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ORIGINAL

Kinematic Characteristics Based on Proficiency In Geoduepyeopchagi in Taekwondo Poomsae Koryo

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Objective: The purpose of this study was to help improve game performance and provide preliminary data to enhance the efficiency of the kick and stability of the support foot by comparing the kinematic characteristics of the repeated side kick (geodeupyeopchagi) in poomsaeKoryo between expert and non-expert groups.

Method: The subjects were divided into 2 groups according to proficiency in Taekwondo, an expert group and a non-expert group (n = 7 in each group), to observe the repeated side-kick technique. Four video cameras were set at a speed of 60 frames/sec and exposure time of 1/500 sec to measure the kinematic factors of the 2 groups. The Kwon3D XPprogramas used to collect and analyze three-dimensional spatial coordinates. Ground reaction force data were obtained through a force plate with a 1.200-Hz frequency. An independent samplesttest was performed, and statistical significance was defined as .05. The SPSS 18.0 software was used to calculate the mean and standard deviation of the kinematic factors and to identify the difference between the experts and non-experts.

Results: The angular displacement of the hip joint in both the expert and non-expert groups showed statistical significance on E1 and E4 of the left support foot and E5 of the right foot ($p<.05$). The angle displacement of the knee joint in both groups showed statistical significance on E4 of the left support foot, and E1 and E2 of the right foot ($p<.05$). The angular velocity of the lower leg in both groups showed no statistical significance on the left support foot but showed statistical significance on E2 and E6 of the right foot ($p<.05$). The angular velocity of the foot in both groups showed no statistical significance on the left support foot but showed statistical significance on E2 of the right foot ($p<.05$). The vertical ground reaction force in both groups showed statistical significance on E2 ($p<.05$). The center of pressure in all directions in both groups showed statistical significance ($p<.5$).

Conclusion: While performing the repeated side kick (geodeupyeopchagi), the experts maintainedconsistency and stability of the angle of the support leg while the kick foot moved high and fast. On the other hand, the angle of the support foot of non-experts appeared inconsistent, and the kick foot was raised, relying on the support leg, resulting in unstable and inaccurate movement.

Keywords: PoomsaeKoryo, Geodeupyeopchagi, Force plate, COP

INTRODUCTION

Among the 3 basic components of Taekwondo (poomsae, kyeorugi, and kyeokpa), poomsae is a series of techniques that allows the practitioner to master offensive and defensive techniques by practicing them on an imaginary opponent (Korea Taekwondo Association, 2014). Based on the background of its creation, poomsae is divided into gong-in poomsae, kyeonggipoomsae, and jayupoomsae. Poomsae, which is acknowledged by the World Taekwondo Headquarters and International Taekwondo Association, is a standard for Taekwondo training worldwide and helps transmission of techniques (Gwak & Kim, 2014).

The training method of Taekwondo was consideredpoomsaebased. In the past, poomsae was simply used as a promotional tool. However, poomsae has evolved and has been recognized as a competitive sport. Therefore, Taekwondo organizations and universities started assembling poomsae athletes. The value and importance of poomsae, which was merely anevaluation tool, have been recognized and induced evolution.

The Korean poomsae competition is a tournament-style event that randomly assigns 2 poomsaes (Taegeuk 4-5-6-7-8 jang, Koryo, Geumkang, Taebaek, Pyoungwon, Shibjin, Jitae, Cheon-gwon, or Hansoo) to each group per match. PoomsaeKoryo has the most number of positions and requires high-level movements such as Chagi. Therefore, poomsae-Koryo is included in each group (Yoo & Ryu, 2012; Korea Taekwondo Association, 2011).

Geoduepyeopchagi in poomsaeKoryo is a repetitive side-kicking technique (Kukkiwon, 2010). It is usually initiated with a low kick followed by a kick on the trunk or face. The initial low kick is solely intended to fool the opponent by pretending to kick, and the second kick is intended to bring down the opponent (WTF Taekwondo Terminology Dictionary, 2010).

Actual Korean poomsae competitions show that the results of poomsae matches are determined by the balance errors or proficiencies in the second kick rather than in the first kick (Lee, Han & Jee, 2004). Side kicks in Taekwondo poomsae require high proficiency and have been extensively studied.

Previous studies on yeopchagi by Kim (1999) and Yoon and Chae (2008) defined Taekwondo yeopchagi as a throw-like and pushing motion. Meanwhile, the study by Shin and Jin (2000) compared yeopchagi and dolyeochagiby using three-dimensional (3-D) kinematic variables. A study by Sangbok Kim (2000) analyzed the joint movements in each segment and defined the relationship with anatomical motion. Studies by Park (2003) and Kim (2009) investigated effective ways to defend from the opponent's attacks in kyeolugi. Studies have also analyzed and compared highlyskilled athletes and non-skilled athletes. The study by Lo (2012) investigated the changes in center of body mass during poomsaeyeopchagi. A study by Yoo and Ryu (2012) investigated the balances in frontal and turn-side kicks in winning and losing cases. A study by Heo (2015) investigated the changes in the center of body mass during apggoaseogiyeopchagi in Taekwondo and the angle between the kicking and supporting legs, as well as muscle activities. A study by Hong (2015) investigated the different kinematic properties based on the height of the target during poomsae yeochagi.

Although many studies have been conducted on the motional components and properties of yeopchagito provide reference material on proper movements from a scientific perspective, studies on geoduepyeopchagi and its scientific basis are lacking. Therefore, kinematic analysis on geoduepyeopchagi is necessary to provide scientific reference materials that could improve the performance of athletes. The purpose of this study was to investigate the different kinematic properties in skilled and non-skilled athletes during geoduepyeopchagi to determine the correct form of the supporting leg and to maximize the accuracy of the kick.

METHODS

1. Participants

In this study, the participants were divided into 2 groups based on their proficiency levels. The skilled group was composed of 7 college athletes who had won medals in national competitions and were registered to the Korean Taekwondo Association. The non-skilled group was composed of 7 college students from the physical education department who only had Taekwondo learning experience. The participants' physical characteristics are shown in (Table 1).

Table 1. Characteristics of the subjects

		Age (years)	Height (cm)	Weight (kg)	Career (Years)
Skilled (n=7)	Mean ± SD	20.14 ±.69	174.42 ±2.99	64 ±6.13	10 ±2.38
Unskilled (n=7)	Mean ± SD	22.85 ±2.19	176.28 ±3.63	70.71 ±6.92	0±0

2. Equipment

The video recording and ground reaction measuring equipment used in this study are shown in (Table 2).

Table 2. Experimental equipment

Equipment	Experimental equipment	Manufacturer
Video camera	GR-HD1KR	JVC
Synchronize	LED lamp	Visol
Calibration	Control object (1 × 2 × 2 m)	Visol
Analysis instrument	Kwon3D XP	Visol
Force plateform	Type 9281B	Kistler
A/D sync box	A/D sync box 32ch	Visol

3. Procedures

The participants' consents were obtained prior to the study, and their personal data were gathered after educating the participants about the study content. The experiment was conducted in the gymnasium of K University. The participants removed their shirts and wore tight short pants. After sufficient warm-ups and practice, before carrying out the movements, the participants were told that the targets were the knee and head based on poomsae competition rules (2010). To video analyze the kinematic properties, 18 markers (shoulder, elbow, wrist, hand, anterior superior iliac spine, knee, ankle, heel, and toe) were placed on leg segments bilaterally. The experimental equipmentwas placed outside the participants' ranges to avoid interference as shown in (Figure 1) and (Figure 2). Four cameras were set to a speed of 60 frames/sec and exposure of 1/500 sec. To collect ground reaction force, ground reaction force measuring equipment was used at a sampling frequency of 1.200 Hz. The experiment was conducted by recording 1-× 2-× 2-m control borders for 10 sec followed by 3 measurements after removing the control borders.

4. Data processing

The motion analyzer program Kwon3D XP (Visol) was used. To calculate 3-D coordinates from 2-D coordinates obtained by digitization

Figure 1. Experimental setup

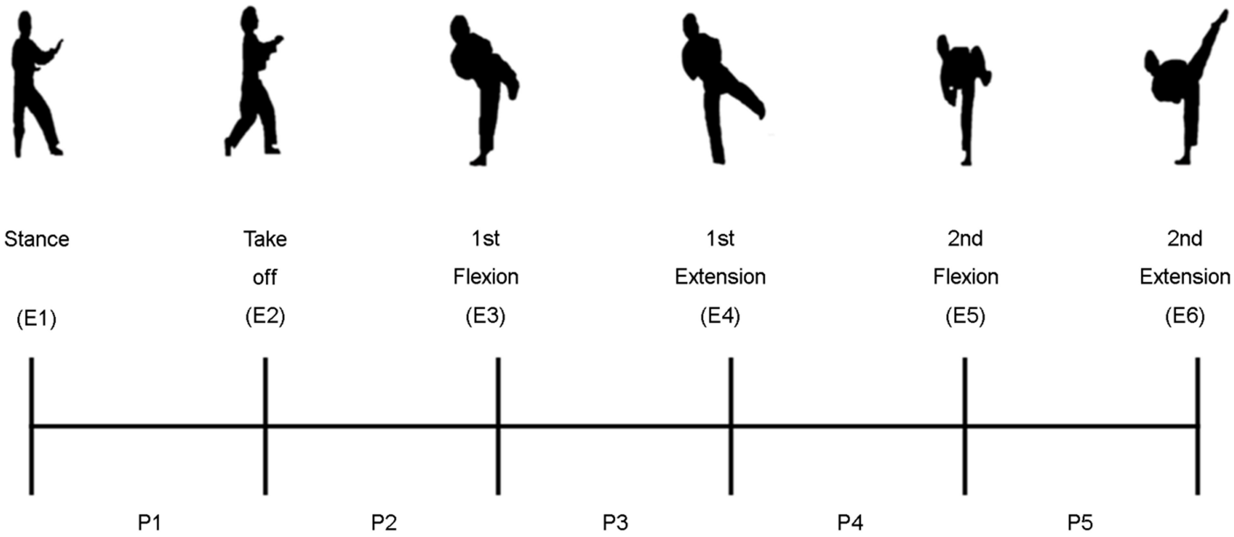

Figure 2. Events (E1: back stance, E2: take-off, E3: first right kick initiative knee moment at the minimum angle, E4: the moment the extension of the kicking foot is knee-high, E5: second right kick initiative knee moment at the minimum angle, E6: the moment the extension of the kicking foot is head-high) and phases (P1: E1-E2, P2: E2-E3, P3: E3-E4, P4: E4-E5, and P5: E5-E6)

and tuning, the direct linear transformation method, which uses known space coordinates as control points, was used (Abdel-Aziz & Karara, 1971). To remove the error produced during digitization, the Butterworth low-pass filter method was used. The cutoff frequency was set to 6 Hz. The world coordinate system was set by setting the direction of motion as the *Y*-axis, the perpendicular direction from the ground surface as the *Z*-axis. The sum of the *Z*- and *Y*-axis vectors was defined as the *X*-axis. To standardize ground reaction force, it was converted into %BW before use. Angular velocity was expressed in degrees per second by dividing the change in the angles of the lower limb joints by the time taken in each frame.

In addition, the geoduepyeopchagi motions of the participants were analyzed and divided into 6 events and 5 phases as shown in (Figure 2). The angles of the lower limb segments are shown in (Figure 3).

5. Statistical analyses

To investigate the differences in the means and standard deviations of the kinematic and mechanical variables between the skilled and non-skilled athletes based on the changes in Taekwondo geoduepyeop-chagi motion, a *t* test was conducted by using the SPSS 18.0 statistical program. The significance level was set to .05.

RESULTS

1. Change in the angles of the lower limb joints during geoduepyeopchagi

1) Hip joint

The changes in the angles of the hip joint in both groups are shown in (Table 3). As shown in (Table 3), significant differences between the skilled and unskilled groups were observed when the supporting left leg was in standby position (E1) and when the right leg was extended to knee-level (E4). Significant differences were observed when the right knee angle was the second lowest ($p<.5$).

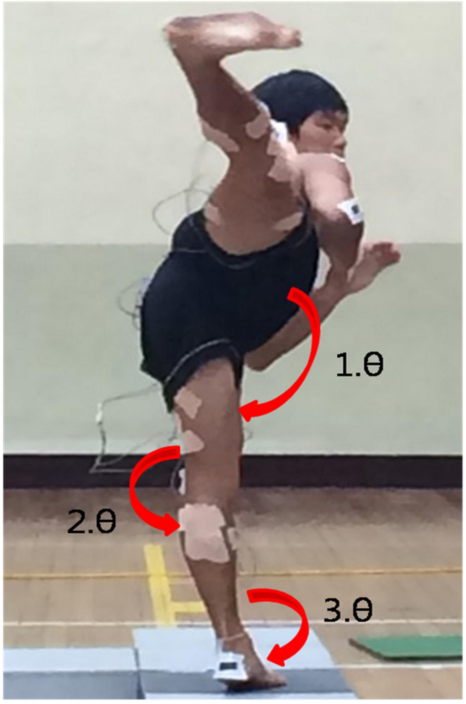

Figure 3. Angles (1: angle at the hip joint, 2: angle at the knee joint, 3: angle at the ankle joint)

2) Knee joint

The changes inthe angles of the knee joint in both groups are shown in (Table 4). As shown in (Table 4), significant differences in the supporting left leg were observed between the skilled and unskilled groups when the right leg was extended to kneelevel (E4). Significant differences were observed in the right leg on standby (E1) and when the right leg left ground surface (E2; $p<.5$).

3) Ankle joints

The changes in the angles of the ankle joint in both groups are shown in (Table 5). As shown in (Table 5), no significant differences in the supporting left leg were found between the skilled and unskilled groups. Significant differences were observed in the right leg on standby position (E1) and when the right leg extended to facelevel (E6; $p<.5$).

2. Changes in the angular velocities of the lower limb segments during geoduepyeopchagi

1) Femur

The changes in femoral angular velocity in both groups are shown in (Table 6). As shown in (Table 6), no significant differences in both the supporting left leg and kicking right leg were found between the skilled and unskilled groups.

2) Lower leg

The changes in the angular velocities of the lower leg in both groups are shown in (Table 7). As shown in (Table 7), no significant differences in the supporting left leg were observed between the skilled and unskilled groups. Significant differences were observed in the right leg when it left ground surface (E2) and when the right leg extended to facelevel (E6; $p<.5$).

3) Foot

The changes in the angular velocities of the foot in both groups are shown in (Table 8). As shown in (Table 8), no significant differences in the supporting left leg were observed between the skilled and unskilled groups. Significant differences were observed in the right leg when it left ground surface (E2; $p<.5$).

3. Changes in ground reaction force during geoduepyeopchagi

The changes in ground reaction force in both groups are shown in (Table 9), (Table 10), and (Table 11). As shown in (Table 9), significant

Table 3. Change in the angle at the hip joint (unit: degrees)

			E1	E2	E3	E4	E5	E6
Skilled	Mean ± SD	Left	143.58±9.38	163.06±7.23	155.20±12.99	145.47±9.23	122.69±12.63	105.54±6.43
		Right	152.27±6.89	157.14±6.84	158.14±9.91	151.81±8.13	101.18±7.87	103.55±5.59
Unskilled	Mean ± SD	Left	155.00±5.64	162.42±3.17	150.09±3.87	131.99±4.40	110.66±6.75	108.53±11.00
		Right	148.78±3.72	154.97±7.87	152.04±12.44	158.14±14.69	121.96±9.82	112.14±13.93
	t	Left	-2.762	.215	.997	3.486	2.221	-.621
		Right	1.18	.55	1.01	-1.00	.47	-1.51
	p	Left	.017*	.833	.338	.004**	.046	.546
		Right	.26	.59	.33	.34	.00**	.16

*$p<.05$, **$p<.01$, ***$p<.001$

Table 4. Change in angle at the knee joint (unit: degrees)

			E1	E2	E3	E4	E5	E6
Skilled	Mean ± SD	Left	153.97±8.22	153.10±4.22	161.93±5.37	169.38±6.07	163.51±6.24	148.72±4.59
		Right	137.53±18.62	130.44±7.61	101.13±16.45	148.32±8.23	93.91±7.91	169.26±5.87
Unskilled	Mean ± SD	Left	161.56±4.63	157.83±6.98	163.33±8.07	158.94±10.58	160.07±3.56	154.25±7.02
		Right	168.35±6.84	145.65±1.59	106.96±15.81	157.98±12.00	107.85±25.16	160.23±11.89
	t	Left	-2.129	-1.535	.121	2.263	1.265	-1.744
		Right	-4.11	-2.90	-.68	-1.76	-1.40	1.80
	p	Left	.055	.151	.710	.043*	.230	.107
		Right	.00**	.01*	.51	.10	.19	.10

*$p<.05$, **$p<.01$, ***$p<.001$

Table 5. Change in the angle at the ankle joint (unit: degrees)

			E1	E2	E3	E4	E5	E6
Skilled	Mean ± SD	Left	116.39±5.71	99.56±7.77	109.69±14.64	104.60±13.71	104.91±5.10	113.36±7.99
		Right	78.76±9.38	118.71±12.20	110.17±18.85	104.34±17.26	94.93±19.61	96.63±12.34
Unskilled	Mean ± SD	Left	120.68±8.91	104.46±12.74	103.89±11.46	97.14±7.57	106.46±4.85	111.76±5.23
		Right	95.50±11.49	113.70±9.12	100.78±12.25	104.53±12.11	101.07±15.11	113.78±12.25
	t	Left	-1.073	-.869	.825	1.260	-.583	.444
		Right	-2.986	.871	1.105	-.023	-.656	-2.611
	p	Left	.305	.402	.425	.232	.571	.665
		Right	.011*	.401	.291	.982	.524	.023*

*$p<.05$, **$p<.01$, ***$p<.001$

Table 6. Changes in angular velocity at the thigh level (unit: degrees/sec)

			E1	E2	E3	E4	E5	E6
Skilled	Mean ± SD	Left	43.93±19.47	125.18±70.61	93.02±55.67	119.39±67.94	111.98±53.98	52.67±26.27
		Right	42.47±25.88	378.17±60.51	474.33±125.54	442.30±258.97	556.17±81.26	108.42±84.89
Unskilled	Mean ± SD	Left	55.78±22.33	90.61±62.08	84.31±51.16	101.52±60.00	102.04±62.27	52.77±33.72
		Right	81.95±76.08	302.89±109.28	333.05±107.29	260.84±139.94	504.97±93.10	157.72±61.79
	t	Left	-1.059	.973	.305	.522	.319	-.006
		Right	-1.300	1.594	2.263	1.631	1.096	-1.242
	p	Left	.311	.350	.766	.611	.755	.996
		Right	.218	.137	.043*	.129	.294	.238

*$p<.05$, **$p<.01$, ***$p<.001$

differences in vertical ground reaction force were found between the skilled and unskilled groups when the right leg left ground surface (E2; $p<.5$). As shown in (Table 10) and (Table 11), no significant differences were observed in the ground reaction forces Fx and Fy.

Table 7. Changes in angular velocity at the shank level (unit: degrees/s)

			E1	E2	E3	E4	E5	E6
Skilled	Mean ± SD	Left	60.57±45.02	57.45±18.96	190.17±73.65	112.00±85.32	177.85±44.29	34.22±19.32
		Right	66.70±35.49	486.51±65.44	768.71±61.54	452.66±228.36	753.09±75.76	129.73±108.79
Unskilled	Mean ± SD	Left	114.71±66.10	89.89±57.99	140.88±64.77	135.85±101.74	170.93±71.51	49.30±30.60
		Right	72.54±52.90	329.02±63.20	679.45±114.91	418.01±215.78	676.45±83.44	345.37±170.07
	t	Left	-1.791	-1.407	1.330	-.475	.218	-1.102
		Right	-.243	4.580	1.812	.292	1.799	-2.826
	p	Left	.099	.185	.208	.643	.831	.292
		Right	.812	.001***	.095	.775	.097	.015*

$^*p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 8. Changes in angular velocity at the foot level (unit: degrees/sec)

			E1	E2	E3	E4	E5	E6
Skilled	Mean ± SD	Left	115.63±95.22	104.78±65.93	586.47±285.24	545.57±273.85	318.30±132.72	41.37±32.71
		Right	81.82±94.23	699.95±127.61	866.13±231.17	440.01±246.47	342.89±99.56	178.29±160.24
Unskilled	Mean ± SD	Left	192.77±165.86	46.00±28.86	405.59±234.42	419.80±259.83	223.36±117.41	90.18±72.91
		Right	118.22±66.42	481.40±135.92	665.86±136.97	285.36±141.35	245.24±140.84	368.28±241.25
	t	Left	-1.067	2.161	1.296	.881	1.418	-1.616
		Right	-.835	3.101	1.972	1.440	1.498	-1.736
	p	Left	.307	.052	.219	.395	.182	.132
		Right	.420	.009**	.072	.175	.160	.108

$^*p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 9. Ground reaction force (Fx) (unit: %BW)

		E1	E2	E3	E4	E5	E6
Skilled	Mean ± SD	63.40±45.50	59.85±44.29	72.97±43.11	90.69±47.95	97.52±20.98	103.94±11.04
Unskilled	Mean ± SD	86.06±20.77	113.19±14.65	95.90±16.70	95.78±23.06	88.86±39.43	94.40±11.16
	t	-1.199	-3.026	-1.313	-.253	.513	1.608
	p	.254	.018*	.214	.804	.617	.134

$^*p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 10. Ground reaction force (Fx) (unit: %BW)

		E1	E2	E3	E4	E5	E6
Skilled	Mean ±SD	5.22±34.08	-5.23±22.11	-23.89±36.10	-9.38±11.71	-0.78±16.19	25.16±30.91
Unskilled	Mean ±SD	-4.25±29.22	13.62±46.88	1.85±27.35	-0.90±27.54	-11.19±24.34	12.20±43.44
	t	.720	.020	.784	.026	.240	.445
	p	.558	-.962	-1.504	-.749	.943	.643

$^*p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 11. Ground reaction force (Fy) (unit: %BW)

		E1	E2	E3	E4	E5	E6
Skilled	Mean ± SD	33.95±38.89	12.14±30.48	28.98±37.45	32.74±39.48	23.43±29.62	15.15±61.41
Unskilled	Mean ± SD	82.16±56.18	25.27±37.32	8.835±23.67	63.88±81.47	36.12±105.69	27.81±87.59
	t	.436	.566	.199	.009	.032	.272
	p	-1.86	-.72	1.20	-.910	-.30	-.313

*$p<.05$, **$p<.01$, ***$p<.001$

Table 12. *Y*-axis COP (unit: cm)

		E1	E2	E3	E4	E5	E6
Skilled	Mean ± SD	.49±.03	.50±.03	.50±.01	.51±.02	.51±.03	.50±.04
Unskilled	Mean ± SD	.16±.05	.14±.04	.14±.05	.16±.05	.16±.03	.16±.03
	t	15.653	19.830	18.744	18.556	22.813	18.457
	t	.000***	.000***	.000***	.000***	.000***	.000***
	p	.000***	.000***	.000***	.000***	.000***	.000***

*$p<.05$, **$p<.01$, ***$p<.001$

Table 13. *X*-axis COP (unit: cm)

		E1	E2	E3	E4	E5	E6
Skilled	Mean ± SD	.99±.30	1.04±.08	1.03±.08	1.04±.09	1.04±.09	1.06±.06
Unskilled	Mean ± SD	.06±.12	.32±.08	.34±.08	.36±.07	.36±.07	.35±.08
	t	13.628	17.109	16.063	15.968	15.311	18.950
	t	.000***	.000***	.000***	.000***	.000***	.000***
	p	.000***	.000***	.000***	.000***	.000***	.000***

*$p<.05$, **$p<.01$, ***$p<.001$

4. Changes in COP during geoduepyeopchagi

1) Change in *Y*-axis COP

Changes in the *Y*-axis COP in both groups are shown in (Table 12). As shown in (Table 12), significant changes were observed in both groups $p<.05$).

2) Changes in *X*-axis COP

Changes in the *X*-axis COP in both groups are shown in (Table 13). As shown in (Table 13), significant changes were observed in both groups ($p<.05$).

DISCUSSION

In this study, 7 skilled and 7 unskilled Taekwondo athletes were evaluated to observe different geoduep-yeop-chagi techniques based on proficiency. This study aimed to provide training reference data to maximize the stability and effectiveness of the support leg and during poomsaeKoryo geoduepyeopchagi. The difference between the 2 groups was investigated by quantifying changes in angles of the hip, knee, and ankle joints; changes in the angular velocities of the femur, lower leg, and feet; stability of the support leg, vertical ground reaction force, and before/after and left/right COP.

1. Changes in the angles of the lower limb joint during geoduepyeopchagi

The changes in the angles of the hip joint revealed a slight flexion until the right leg left ground surface. The hip joint angle gradually flexed since the right leg has left ground surface (E2) and showed the least flexion when it reachedface level (E6). The study by Lo (2012), which investigated the kinematic properties of a body during Taekwondo poomsaeyeopchagi, reported that the hip joint angle decreased when the kicking leg reachedthe target and that the ideal hip angle is about

94˚. However, the results of this study indicated that the hip joint angle whenthe kicking leg reachedthe target at facelevel (E6) was 103.55˚± 5.59˚ for the skilled athletes and 112.14˚±13.93˚ for unskilled athletes. The results of this study differed from the ideal hip joint angle reported by a previous study by Lo. It can be inferred that the difference in angle is due to the nature of geoduepyeopchagi, which quickly kicks the leg low before attacking the face. From the moment the right kicking leg extended to the knee level (E4) to the moment the knee joint angle of the right leg was the second lowest (E5), the knee joint angle of the kicking leg was more flexed in the skilled group than in the unskilled group. These observations coincide with the results of the study by Jisu Kim (2009), which investigated the kinematics of the Taekwondo jump dwichagi. Kim reported that the knee angle is reduced when the kicking leg leaves the ground surface. The reason the knee angle of the kicking leg decreases is that the femur moves toward the body to aim for the target, which also decreases hip joint angle.

The knee joint is a hinge joint that provides stability and maintains a wide range of motion (Lo, 2012). When the changes in the knee joint angle were examined, the changes in the knee joint angle of the supporting left leg showed no significant changes in both groups. In the right leg, the knee joint angle was the smallest when the knee angle of the kicking leg was the second smallest (E5) and extended the most when the leg reached facelevel (E6). A study by Seungtae Jeon (1998), which investigated different swift dolryeochagi motions based on Taekwondo practitioners' stances, reported that greater flexion of the knee joint angle between the ready stance and hitting the target means larger energy content, which indicates that a larger energy could be transferred to the target when the knee joint of the kicking leg is extended. In another study, Sangrae Hong reported that the impact on the target increases as the knee joint angle approximates 180˚ on contact. In this study, the reason the kicking right leg was more extended when it reached facelevel (E6) than when it reached knee level (E4) is because the kick at knee level (E4) was a fake distraction. Although no significant differences in the changes in the knee joint angles of the supporting left leg were observed, the knee angle was larger in the unskilled group between the ready stance (E1) and kneelevel (E4), which indicates that the subjects in the unskilled group were more likely to perform an inaccurate motion.

In their studies, Park (2010) and Lo (2012) reported that the ideal poomsae-yeop-chagi motion is composed of plantar flexion of the foot to transfer energy at the impact. In this study, although significant differences were observed between the skilled and unskilled groups at ready stance (E1) and facelevel (E6), the knee angles were >90˚ at the time of impact. The large angle at impact coincided with the ideal form suggested by previous studies.

2. Changes in the angular velocities of the lower limb joints during geoduepyeopchagi

The changes in the angular velocities of the femur of the kicking leg were observed to increase until the smallest kicking knee angle (E3) was attained. The angular velocities decreased when the leg reached kneelevel (E4) and when the angle between the upper and lower legswas the smallest. Although the angular velocity increased when the knee angle was the second smallest (E5), the decreases observed were larger in the skilled participants than in the unskilled participants when the legs were extended. A study by Gwangdong Park (2003), which investigated the kinematics of Taekwondo yeopchagi, reported that the axial rotation at the ready stance flexes the hip joint and the knee joint is flexed by quickly moving in the horizontal and vertical directions. When the knee joint angle is the smallest, the hip and knee joints are flexed at a high magnitude to reduce the range of rotation. The leg is extended at a high magnitude at the time of impact to transfer the angular energy to linear energy. In this study, dorsiflexion was observed until the knee joint angle was the second lowest (E5). It can be inferred that this dorsiflexion is done to quickly extend and impact the target at facelevel (E6). In the left supporting leg, the angular velocities of the femur increased from the stance (E1) to when the leg left the ground surface (E2) in both groups. When the knee joint angle of the kicking leg was the second smallest (E5), the angular velocity decreased, followed by an increase when the leg reached facelevel (E4). Between the second lowest knee joint angle of the kicking leg (E5) and the facelevel (E6), the angular velocities constantly decreased in both groups.

3. Changes in vertical ground reaction force during geoduepyeopchagi

In the skilled group, the vertical force was smaller when the kicking leg left ground surface (E2) than in the ready stance (E1). When the knee joint angle of the kicking leg was the smallest (E3), the vertical force gradually increased until it reached facelevel (E6). In the unskilled group, the vertical force was larger when the kicking leg left ground surface (E2) than in the ready stance (E1). When the knee joint angle of the kinking leg was the smallest (E3), the vertical force was weak until the knee joint angle was the second smallest (E5). The vertical force then increased when the leg reached facelevel (E6).

We can infer that these findings are due to the fact that unskilled athletes rely more on the supporting leg to raise the kicking leg. Increase in the vertical motion of the leg could interfere with stable kicks.

4. Changes in the COP during geoduepyeopchagi

In this study, the changes in the anterior/posterior and left/right COP were larger in the skilled group than in the unskilled group. Hong (2015) reported that the anterior/posterior and left/right COP ranges were larger in the skilled group, which was caused by the rotation of the heel of the supporting leg toward the kicking direction during yeopchagi. Therefore, unskilled athletes should train to rotate the heel of the supporting leg between stance (E1) and facelevel (E4) to attain stability and balance.

CONCLUSION

By using 3-D video and ground reaction force analyses, we aimed to measure and analyze the Taekwondo poomsaeKoryogeoduep-yeopchagi motion based on proficiency level. The acquired kinematic data would provide reference information to improve the performance of Taekwondo athletes.

The following results were obtained: First, although the changes in the hip joint angle of the supporting leg were similar to flexion, the changes in the flexion pattern were different from those ofthe right kicking leg. A significant differencein the supporting leg was found between the 2 groups during the ready stance (E1) and when the right kicking leg reached facelevel (E4; $p<.5$). When the knee joint angle of the right kicking leg was the second lowest, significant differences were observed between 2 groups ($p<.5$). A significant difference in the knee joint angle was observed only in the left supporting leg when the right kicking leg reached kneelevel ($p<.5$). Second, the angular velocities of the lower limb segments in both groups were observed to accelerate first in the femur, followed by the lower leg and foot. Between the 2 groups, significant differences in angular velocities were observed only in the right kicking leg when the knee angle of the right leg was the smallest (E3; $p<.5$). Third, in the skilled group, no change in vertical ground reaction force was observed between the ready stance (E1) and the moment the kicking leg left ground surface (E2). The vertical ground reaction force was observed to gradually increase between the moment the leg left the ground surface (E2) and the moment the leg reached face level (E6) in the skilled group. However, irregular changes in vertical ground reaction force were observed in the unskilled group. Fourth, changes in the anterior/posterior and right/left COP were significantly different in all motions between the 2 groups ($p<.5$).

The results showed that to successfully perform geoduepyeopchagi, leg strength is necessary to maintain the angles and vertical ground reaction force of the supporting left leg while the right kicking leg moves from the ground surface (E2) until the knee joint angle of the right leg is smallest (E3). Balance and stability of the supporting left leg should be acquired by training to rotate the heel of the supporting leg toward the kicking direction. Further studies should be conducted for in depth investigation of the balance, stability, and muscle activity of the left supporting leg during geoduepyeopchagi.

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