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The Distinction of Anomalous Kicks in Taekwondo Using IMU Sensors

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Abstract

The present study intends to find a way to distinguish an anomalous kick that appeared as a side effect of the introduction of the electronic Protector and Scoring System (PSS) in taekwondo through Inertial Measurement Unit (IMU) sensors. The 10 normal kicks and 1 anomalous kick were selected for the study. Four IMU sensors were attached to the trunk, pelvis, and both feet of each of 10 taekwondo athletes to obtain the total acceleration and total angular velocity of the right foot based on the trunk and the pelvis. Seven athletes were randomly selected to calculate the reference data of 11 types of kicks and the data were compared with the data of 11 kicks of the remaining three athletes through correlation analysis. The accuracy of distinguishing the anomalous kick through each variable was 83.3%, and the probability of misunderstanding a normal kick as an anomalous kick was 6.7%. When the results of the correlation analysis of the four variables were synthesized and analyzed, the accuracy of distinguishing anomalous kicks improved to 100%, and the ratio of cases of misunderstanding normal kicks as anomalous kicks decreased to 0%. The results of the present study provide a simple but reliable method to distinguish anomalous kicks in taekwondo competitions. If the limitations of the findings of the study are settled and introduced into the taekwondo EPSS, the problem of anomalous kicks in current taekwondo competitions can be solved.

Keywords: Taekwondo, Anomalous kick, Monkey kick, IMU sensor, PSS

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Introduction

Taekwondo is a national sport of South Korea that features flashy, fast, and powerful kicking techniques. Although it was adopted as an official event at the 2000 Sydney Olympic Games, there was distrust due to judgment disputes and wrong judgments, and the World Taekwondo Federation introduced the electronic Protector and Scoring System (PSS) to overcome this distrust. Electronic PSS has been used in most competitions hosted by the World Taekwondo Federation since 2008 and in all Olympic Games thereafter, from the 2012 London to the 2020 Tokyo Olympic Games. The introduction of electronic PSS was a means to secure fairness in the taekwondo competitions. The electronic PSS played a very important role in reducing judgment disputes and wrong judgments that appeared in the 2000s. However, due to the introduction of the electronic PSS, powerful and flashy kicks reduced, and the anomalous techniques appeared to merely gain points. Combat sports in which athletes strike each other with their feet and hands are not limited to taekwondo but include a variety of other combat sports such as kung fu, karate, muay thai and capoeira. These combat sports are distinguished from each other because of differences in techniques. That is, techniques mean the essence of combat sports or martial art sports. The electronic PSS introduced for fairness is ironically undermining the essence of the martial art sport per se.

According to a study conducted by Kim & Lee (2020), athletes agreed that the electronic PSS played a positive role in enabling athletes to compete fairly and in reducing biased judgments. However, there were also negative opinions due to sensor errors and recognition differences according to the brand of the system, and above all, some expressed concerns about the situation where games are mainly played with anomalous kicks rather than taekwondo kicks due to the electronic PSS. When taekwondo electronic PSS-related news reports were examined, it was found that although “fairness” appeared the most frequently, the limitations of the electronic PSS such as “anomaly,” “foot fencing,” and “scoring rule” also appeared quite frequently (Lee & Choi, 2020). A method to supplement the shortcomings of the electronic PSS while maintaining fairness, which is the strength of electronic PSS, is necessary. Since the existing electronic PSS judges the success or failure of attacks using techniques based only on whether there was a hit and whether the impact of the hit exceeded a certain level, whether the techniques used were successfully implemented should be included in the judgment criteria to protect taekwondo techniques and make taekwondo competitions more exciting. To that end, a technology to distinguish anomalous kicks from normal taekwondo kicks is necessary.

Cho et al. (2020) classified anomalous kicks and normal kicks through Long-Short Term Memory (LSTM), which is a recurrent neural network model. The researchers made the LSTM learn 10,000 data calculated through data on 11 types of kicks obtained by attaching 11 inertial sensors to the entire body of the subject and the LSTM distinguished anomalous kicks from various kicks with a probability of 94.9%. Although the outcome of distinguishing anomalous kicks among various kicks at high probability was achieved, this model cannot be regarded to be very applicable to reality in that anomalous kicks can be distinguished only when 11 inertial sensors are used to collect data.

Cho et al. (2021) proposed a system to detect taekwondo anomalous kicks using a machine learning-based Support Vector Machine (SVM) model. In this study, kicks were classified using only four inertial sensors and an accuracy value of 91.4% was shown. In this study, anomalous kicks were distinguished from four kinds of kicking movements, and it is difficult to guarantee that anomalous kicks can be distinguished with a high probability as shown now when more kinds of kicking movements are measured.

Therefore, the present study is intended to seek a way to distinguish anomalous kicks from various types of kicks through data from the number of inertial sensors that is applicable to reality.

Method

Subjects

For this study, 10 athletes were selected who had at least a fourth-degree black belt, majored in taekwondo in a college, and had been active in competition teams belonging to universities or sport associations for at least two years. All the subjects preferred the right foot. Basic information of the subjects is shown in <Table 1>. The subjects were randomly divided into two groups. The first group of seven subjects (group A) was to understand the basic patterns of taekwondo kicks, and the second group of three subjects (group B) was for comparison of basic kick patterns with the first group.

Table 1. Subject information

Group	Age (yrs.)	Height (cm)	Weight (kg)	Career (yrs.)
A	25	178	76	15
	26	174	78	10
	26	175	84	8
	26	174	62	10
	20	185	82	8
	24	177	72	10
	21	175	63	10
B	26	178	75	13
	20	158	54	7
	23	158	57	8
Mean ± SD	23.7±2.5	173.2±8.6	70.3±10.6	9.9±2.5

Experimental tool

Four inertial sensors (Delsys Inc., United States) were used to compare and distinguish the kinematic characteristics of taekwondo kicks. The measurement range of the inertial sensors was ±16G (acceleration) and ±2000 degrees per second (gyro), and data were collected at 148 Hz.

Considering the sensitivity of the inertial sensors, the trunk (thoracic vertebrae T1), pelvis (sacrum), and both feet (the soleus muscle), which are locations with the least contact in sparring situations, were selected for attachment <Figure 1>. The inertial sensors were firmly attached to the band positions of the existing protector so that the study subject would not feel any difference and their kicking movements would not be disturbed.

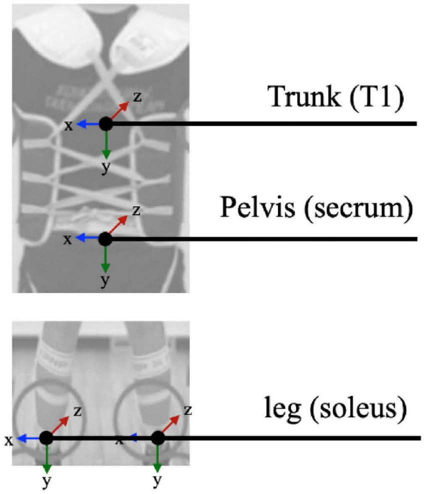


Figure 1. IMU sensor attachment locations and axial orientation

Experimental procedures and methods

1) Explanation of the study and consent

The purpose of this study was explained to the study subjects, and their consent was obtained for the use of motion measurement data and personal information.

2) Kick type and measurement method

After providing the study subjects wearing the protector with inertial sensors attached sufficient time to warm up, a total of 11 types of kicks (10 basic kicks and one anomalous kick) were explained to them. A total of 10 types of taekwondo kicks were selected as basic kicks in consideration of kick types, frequencies, directions, and situations through competition analysis literature (Kim & Jeong, 2019) and a meeting of experts majoring in sparring competition, and anomalous kicks were distinguished following the criterion that “If a kick is made with the knee facing outward and the opponent is hit with the sole of the foot, it shall not be counted as a score” defined through discussions by the Technical Committee of the World Taekwondo Federation <Table 2>. Each kick was repeated 10 times, and the distance to the mitt was adjusted for the convenience of the study subjects. In consideration of the production of actual game situations and the locations of the sensors, the subjects wore the existing protector and hit a mitt held by an assistant<Figure 2>.

Table 2. Kick Type Classification

Type of kick	
Taekwondo kicks	Pushing kick
	Front Pushing kick
	Roundhouse kick (trunk)
	Roundhouse kick (head)
	Front Roundhouse kick (trunk)
	Front Roundhouse kick (head)
	Back kick
	Back Spin kick
	Axe kick
	Half Moon kick
Anomalous kick	Monkey kick

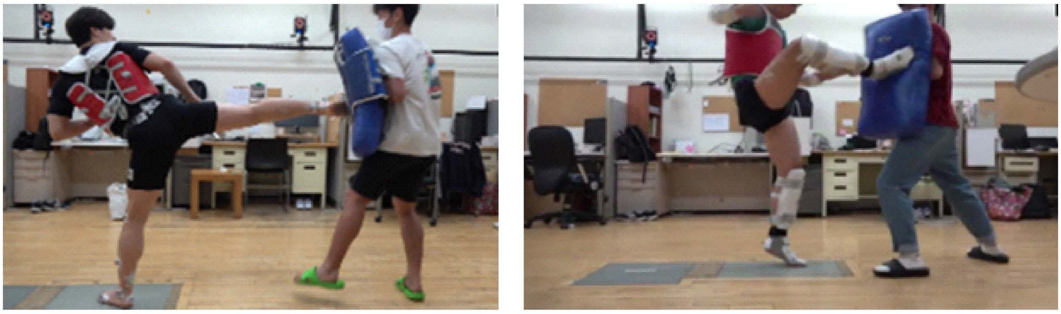


Figure 2. Example of an experimental scene

Data processing

The collected data were processed by using the Visual 3D (C-Motion, USA) program. For noise removal, all signals were smoothed by using a low-pass Butterworth filter (cut off frequency 6 Hz). For analysis, data for 0.5 seconds before and after the moment of hitting (the maximum point of the accelerometer sum acceleration), a total of 1 second, were extracted, and the time was normalized with 101 data. Through the experiment, the total acceleration and total angular velocity of each inertial sensor were calculated through the 3-axis linear acceleration and 3-axis angular velocity values extracted from the inertial sensors attached to the trunk, pelvis, right foot, and left foot. Through these data, the total acceleration of the right foot based on the trunk, the angular velocity of the right foot based on the trunk, the linear acceleration of the right foot based on the pelvis, and the angular velocity of the right foot based on the pelvis, which are the variables of the present study, were calculated.

Variable calculation and analysis methods

The total acceleration and total angular velocity were obtained from the 3-axis linear acceleration and 3-axis angular velocity values extracted through the experiment. Based on the calculated data, the study variables, i.e, total acceleration of the right foot based on the trunk, the angular velocity of the right foot based on the body, the linear acceleration of the right foot based on the pelvis, and the angular velocity of the right foot based on the pelvis were calculated.

The criteria for the 11 types of kicks were determined with the average of the four variables (total acceleration of the right foot based on the trunk, angular velocity of the right foot based on the trunk, linear acceleration of the right foot based on the pelvis, and angular velocity of the right foot based on the pelvis) of the 11 types of kicks of seven subjects in group A. The inertia data of 11 types of kicks of three study subjects belonging to group B were compared with the reference data of 11 kicks calculated above by simple correlation analysis. A method to distinguish anomalous kicks by comparing the magnitudes of the Pearson correlation coefficients obtained through the correlation analysis was sought. The correlation analysis was conducted using the SPSS Statistics 26 (IBM, USA) program.

Results

Comparison of the total acceleration of the right foot based on the trunk

<Figure 3> shows the graphs of the averages of the total acceleration of the right foot based on the trunk of 11 types of kicks of group A. The time series graph of the total acceleration of anomalous kicks showed a pattern different from the patterns of the 10 types of basic kicks, and the kick deviations of back kicks and monkey kicks were shown to be larger than those of other kicks.

Comparison of the total angular velocity of the right foot based on the trunk

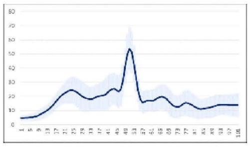
<Figure 4> shows the graphs of the averages of the total angular velocity of the right foot based on the trunk of the 11 types of kicks of group A. The time series graph of the total angular velocities of anomalous kicks showed similar patterns to those of roundhouse kicks (trunk), roundhouse kicks (head), front roundhouse kicks (trunk), and front roundhouse kicks (head). The deviations of front roundhouse kicks (trunk), front roundhouse kicks (head), and monkey kicks were shown to be larger compared to other kicks.

Comparison of the total acceleration of the right foot based on the pelvis

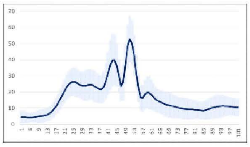
<Figure 5> shows the graphs of the averages of the total acceleration of the right foot based on the pelvis of 11 types of kicks of group A. The time series graph of the total acceleration of the right foot based on the pelvis of anomalous kicks showed similar patterns to those of roundhouse kicks (head), front roundhouse kicks (head), and back spin kicks. The deviations of all kicks were shown to be large.

Comparison of the total angular velocity of the right foot based on the pelvis

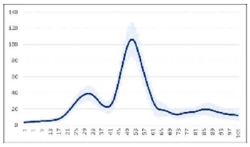
<Figure 6> shows the graphs of the averages of the total angular velocity of the right foot based on the pelvis of the 11 types of kicks of group A. The time series graph of the total angular velocity of the right foot based on the pelvis of anomalous kicks showed a pattern similar to the patterns of pushing kicks, and the deviations of kicks of back kicks and monkey kicks were shown to be larger compared to other kicks.



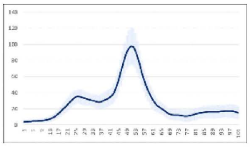
Pushing kick



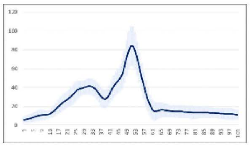
Front Pushing kick



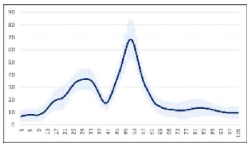
Roundhouse kick (trunk)



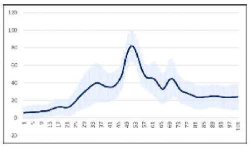
Roundhouse kick (head)



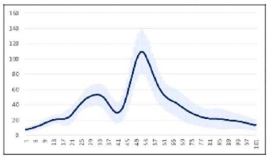
Front Roundhouse kick (trunk)



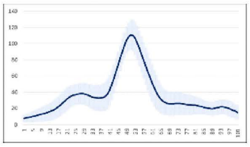
Front Roundhouse kick (head)



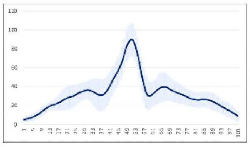
Back kick



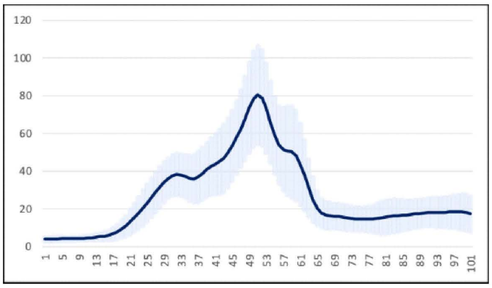
Back Spin kick



Axe kick

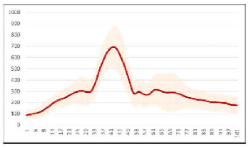


Half Moon kick

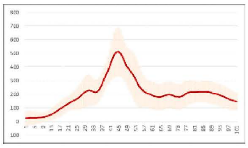


Monkey kick

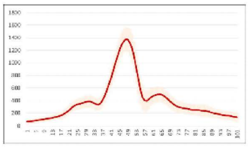
Figure 3. Graphs of total acceleration of the right foot based on the trunk of 11 kicks



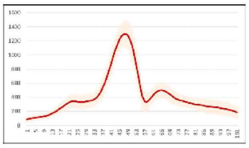
Pushing kick



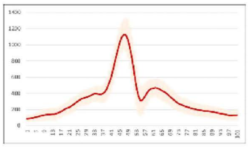
Front Pushing kick



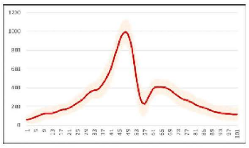
Roundhouse kick (trunk)



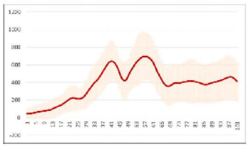
Roundhouse kick (head)



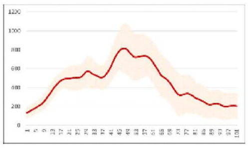
Front Roundhouse kick (trunk)



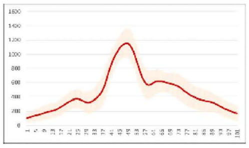
Front Roundhouse kick (head)



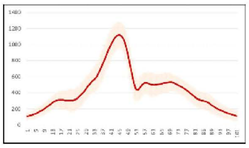
Back kick



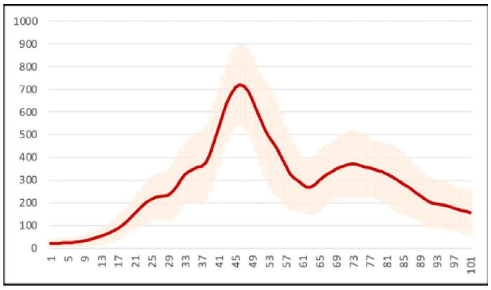
Back Spin kick



Axe kick

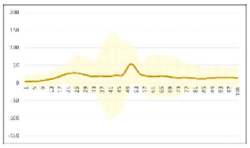


Half Moon kick

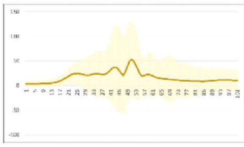


Monkey kick

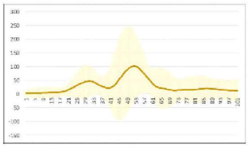
Figure 4. Graphs of total angular velocity of the right foot based on the trunk of 11 kicks



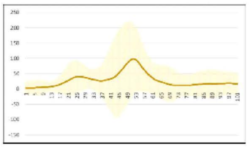
Pushing kick



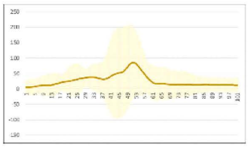
Front Pushing kick



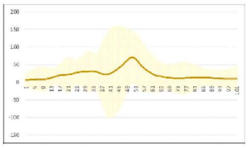
Roundhouse kick (trunk)



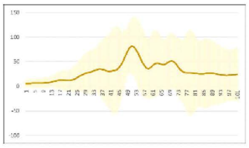
Roundhouse kick (head)



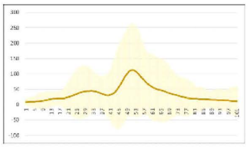
Front Roundhouse kick (trunk)



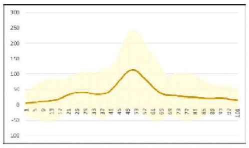
Front Roundhouse kick (head)



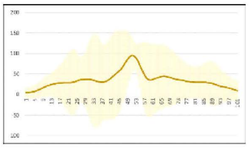
Back kick



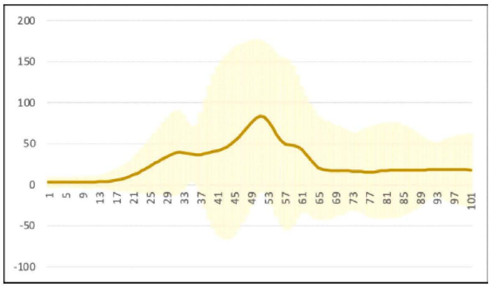
Back Spin kick



Axe kick

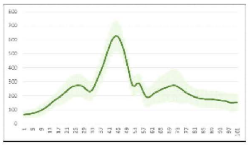


Half Moon kick

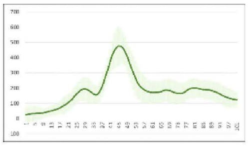


Monkey kick

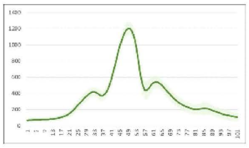
Figure 5. Graphs of total acceleration of the right foot based on the pelvis of 11 kicks



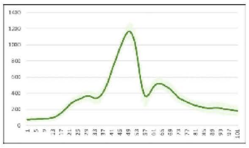
Pushing kick



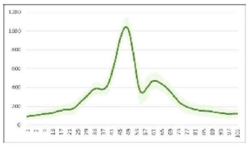
Front Pushing kick



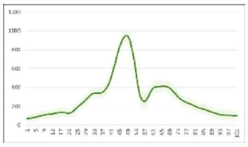
Roundhouse kick (trunk)



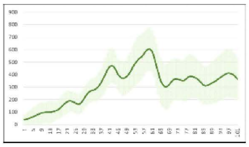
Roundhouse kick (head)



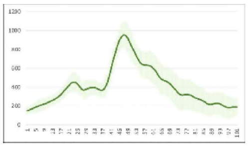
Front Roundhouse kick (trunk)



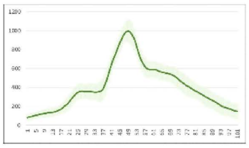
Front Roundhouse kick (head)



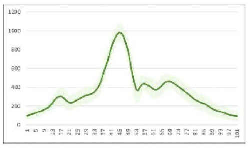
Back kick



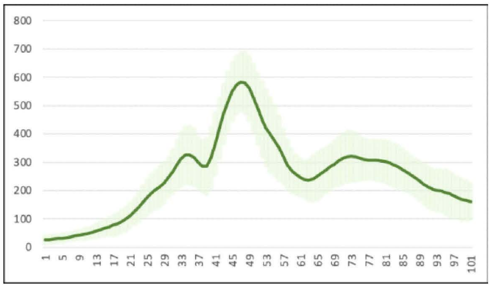
Back Spin kick



Axe kick



Half Moon kick



Monkey kick

Figure 6. Graphs of total angular velocity of the right foot based on the pelvis of 11 kicks

Correlation analysis to distinguish anomalous kicks

First, it was checked whether anomalous kicks could be identified when the study subjects in group B performed anomalous kicks. <Table 3> shows the correlation coefficients and correlation coefficient rankings obtained by comparing the data of monkey kicks of three subjects in group B with the data of 11 types of kicks of subjects in group A. In the case of the first study subject in group B, all of the total acceleration of the right foot based on the trunk (.956**), the total angular velocity of the right foot based on the trunk (.946**), the total acceleration of the right foot based on the pelvis (.930**), and the total angular velocity of the right foot based on the pelvis (.796**) showed the highest correlation coefficients when compared to the 11 types of kicks of group A. However, in the case of the second study subject in group B, the total acceleration of the right foot based on the trunk (.957**), the total angular velocity of the right foot based on the trunk (.959**), and the total angular velocity of the right foot based on the pelvis (.648**) showed the highest correlation coefficients, but the total acceleration of the right foot based on the pelvis showed a greater correlation with half moon kicks (.800**) than with monkey kicks (.778**) among the 11 types of kicks of group A. In the case of the third study subject in group B, the total angular velocity of the right foot based on the trunk (.882**), the total acceleration of the right foot based on the pelvis (.958**), and the total angular velocity of the right foot based on the pelvis (.856**) showed the highest correlation coefficients, but the total acceleration of the right foot based on the trunk showed greater correlations with the front pushing kicks (.942**) and roundhouse kicks (head) (.927*) than with the monkey kicks (.920**) among the 11 types of kicks of group A.

Next, the possibility to misunderstand taekwondo kicks performed by the study subjects in group B as anomalous kicks was checked. <Table 4> shows the correlation coefficients and correlation coefficient rankings obtained by comparing the data of taekwondo kicks of three subjects in group B with the data of monkey kicks of subjects in group A. In this case, the correlation coefficient rankings mean the rankings of correlation of one of the taekwondo kicks of study subjects in group B with 11 types of kicks of group A. The total angular velocity of the right foot based on the trunk of the front roundhouse kicks (trunk) of the first subject of group B was shown to be closer to that of the monkey kicks (.941**) than that of the front roundhouse kicks (trunk)(.923**) of group A.

Table 3. Comparison of group A 11 kicks and group B monkey kick (a: Total acceleration of the right foot based on the trunk, b: Total angular velocity of the right foot based on the trunk, c: Total acceleration of the right foot based on the pelvis, d: Total angular velocity of the right foot based on the pelvis)

	Group A - kick type	Group B - Monkey kick											
		Subject #1				Subject #2				Subject #3			
		a	b	c	d	a	b	c	d	a	b	c	d
Correlation coefficient	Roundhouse kick (trunk)	.926**	.931**	.877**	.729**	.903**	.905**	.693**	.523**	.898**	.822**	.933**	.804**
	Roundhouse kick (head)	.907**	.898**	.872**	.720**	.906**	.880**	.688**	.526**	.927**	.808**	.945**	.811**
	Front Roundhouse kick (trunk)	.837**	.868**	.834**	.609**	.824**	.861**	.601**	.385**	.853**	.742**	.931**	.713**
	Front Roundhouse kick (head)	.854**	.891**	.868**	.683**	.826**	.885**	.621**	.449**	.849**	.764**	.940**	.768**
	Back Spin kick	.930**	.930**	.580**	.512**	.885**	.902**	.332**	.294**	.902**	.640**	.935**	.714**
	Back kick	.914**	.839**	.609**	.505**	.914**	.858**	.717**	.622**	.831**	.713**	.814**	.600**
	Axe kick	.741**	.727**	.654**	.519**	.773**	.728**	.470**	.340**	.788**	.648**	.813**	.716**
	Half Moon kick	.698**	.754**	.888**	.670**	.744**	.783**	.800**	.571**	.749**	.819**	.850**	.782**
	Pushing kick	.804**	.786**	.687**	.419**	.830**	.795**	.417**	.191	.814**	.613**	.849**	.626**
	Front Pushing kick	.899**	.909**	.874**	.705**	.904**	.892**	.681**	.510**	.942**	.862**	.951**	.850**
	Monkey kick	.956**	.946**	.930**	.796**	.957**	.959**	.778**	.648**	.920**	.882**	.958**	.856**
Correlation coefficient rank	Roundhouse kick (trunk)	3	2	3	2	5	2	4	5	5	3	6	4
	Roundhouse kick (head)	5	5	5	3	3	6	5	4	2	5	3	3
	Front Roundhouse kick (trunk)	8	7	7	7	9	7	8	8	6	7	7	9
	Front Roundhouse kick (head)	7	6	6	5	8	5	7	7	7	6	4	6
	Back Spin kick	2	3	11	9	6	3	11	10	4	10	5	8
	Back kick	4	8	10	10	2	8	3	2	8	8	10	11
	Axe kick	10	11	9	8	10	11	9	9	10	9	11	7
	Half Moon kick	11	10	2	6	11	10	1	3	11	4	8	5
	Pushing kick	9	9	8	11	7	9	10	11	9	11	9	10
	Front Pushing kick	6	4	4	4	4	4	6	6	1	2	2	2
	Monkey kick	1	1	1	1	1	1	2	1	3	1	1	1

In addition, the total acceleration of the right foot based on the pelvis of the half moon kicks of the first subject of group B was shown to be closer to that of the monkey kicks (.930**) than the half moon kicks (.881**) of group A. The total angular velocity of the right foot based on the trunk of the back spin kicks of the second subject of the group B was shown to be closer to that of the monkey kicks (.947**) than the back spin kicks (.937**) of group A. In addition, the total acceleration of the right foot based on the pelvis and the total angular velocity of the right foot based on the pelvis of the front pushing kicks of the second subject of group B were shown to be closer to those of the monkey kicks (.925**, .888**) than the front pushing kicks (.890**, .887**) of group A. The total acceleration of the right foot based on the pelvis and the total angular velocity of the right foot based on the pelvis of the back kicks of the third study subject of group B were shown to be closer to those of the monkey kicks (.723**, .337**) than the front pushing kicks (.545**, .097) of group A. In addition, the total angular velocity of the right foot based on the trunk of the half moon kicks of third study subject of group B was shown to be closer to that of monkey kicks (.872**) than half moon kicks (.835**) of group A.

Table 4. Comparison of group B taekwondo kick and group A monkey kick (a: Total acceleration of the right foot based on the trunk, b: Total angular velocity of the right foot based on the trunk, c: Total acceleration of the right foot based on the pelvis, d: Total angular velocity of the right foot based on the pelvis)

Group B	Kick type	Group A - Monkey kick							
		Correlation coefficient				Correlation coefficient rank			
		a	b	c	d	a	b	c	d
Subject #1	Roundhouse kick (trunk)	.918**	.899**	.896**	.801**	5	6	6	7
	Roundhouse kick (head)	.904**	.878**	.872**	.824**	5	6	9	10
	Front Roundhouse kick (trunk)	.899**	.941**	.929**	.883**	2	1	6	6
	Front Roundhouse kick (head)	.864**	.935**	.886**	.848**	5	3	7	10
	Back Spin kick	.809**	.854**	.671**	.777**	4	5	8	7
	Back kick	.649**	.547**	.418**	.420**	6	6	2	2
	Axe kick	.612**	.557**	.601**	.635**	10	10	5	4
	Half Moon kick	.766**	.809**	.728**	.713**	3	3	7	7
	Pushing kick	.830**	.811**	.930**	.833**	6	6	1	6
	Front Pushing kick	.896**	.892**	.886**	.828**	5	6	6	7
Subject #2	Roundhouse kick (trunk)	.953**	.947**	.861**	.783**	3	2	6	7
	Roundhouse kick (head)	.949**	.942**	.855**	.724**	5	4	6	7
	Front Roundhouse kick (trunk)	.764**	.777**	.766**	.697**	6	5	7	8
	Front Roundhouse kick (head)	.870**	.852**	.847**	.775**	6	7	6	7
	Back Spin kick	.938**	.947**	.659**	.719**	2	1	5	9
	Back kick	.635**	.843**	.498**	.498**	6	3	4	3
	Axe kick	.691**	.700**	.487**	.578**	7	6	4	4
	Half Moon kick	.814**	.836**	.709**	.680**	6	4	3	5
	Pushing kick	.822**	.812**	.884**	.828**	7	6	6	6
	Front Pushing kick	.855**	.872**	.925**	.888**	3	3	1	1
Subject #3	Roundhouse kick (trunk)	.892**	.870**	.910**	.877**	7	6	7	5
	Roundhouse kick (head)	.885**	.854**	.821**	.807**	7	7	10	7
	Front Roundhouse kick (trunk)	.872**	.853**	.897**	.858**	8	6	5	9
	Front Roundhouse kick (head)	.836**	.915**	.895**	.878**	10	6	6	7
	Back Spin kick	.799**	.681**	.784**	.767**	9	7	9	7
	Back kick	.580**	.384**	.723**	.337**	2	4	1	1
	Axe kick	.674**	.567**	.421**	.579**	6	5	8	4
	Half Moon kick	.613**	.872**	.650**	.874**	5	1	5	2
	Pushing kick	.670**	.678**	.527**	.636**	8	10	8	8
	Front Pushing kick	.835**	.882**	.851**	.850**	8	2	8	2

Accuracy of distinguishing anomalous kicks

Correlation analyses were conducted with the reference data produced through the kick data of seven subjects of group A and the four variables in the kick data of three subjects of group B, respectively, and according to the results, the accuracy of distinguishing anomalous kicks was 83.3% (10 times/12 times). Anomalous kicks were misunderstood as normal kicks in 16.7% (two times/12 times) of the cases and normal kicks were misunderstood as anomalous kicks in 6.7% (eight times/120 times) of the cases.

However, four variables can be calculated through one kick, and the results of the correlation analyses of the four variables can be synthesized and analyzed.

The first method is to add all the ranks of the correlation coefficients of the data of the anomalous kicks compared to the reference data for the 11 kicks and compare the results. In such a case, the accuracy of distinguishing anomalous kicks increased to 100% (three times/three times), and the percentage of cases where anomalous kicks were misunderstood as normal kicks decreased to 0% (0/3 times), and the percentage of cases where normal kicks were misunderstood as anomalous kicks did not change from 6.7% (two times/30 times).

The second method is to compare the numbers of rank 1 among the ranks obtained through correlation analyses of four variables. The number of rank 1 can be between 0 to 4. When the criterion of the number of rank 1 was set to 3, the accuracy of distinguishing anomalous kicks increased to 100% (three times/three times), the percentage of cases where anomalous kicks were misunderstood as normal kicks decreased to 0% (0 times/three times), the percentage of cases where normal kicks were misunderstood as anomalous kicks decreased to 0% (two times/30 times) but the percentage of cases where normal kicks could not be identified as normal kicks or anomalous kicks was 56.7% (17 times/30 times).

Consequently, it was found that comparing the numbers of rank 1 among the ranks obtained by correlation analyses of the four variables is the best way to accurately distinguish anomalous kicks without misunderstanding normal kicks as anomalous kicks.

Discussion

The purpose of this study is to seek a way to distinguish anomalous kicks among taekwondo kicks using inertial sensors.

Cho et al. (2020) used 11 inertial sensors to distinguish anomalous kicks, but in the present study only four inertial sensors were used to distinguish anomalous kicks. In addition, Cho et al. (2021) used four inertial sensors to distinguish anomalous kicks but compared only three types of normal kicks with anomalous kicks. In our study, the shortcomings of the previous studies were supplemented so that anomalous kicks were distinguished from among 11 types of taekwondo kicks using four inertial sensors.

When the four variables produced in the present study were analyzed separately, the accuracy of distinguishing anomalous kicks was 83.3%, which was lower compared to 94.9% (Cho et al., 2020), which is the result of a study using 11 inertial sensors, and 91.4% (Cho et al., 2021), which is the result of a study where anomalous kicks were compared with three basic kicks. However, when the numbers of rank 1 among the ranks of correlation coefficients of the four variables proposed in our were compared, it was expected to be able to distinguish 100% of anomalous kicks.

In addition, when the four variables produced in the present study were analyzed separately, the ratio of misunderstanding normal kicks as anomalous kicks was 6.7%, which is lower than 8.8%, which is the result of a study where anomalous kicks were compared with three types of basic kicks (Cho et al., 2021). If the numbers of rank 1 among the ranks of correlation coefficients of the four variables presented in our study are used in analysis, the ratio of misunderstanding can be reduced to 0%.

In Cho et al. (2020) and Cho et al. (2021), the recurrent neural network model Long-Short Term Memory (LSTM) and the machine learning model Support Vector Machine (SVM) were used to classify taekwondo kicks. These methods require a large amount of data, and the more the data are accumulated, the more accurately the classification can be made. However, the correlation analysis used in this study can create reference data with fewer data than the existing methods.

Conclusion and Suggestions

The present study was intended to find a way to distinguish anomalous kicks through inertial sensors in order to quantitatively distinguish anomalous kicks that appeared as a side effect of electronic PSS introduction.

A method to distinguish anomalous kicks out of 11 types of kicks using four inertial sensors was sought in the study, and since fewer inertial sensors were used compared to previous methods of classification using inertial sensors (Cho et al., 2020; Cho et al., 2021), basic kick data could be easily collected, and anomalous kicks could be distinguished from among various kicks. However, the present study has the following limitations and should be supplemented and developed through subsequent studies.

First, only data from adult male athletes in their early 20s were compared. Hereafter, data by gender and by weight class should be systematically collected and compared.

Second, reference data on kicks were collected in the laboratory. It will be necessary to clarify the difference between kicks in actual sparring situations and kicks in the laboratory, and accuracy should be guaranteed by collecting basic kick data in the presence of experts.

Third, it will be necessary to verify whether the judgement of anomalous kicks is possible in competition situations by substituting the kick data collected in the actual competition situations into the method presented in this study.

It is necessary to introduce a judgment system that can make objective and accurate judgments through various studies. It is expected that the essence and the beauty of taekwondo will be maintained and more people will be able to enjoy taekwondo if electronic PSS is developed further through more researches in the future.

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