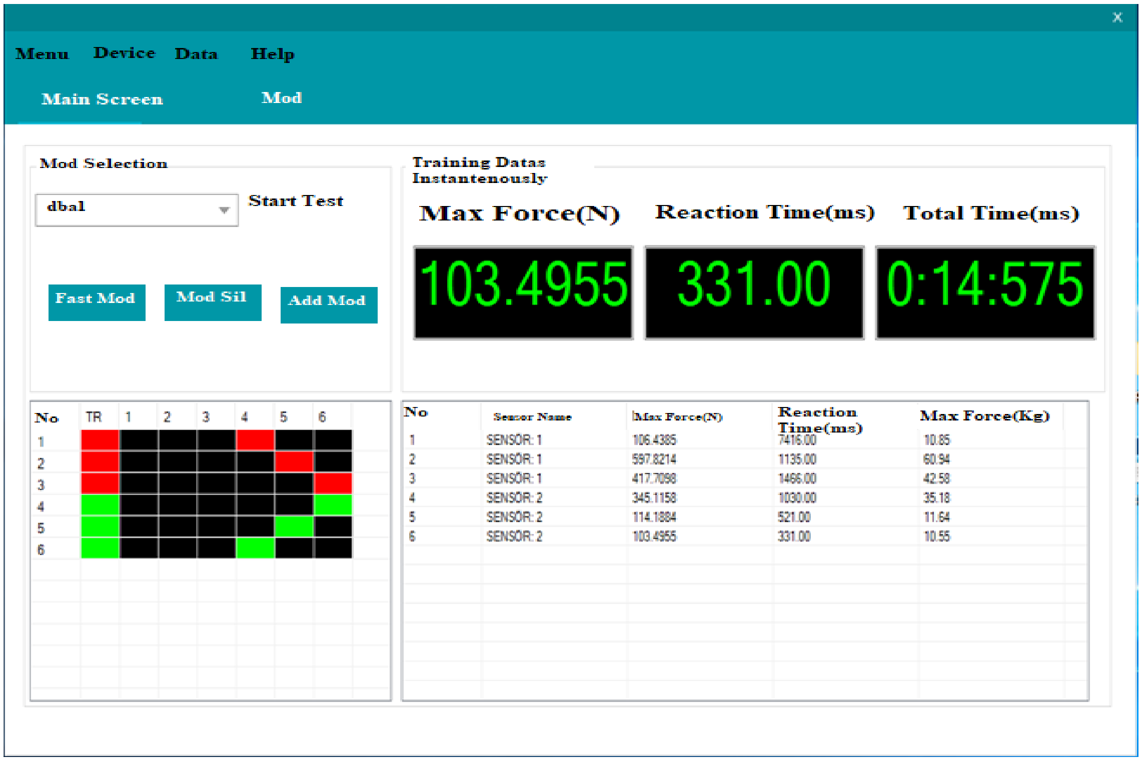

Figure 11. The computer software of the training and performance measurement systems.

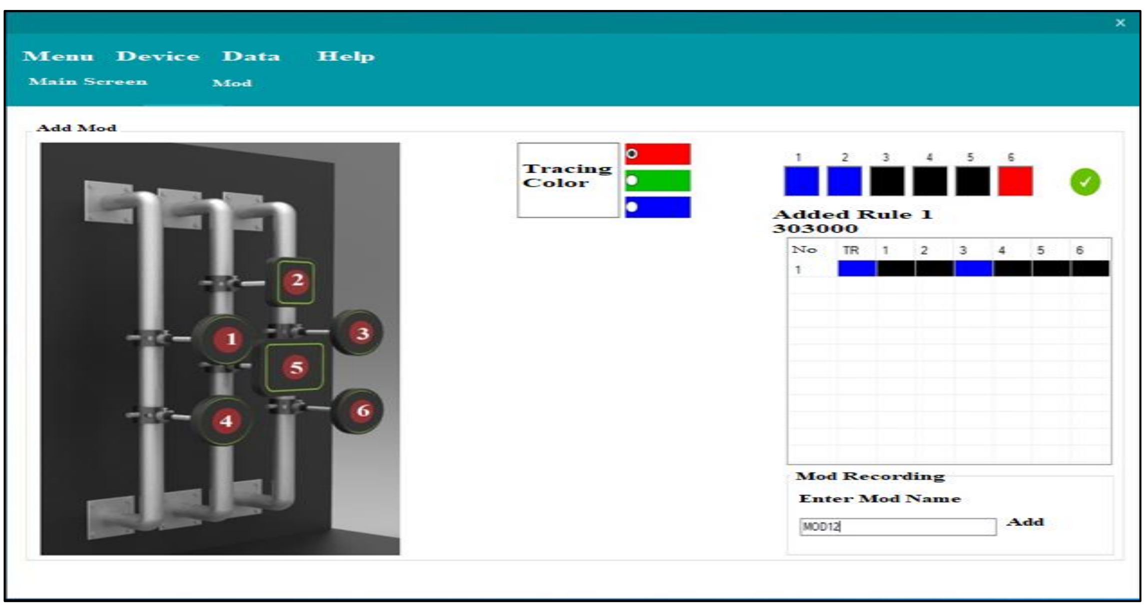

Figure 12. Determination of training protocols in computer software for the training and performance measurement systems.

Figure 12 shows the MOD screen of the computer software of the training and performance measurement system. Features such as selecting the following color on this screen in the computer software, creating training protocols as desired, displaying these protocols in a list instantly, and recording these protocols to reach them later via software were added. The maximum strength, reaction time, and total training time obtained from the athlete according to the training protocols were shown on the software screen for easy user follow-up. It was provided that these performance data were recorded in the desired file format so that the athlete's current performance and general performance could be monitored over time.

Figure 13 shows the report format generated due to the training performed with ten training protocols created by computer software. The raw data obtained in the report format were plotted, and the data obtained were analyzed independently for each of the 6 measurement units on the training device to make it easy to interpret by experts.

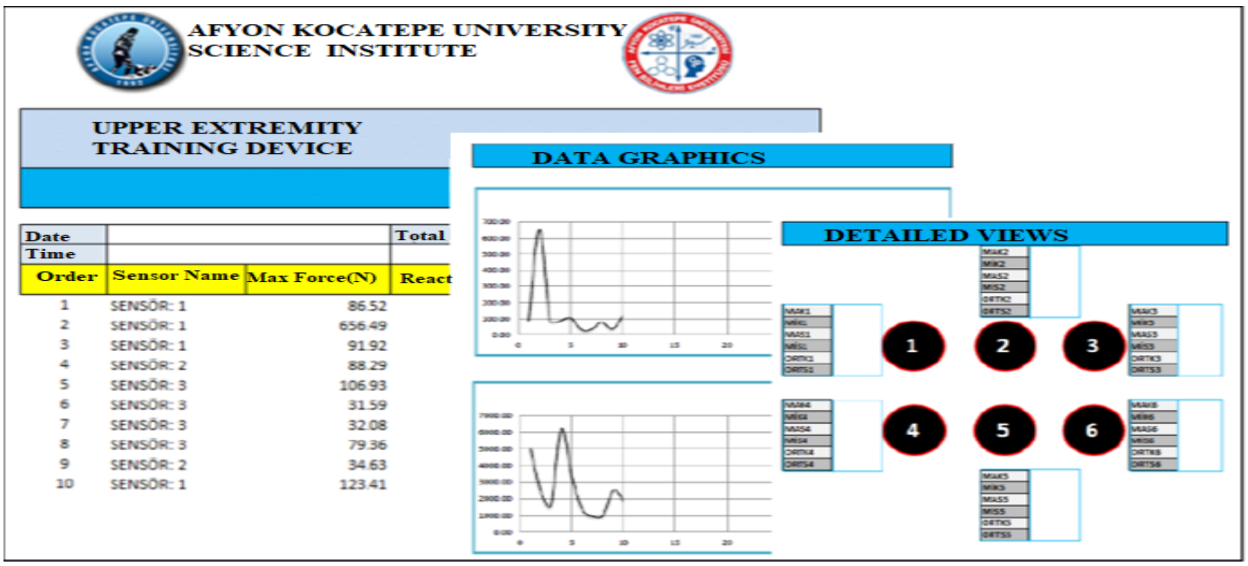

Figure 13. Report Format.

Mobile Device-Based Measurement System Software

Figure 14 shows the application that enabled the training and performance measurement system to be used with mobile devices. Figure 14a shows the connection screen with the system realized using the Bluetooth feature of the mobile devices. On this screen, the training device's connection was achieved by selecting the Bluetooth address of the training device. In the section shown in Figure 14b, the protocols were created after the color selection to be followed by the athlete, and these protocols were recorded in the mobile device’s memory for use in the next training session.

After the protocols were created, the desired screen was sent to the training device with the application's test screen, and the testing process was started. The kinetic and kinematic parameters taken from the athlete during the training were shown instantly on the application. These data, which expressed the athlete's performance, were recorded in the .txt file format with the application and stored to monitor the athlete's development.

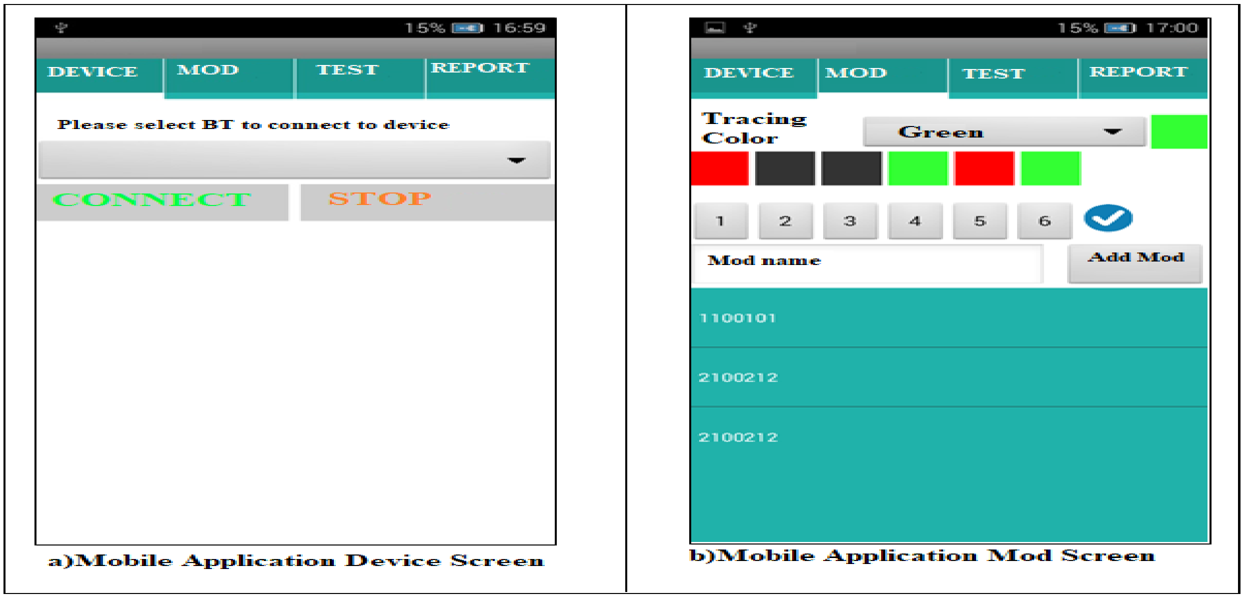

Figure 14. The mobile application of the training measurement system.

DISCUSSIONS

Sport is the totality of people's ability to protect their physical and mental health and their efficient physical activities by maximizing their physical performance. As a means of intercultural interaction, sports have become an area where national identity and reputation are proven to increase competition. The rapid change in science and technology contributes to sports and many other fields, including the economic, political, and cultural fields. Thus, new methods and techniques are emerging every day. Advances in technology, health, and training sciences have enabled athletes to be trained in every aspect. With the application of technology to health and training sciences, athletes' performances have increased, and their sporting success has been improved.

In this study, a training and performance measurement system based on kinetic and kinematic parameters in combat sports such as boxing, judo, and karate was developed for combat sports branches requiring upper extremity performance. In the developed system, the cognitive effects were included in the training program, and instantaneous measurement of strength, speed, and coordination parameters was provided. Upper extremity strength with cognitive stimuli from six different points was measured with a TAS606-200kg load cell and an HX711 24-bit resolution differential ADC. These data were transferred to the computer interface and mobile device unit via an NRF24L01 wireless communication module with a 2.4 GHz operating frequency. Parameters such as the force applied by the athlete against the colored cognitive stimuli that could be determined by the coach during the training, the response time given to the stimuli, and the total training time were evaluated. The parameters were shown instantly by the developed computer program. The system's error rate was determined by comparing the kinetic and kinematic parameters measured with the developed system to the reference device values that were accepted as correct. Then, the measurements were repeated to test the device’s efficiency and whether there were repeatable measurements. The performance data obtained during the training were reported at the end of the training and saved in the desired file format. By storing the athletes' performance data, it was ensured that experts in this field could examine the data and follow the athlete's development process under controlled conditions.

This study differs from existing upper extremity martial training systems in that it gives the colored stimulus directly to the box mash and performs the desired number of training protocols on the software of PC or mobile device[16, 18]. Thanks to the program's threshold level, it can be tested whether the athlete gives the desired strength to the desired stimulus in the desired period. It is very cheap, robust and useful its other advantages. The disadvantage is that the system is heavy and not portable.

CONCLUSIONS

The main purpose of coaches and athletes is to obtain the highest performance in their sports branch. Many factors determine the athlete's performance in their sport of interest. One of these factors is the athlete's motoric characteristics such as endurance, strength, speed, agility, flexibility, and skill. Development and follow-up of these motoric features may be achieved through practices and training specific to the sports branch. The use of technology in sports has led to accurate measurements and evaluation of athlete performances with quantitative data rather than qualitative data. The effectiveness of the training program planned by coaches and the athlete's performance during the training may only be determined in the next test. This study has been achieved to measure both the training of athletes who require upper extremity performance during the training process and the data related to the athlete's sporting performance during the training. With these data, it is ensured that sports performance is followed, proper training methods and effectiveness of the training program are determined, and the risk of injury can be predicted. The study will continue by establishing control and test groups to determine the effectiveness of the system. The system's validity and reliability will be determined by comparing the groups' development with statistical methods.

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DISCLOSURE STATEMENT

The authors reported no potential conflict of interest.

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