３．大外刈りのバイオメカニクス的解析

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3. Kinetic and kinematic analysis of a judo throwing technique: Osoto-gari

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要約

　柔道の技術指導は、指導者の経験則に委ねられているところが大きく、その指導者の主観的な判断や勘に頼らざるを得ない。その経験則は、選手時代に何千回と練磨を積み重ねた経験的事実に基づいて判断されるため、客観的なデータを共有することは難しいと考えられてきた。しかし、このような状況は、柔道の普及や発展を妨げることになるのではないだろうか。そこで本研究では、立技のひとつである「大外刈り」に着目し、熟練者と初心者の動きをバイオメカニクス的見地から比較し、客観的な知見を得ることを目的とした。

　熟練者と初心者それぞれ１名に大外刈りを５回試行させ、その際フォースプレートと３Dビデオカメラを使い、バイオメカニクス変数を測定した。

　熟練者と初心者は以下のような違いを示した。

1) 熟練者の試行時間は初心者よりも53.6％短く、特に刈り脚の振り上げ時間に顕著な差（124.3％）が見られた。
2) 熟練者の踏み込みおよび刈り動作時の相対地面反力はそれぞれ初心者よりも84.9％、61.9％高かった。
3) COP（Center of Pressure: 圧力中心）の分析では、初心者が歩行時のように踵から踏み込み、つま先に体重を移動しているのに対して、熟練者はつま先だけを着いてバランスをコントロールしていることが分かった。

4）大外刈りの試行中、熟練者は足首、膝、腰を連動的に屈曲、伸展している事が明らかになった。

5）熟練者は初心者と比べ、刈り足の振上げ時に腰をより広範囲（94.5％）に回転していることが分かった。

柔道の技術指導に関する客観的、科学的なデータを示すことは日本国内のみならず、海外の指導者との活発な意見交換をする上でも重要であろう。それぞれの指導者がそれぞれ独自の経験則を持っているが、それを継承していくためには定量的に示す必要がある。さらに、発育期の子どもや選手の技術練習を改善していく上でも有用であろう。

Introduction

The sport of Judo is a martial art invented from Jujitsu, Japanese ancient martial art, in 1882 by Jigoro Kano (Harter & Bates, 1985). It became a worldwide known sport after being included in the Olympic Games for the first time at Tokyo in 1964. In judo, competitors are allowed to use a variety of throwing techniques (Tachiwaza), as well as subdivided groundwork techniques such as holding (Newaza), choking (Shimewaza) and arm locking (Kansetsuwaza) (Vieten & Riehle, 2000).

Osoto-Gari (Major outer reap), the task of interest in this study, is a popular Judo throwing technique that also has distinctive mechanical characteristics (Gomes, Meira, Franchini, & Tani, 2002). Osoto-Gari can be defined as a throwing technique to knock down a faced opponent backward by hooking swinging leg against opponent's support leg from outside and sweeping it vigorously (Marrero-Gordillo et al., 1998). In this technique, the contacting point between the opponent's support leg and the thrower's swinging leg acts as a fulcrum of a lever. By the effect of the lever, the thrower can move opponent's projection point of the center of mass (COM) to outside (backward) of his base of support (BOS) and break his balance effectively. In Judo competition, this technique is often executed to obtain Ippon, a definitive point to win.

Although Osoto-Gari, as well as other throwing techniques of Judo, reveals distinct mechanical features, biomechanical assessment for these features has been still limited, and thus, the nature of the technique has not been identified objectively (Minamitani, Fukushima, Yamamoto, Suganami, & Hirose, 1988; Pucsok, Nelson, & Ng, 2001; Sacripanti, 1987; Takahashi, 1992; Tezuka, Funk, Purcell, & Adrian, 1981). In this situation, training programs and skill assessment methods to the technique seems to depend too much on subjective criteria, without any objective data.

Therefore, this study was executed to enhance objective, especially biomechanical knowledge about the nature of Osoto-Gari. Specifically, the purposes of this study were; 1) to measure kinetic and kinematic variables with respect to thrower's stepping leg for a skilled Judo athlete and a novice subject during execution of Osoto-Gari and 2) to assess significant factors which may be able to distinguish expert from novice.

Methods

Subject

In this study, each of one skilled Judo athlete (31 year-old female, 157cm in height, 53kg in weight, with 27 years' experience) and one novice (33 year-old male, 170cm in height, 73kg in weight, with 1 year's experience) was asked to perform Osoto-Gari in the HPER Biomechanics Laboratory at the University of Nebraska at Omaha. To minimize between-subject variability, one male (28 year-old male, 160cm in height, 65kg in weight, with 3 years' experience) served as an opponent for each trial executed by each subject. Prior to the study, all participants were fully informed about the experimental procedures.

Instrumentation

Kinetic analysis devices

A Kistler piezoelectric force platform (Kistler 9281B, Kistler Instrument Corporation, Amherst, NY) and A Kistler signal conditioner/amplifier (Kistler 9865, Kistler Instrument Corporation) were used to collect data from the subject's support leg (right leg) with respect to the ground reaction forces (GRF) with 1,250 Hz sampling rate. This platform was embedded to the floor which is on the halfway of an experimental walkway.

Kinematic analysis devices

Two high speed digital cameras (RedLake Digital Cameras, RedLake, San Diego, CA) were used to collect 3D kinematic data from the subject's support leg with 125 Hz sampling rate. The cameras were connected to a computer in which video tracking system was installed. To obtain 3D coordinate system from data sets obtained by the two cameras (i.e., to calibrate), a calibration frame and a global reference frame (Peak Performance Technologies) were used.

Parameters

Temporal parameters

In this study, a series of motion of Osoto-Gari were divided by five specific events, and then four phases were determined (Table 1, Table 2).

Kinetic parameters

The kinetic parameters employed in this study were summarized in Table 3. By using the fist five data sets, time series graphs were developed for each subject. Moreover, location of COP on the force platform was identified with the last two parameters. In the following sections, only significant parameters that kinetically revealed the difference of the performance between two subjects were reported and discussed.

Kinematic parameters

The kinematic parameters obtained by the data processing were summarized in Table 4. By using all of the data sets, time versus angular displacement graphs were developed for each subject. Moreover, by using the First Central Difference Method, time series of angular velocity and acceleration were calculated and graphs were also developed. In the following sections, only significant parameters that kinematically revealed the difference of the performance between two subjects were reported and discussed.

Results

Temporal analysis

Table 5 showed the phase durations and total performance time of both subjects and a percentage of difference between the subjects based on scores of the skilled subject. Figure 1 provided sequence pictures of the performance executed by the subjects.

Kinetic analysis

Impact peak of stepping and active loading

Figure 2 showed that the skilled and novice subjects received 1.96 BW (1,018 N) and 1.06 BW (775 N) vertical GRF (impact peak) 0.042 and 0.010 sec after ST, respectively. These results showed that after ST, the skilled subject stepped and loaded weight stronger than the novice subject.

GRF at MS

Figure2 also revealed clear difference between the two subjects at MS. Theoretically, the vertical GRF may be largely reduced in proportion as the swing leg is raised since this motion elevates the subject's COM, and it probably becomes below 1 BW if the subject stands or walks normally. Just like this theory, the novice subject received small vertical GRF (0.66 BW, 482 N) after he experienced local minimum. It may imply that his performance was quite similar to normal walking.

To the contrary, at this point, the skilled subject still received relatively large vertical GRF (1.22 BW, 634 N) before she experienced local minimum.

Active loading around RE

Figure2 still more revealed very apparent difference between the two subjects around RE. That is, the skilled subject experienced clear second active loading, which was almost same as the first one (1.91 BW, 993 N), around RE (0.403 sec), while the novice subject experienced very weak peak (1.18 BW, 868 N at 0.672 sec).

Location of COP

Figure 3 and Figure 4 showed the location of COP for the skilled and novice subjects, respectively. These two graphs evidently illustrated the difference of stepping strategies between the subjects. Through examination of Figure 4, as well as of visual information (see Figure 1), it was considered that the novice subject stepped his support leg by using medial heel, and moved the position of COP anterolaterally throughout the performance almost like walking.

On the other hands, the skilled subject seemed to step her support leg, and then, keep balance until FA by using only anterior sole (Figure 3). Although the position of COP was slightly moved toward posterior during USP, she did not touch her heel on the ground through the performance. Moreover, at FA, she almost stood on tiptoe.

Kinematic analysis

Synchronization of three joints in the saggital plane

The significant kinematic characteristics of the skilled subject were observed in a similarity of curve configuration between ankle, knee, and hip movements in the sagittal plane (Figure 5). Specifically, these three joints maintained large degree of flexion until MS and then, extended rapidly until FA.

Hip rotation

Figure 6 showed rotational displacement of hip joint. According to this graph, the skilled subject experienced 35.6 degrees of ROM between ST and HI, whereas the novice subject experienced only 18.3 degrees of ROM.

Discussion

Temporal analysis

The result clearly revealed that the skilled Judo athlete could execute Osoto-Gari much faster (0.350 sec and 34.9% faster) than the novice subject. Especially, the differences of USP and SP were obvious (124.3% and 63.5%, respectively) and these differences seemed to mainly contribute to the difference in the total task time. As a matter of course, to enhance the effectiveness of the technique (and then, to defeat the opponent in a fight), a Judo player is required to execute this technique very quickly. It is speculated that through considerable long-tem training, the skilled subject has acquired some specific strategies to swing up her sweeping leg and sweep an opponent's support leg very promptly. These strategies were explored in the following discussion in detail.

Kinetic analysis

Impact peak of stepping and active loading

To execute following rapid, powerful performance, vigorous stepping may be required, and it is considered that the skilled subject expressed such desirable stepping in this study. On the other hand, the slope analysis showed that the novice subject experienced the impact peak with 74,561 N/sec while the skilled subject experienced with 24,017 N/sec. Since this value indicates hardness (solidness) of the impact, this result showed that the novice subject's step was more bouncy and uncontrolled than the skilled subject. In contrast, the skilled subject seemed to obtain larger impact peak and following active peak with relatively mild (i.e., not bouncy) impact, just as if she controlled (cushioned) the shock with some strategy. Considering the above discussion, large but not bouncy impact peak and large active loading after stepping may be one signature that indicates subjects' proficiency.

GRF at MS

For this result, it is speculated that the skilled subject reached MS with her support leg bending and her COM keeping low level. In fact, Figure 1 clearly expressed this condition. Generally, it may be much hard to elevate a swing leg higher with a support leg bending, and therefore, people may prefer to perform this task just as the novice subject did. Considering the above, the skilled

subject may possess some skill to swing the leg with bending support leg.

What is the meaning or benefit to lift a swing leg to the highest point with a support leg bending? One possible benefit is that by bending the leg, a thrower can shorten USP, and thus, he/she can reduce total task time effectively. In fact, USP of the skilled subject was mush faster then that of the novice subject. Moreover, the thrower may also be able to store elastic, spring-like energy by keeping leg bending at this point and utilize such energy to SP. The meaning of this strategy was also discussed in the following sections.

At any rate, the difference in the GRF at MS was obvious, and the characteristic that the skilled subject showed is considered one signature of proficiency.

Active loading around RE

Because the skilled subject's support leg was fully extended around this period (see Figure 1), the primary source of the active loading around RE is considered a reaction force from the opponent's swept leg. The magnitude of the reaction force was logically considered identical to the action force applied to the opponent's leg, and thereby, the result suggested that the skilled subject successfully applied stronger action force to the opponent's leg. With a rough examination (i.e., by subtracting 1BW from applied vertical GRF), it is estimated that the skilled subject may apply (and receive) about 470 N to (and from) the opponent's leg while the novice subject seemed to apply only about 153 N. Although many other factors may affect, leg bending during USP may be one possible factor to the difference. Again, higher active loading around RE may also be one clear signature to identify thrower's proficiency.

Location of COP

It is worth while to notice that the skilled subject maintained the direction of the COP toward the inside (i.e., left) at FA while the direction of the novice subject's COP was outward throughout the contact. The result clearly revealed that the skilled subject fully used the big toe of her support leg, which may enable her to respond against the opponent's counter attack. This stepping strategy seemed to have strong relevance to her all characteristics observed in the previous discussions. That is, it is considered that by applying this stepping strategy, the skilled subject was able to obtain large impact peak and following active peak with control, swing her sweeping leg quickly to the maximum level with keeping the support leg bending, and apply large action force to the opponent's swept leg. Considering the above, this strategy may work as a primary source to form her skilled performance, and therefore, it is the most typical signature to identify proficiency of skilled Judo athletes.

Kinematic analysis

Synchronization of three joints in the saggital plane

Functional meaning of synchronized hip, knee, and ankle flexions until MS may be to keep leg bending in order to generate fast upward swing, to maintain postural balance, and to enhance the effect of following extension that generates concentric extensor moment to develop vigorous sweeping. The significant point here is that the movement of these three joints was almost perfectly synchronized. By synchronizing together, these joints may bring some synergistic effect to

the system. The coordination among the three joints may also be regarded as one kinematic signature to identify proficiency in the task.

Hip rotation

Large hip ROM by the skilled subject indicated that she functionally used hip external rotation for some purpose during USP and DSP. One possible interpretation is that the hip external rotation might be accompanied with diagonal (i.e., from medial to lateral) list of the swinging leg, which is effective to achieve powerful swing in the limited small space due to bending support leg. Additionally, to maintain appropriate swing angle, she may also try to make the initial step with relatively large internal rotation.

Although the nature of this mechanism was not fully disclosed, the difference of curve configuration between the subjects was evident, and this characteristic of the skilled subject may also be considered one kinematic signature of proficiency.

Conclusion

Through the holistic assessment, several kinetic signatures that can clearly identify the differences in Osoto-Gari performance between the skilled and novice subjects were revealed. They are: 1) controlled large impact peak and following active loading, 2) large vertical GRF at MS (knee bending during USP), 3) large active loading around RE, and 4) stepping strategy with anterior sole. Especially, the stepping strategy was considered the most significant signature because it may work as a primary source to form skilled Osoto-Gari performance and induce other skilled characteristics. Also, two kinematic factors that can evidently determine the differences in Osoto-Gari performance were identified. They are: 1) synchronization of ankle, knee and hip in the saggital plane, and 2) functional hip rotation during USP and DSP.

Although the style of Osoto-Gari can be fairly variable among athletes and coaches, it would be important for them to objectively understand key properties of this throwing technique, which are essential regardless of the styles. This study demonstrated a scientific approach to identify key properties or signatures of proficiency for a judo throwing technique using biomechanical tools. Accumulation of such knowledge is considered very meaningful and useful in the development of objective training programs and/or skill assessment criteria, as well as when introducing the original authentic judo techniques to the world.

References

Gomes, F. R. F., Meira, J. C. M., Franchini, E., & Tani, G. (2002). Specificity of practice in acquisition of the technique of O-soto-Gari in judo. Perceptual and Motor Skills, 95, 1248-1250.

Harter, R. A., & Bates, B. T. (1985). Kinematic and temporal characteristics of selected judo hip throws. Proceedings of the 3rd International Symposium of Biomechanics in Sports, 141-150.

Marrero-Gordillo, N., Balius-Matas, X., Vargas-Barneond, J. C., Carmona-Calero, E., Perez-Gonzaleza, H., Ramos-Gordillo, A. S., & Castaneyra-Perdomo, A. (1998). O Soto Gari vs. Perdelera:

A descriptive kinematics study of a laboratory sample. <u>Coaching and Sport Science Journal</u>, <u>3(2)</u>, 39-46.

Minamitani, N., Fukushima, M., Yamamoto, H., Suganami, M., & Hirose, N. (1988). Biomechanical properties of judo throwing technique, uchimata, especially for newly developed flamingo technique. <u>Proceedings of the 6th International Symposium of Biomechanics in Sports</u>, 245-251.

Pucsok, J. M., Nelson, K., & Ng, E. D. (2001). A kinetic and kinematic analysis of the harai-goshi judo technique. <u>Acta Physiologica Hungarica</u>, <u>88(3-4)</u>, 271-280.

Sacripanti, A. (1987). Biomechanical classification of judo throwing techniques (nagewaza). <u>Proceedings of the 5th International Symposium of Biomechanics in Sports</u>, 181-194.

Takahashi, R. (1992). The application of biomechanics to judo technique "okuri-ashi-barai" (sweeping ankle throw). <u>Sports Coach</u>, <u>15(4)</u>, 30-33.

Tezuka, M., Funk, S., Purcell, M., & Adrian, M. J. (1981). Kinetic analysis of judo technique. <u>Proceedings of the 8th International Congress of Biomechanics</u>, 869-875.

Vieten, M. M., & Riehle, H. (2000). Quantification judo performance: An attempt to judge the effectiveness of throwing attacks. <u>Proceedings of the 18th International Symposium of Biomechanics in Sports</u>, 576-579.

Table 1. Event timing of Osoto-Gari
表１． 　大外刈りの各動作タイミング

Event	Explanation
Stepping (ST)	Time when the thrower stepped his/her support leg
Maximum Swing (MS)	Time when the thrower's swinging leg experienced maximum height
Hitting (HI)	Time when the thrower's swinging leg hit the opponent's support leg
Releasing (RE)	Time when opponent's support leg was released from the thrower's swinging leg
Falling (FA)	Time when opponent hit the ground

Table 2. Phase duration of Osoto-Gari
表２． 　大外刈りの局面

Phase	Explanation
Upward swinging phase(USP)	Interval between ST and MS
Downward swinging phase(DSP)	Interval between MS and HI
Sweeping phase(SP)	Interval between HI and RE
Falling phase(FP)	Interval between RE and FA

Table 3. Kinetic parameters
表３． 　運動力学的パラメーター

Parameter	Unit	Explanation
F_V	Newton, BW	Vertical component of the Ground Reaction Force (GRF)
F_{A-P}		Anterior-posterior component of the GRF. Positive means propulsive force and negative means braking force
F_{M-L}		Medial-lateral component of the GRF. Positive means medial force and negative means lateral force
M_X	N*m	Medial-lateral component of the Ground Reaction Moment (GRM)
M_Y		Anterior-posterior component of the GRM
COP_X	M	Medial-lateral displacement of the Center of Pressure (COP) on the force plat form
COP_Y		Anterior-posterior displacement of the COP on the force plat form

Table 4. Kinematic parameters
表4.　運動学的パラメーター

Parameter (Unit: degree)	Type	Baseline
Ankle Dorsi(+) / Plantar(-) Flexion	Relative	Anatomical reference position
Ankle Inversion(-) / Eversion(+)		
Ankle Abduction(-) / Adduction(+)		
Knee Flexion (+) /Extension (-)		
Shank Distal internal (+) / external (-) Rotation (relative to foot)		
Shank Proximal internal (+) / external (-) Rotation (relative to thigh)		
Shank Abduction(-) / Adduction(+)		
Hip Flexion (+) /Extension (-)	Absolute	Transverse axis of global reference frame
Thigh internal (+) / external (-) Rotation		
Thigh Abduction(-) / Adduction(+)		

Table 5. The phase durations and total time (TT) of both subjects
表5.　両被験者の局面時間と総動作時間

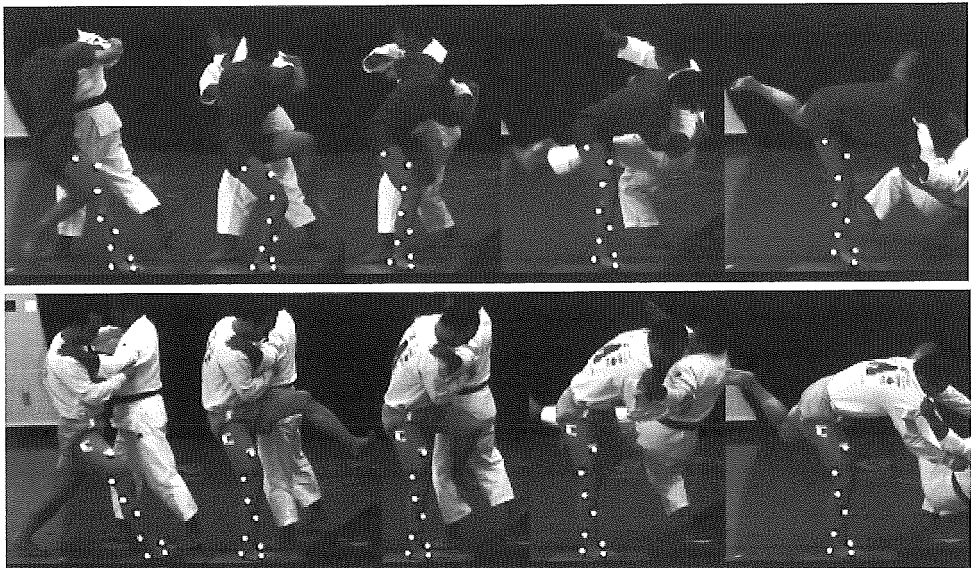| Phase	Skilled (sec)	Novice (sec)	% of difference
USP	0.173	0.388	124.3%
DSP	0.138	0.177	28.3%
SP	0.115	0.188	63.5%
FP	0.227	0.250	10.1%
TT	0.653	1.003	53.6%

Figure 1. Sequence pictures of the performance for skilled (top) and novice (bottom) subjects
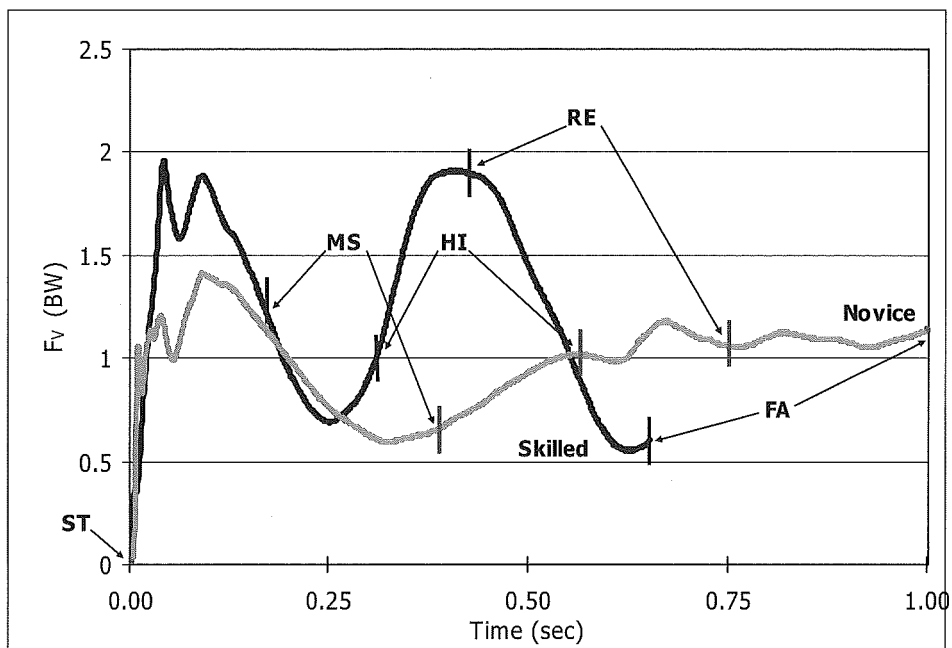図1.　熟練者と未熟練者の大外刈りの連続写真

Figure 2. F_V vs. time curves for skilled and novice subjects
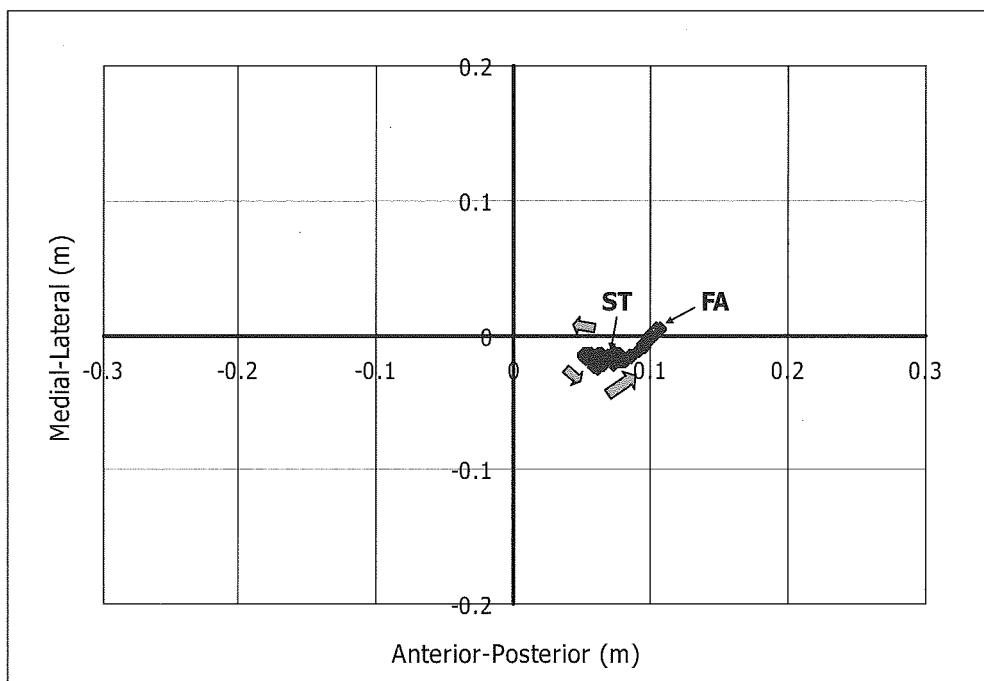図２．　　熟練者と未熟練者のFv値

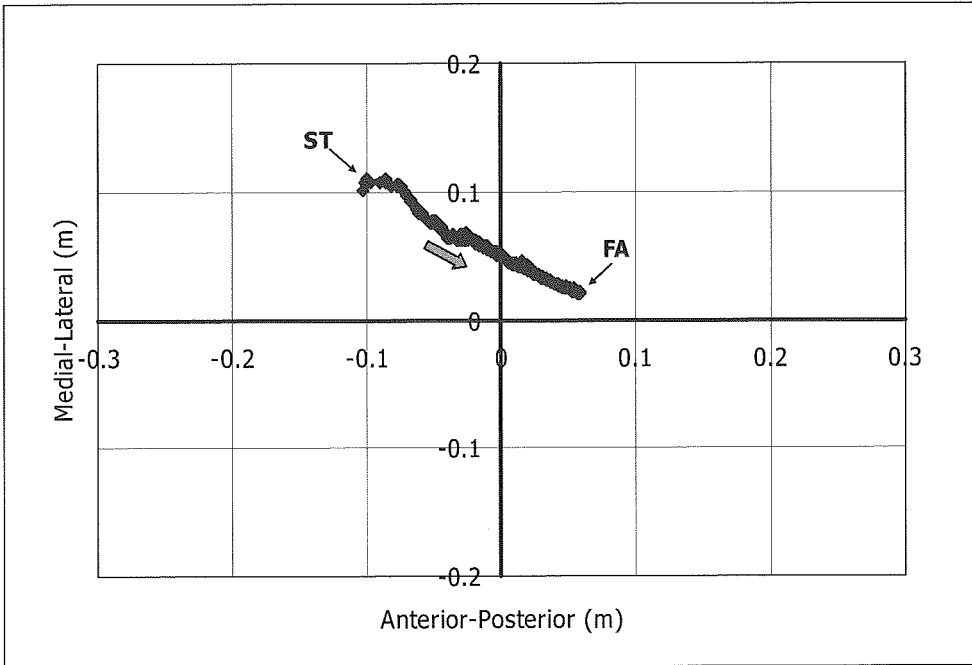Figure 3. Location of COP for skilled subject
図３．　　熟練者の圧力中心の位置

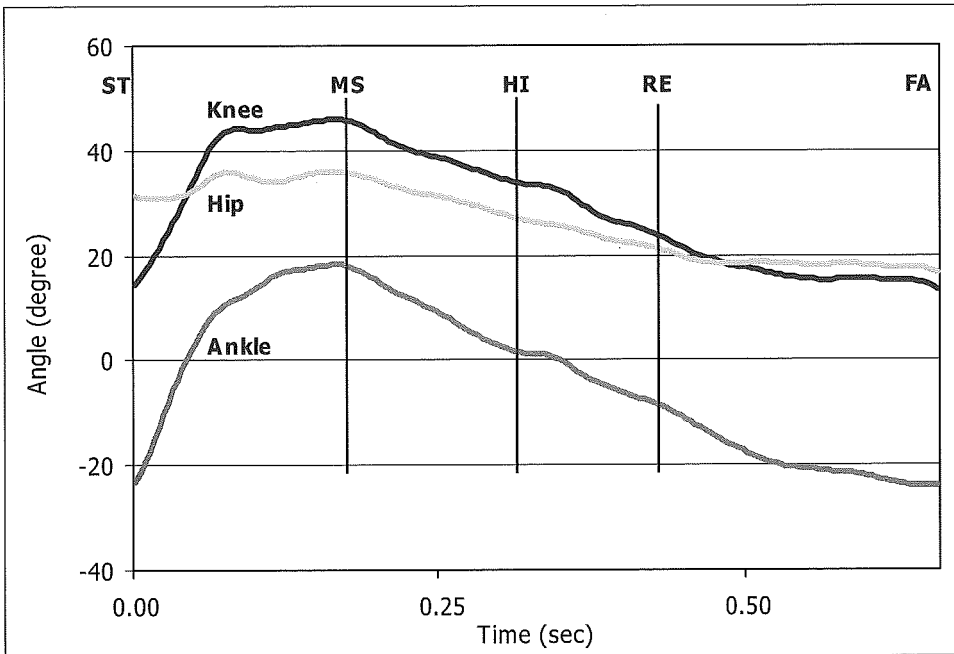Figure 4. Location of COP for novice subject
図4.　　未熟練者の圧力中心の位置

Figure 5. Sagittal displacement of ankle, knee and hip for skilled subject
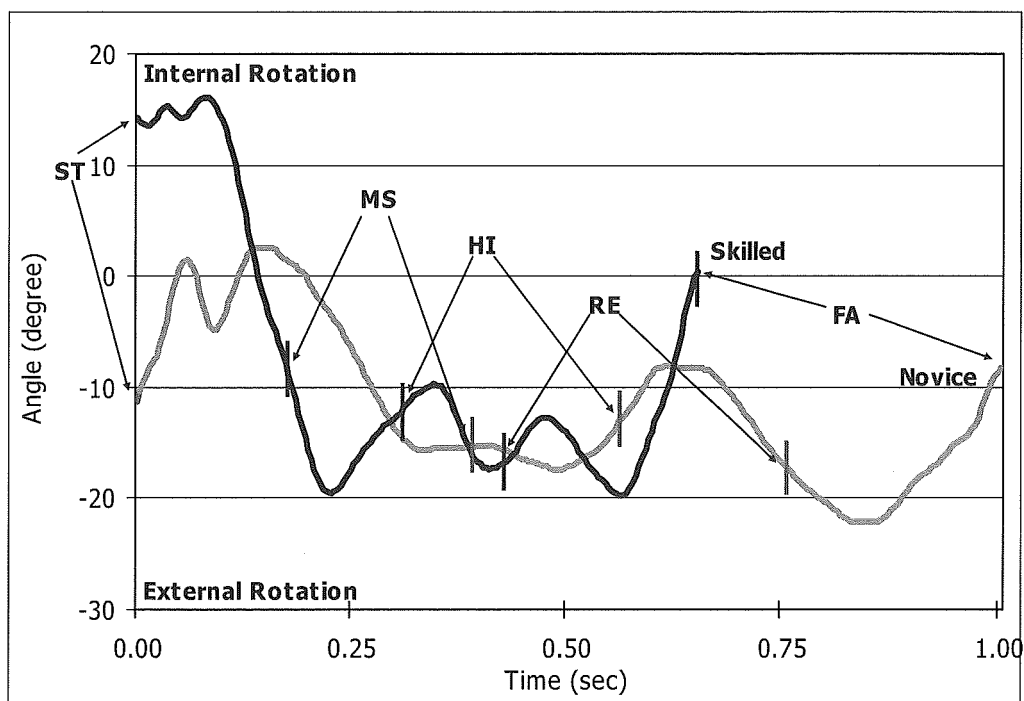図5.　　熟練者の足首、膝、股関節の矢状面上の角度

Figure 6. Thigh rotation displacement vs. time for skilled and novice subjects
図６．　　熟練者と未熟練者の大腿部の回転角度