

7. 大外刈における刈り脚の力学的パワーについて

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キーワード：大外刈，力学的パワー，刈り脚

7. Mechanical Power of the Sweeping Leg During *Osoto-gari*

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要約

本研究の目的は、大外刈における刈り脚の力学的パワーを測定するために逆運動学の計算式を使用することであった。大外刈の刈り脚をハイスピードカメラで撮影し(240Hz)、その後Vicon-Peak Motus ソフトウェアを用いて動作分析を行った。被験者は男性の熟練者(2段)一名と未熟練者(無段)一名であった。それぞれの被験者は受けの代わりとなるバランス棒に対して大外刈の刈り動作を最大努力で行った。それゆえ、力学的パワーの計算は相手に接触しない投げというのが前提となる。力学的パワーはWinter (2005) により開発されたスイング脚の逆運動学の計算式に基づいた。データは、熟練者は未熟練者に比べて、刈り脚(腰、膝、足首)のすべての関節で大きなパワーを発揮したことをはっきりと示した。さらに、熟練者は大外刈の踏み込み時間を短縮し、全体の投げの速度を大きくして、推定される刈りの接触地点への到達を速く行っていた。先行研究でも報告されたように、本研究は被験者間で足首の使い方に大きな違いがみられた。本研究では、いずれの被験者にとっても大きな足関節パワーを生み出す運動伝導のパターンの十分な証拠はなかったけれども、熟練者は未熟練者に比べ大きな足関節底屈を一定して示した。

Introduction

Judo experts have described *osoto-gari* as one of the easiest throws to learn but one of the most difficult to perfect (Daigo, 1994; Yamashita, 1992). Biomechanically, *osoto-gari* is executed

by creating two main forces onto the body of *uke*. The first is a pushing force created by *tori*'s upper body which forces *uke*'s body backwards. The second is a pulling force created by *tori*'s sweeping leg which forces *uke*'s leg's forward. Together, these forces cause *uke* to rotate about their center of mass and likewise be thrown onto their back (Figure 1). While it is arguable which force is more important, the sweeping force has attracted the most attention.

A previous study by Imamura and Johnson (2003) investigated biomechanical differences between the *osoto-gari* performed by novice and black belt judoka. It was hypothesized that black belt belts would create greater velocities for upper body and sweeping leg contributions. Interestingly, significant differences were found only for trunk and ankle contributions, with black belts showing greater trunk flexion and ankle plantarflexion velocities. The findings indicated that more experienced judoka create greater upper body force but not necessarily greater sweeping force. There are a number of speculations as to why black belt players may not be creating greater hip extension and knee flexion velocities than novice players. One speculation is that novice players over emphasize the importance of sweeping force and, in turn, neglect the pushing contributions from the upper body. Another speculation is based on the greater contribution of ankle movement by black belt judoka. Assuming that black belts create a more effective sweep, it is possible that they use their sweeping leg as a kinetic link, which requires timing from the hips and knees to create large ankle velocities.

The purpose of this study was to use inverse dynamic equations to calculate muscle power of the sweeping leg during the *osoto-gari* throw. Since it is difficult to quantify impact forces from *uke*'s leg and upper body, as well as obtain reliable digitized data points from hidden



Figure 1. The dynamics of the *osotogari* throw, illustrating the combination of upper body and sweeping force to create a rotational force onto the body of *uke*.

Source: Imamura, R.T. & Johnson, B.F. (2003). A kinematic analysis of a judo leg sweep: major outer leg reap – *osoto-gari*. *Sports Biomechanics*, 2(2), 191-201.

図1 大外刈の投げの力学，受けの身体に回転力を起こすための上肢と刈り脚の力の組み合わせを説明している。(Imamura (2003)の研究より)

joint markers, this study used equations based on a non-contact throw or a simulation throw without *uke*.

Methods

One male white belt and one male black belt served as subjects for this study. At the time of data collection, the novice white belt had three months of judo training and the black over ten years. Each subject performed the *osoto-gari* throw without *uke* using a stick for balance (Figure 2). Since the stick apparatus was unfamiliar to each subject, they were allowed to practice until they felt comfortable. The subjects were instructed to use maximal speed without losing their footage. In this respect, maximal speeds were encouraged without losing the mechanics of a clean *osoto-gari* throw. The throw was filmed within the sagittal plane using a high speed video camera (Casio; 240 Hz) and the video analyzed using the Vicon-Peak Motus software. The inverse dynamic equations were developed through Microsoft Excel (2007) based on the non-contact swing leg equations presented by Winter (2005). Muscle moment and angular velocity measurements were used to determine the mechanical power acting at three joints (ankle, knee, and hip) of the sweeping leg.



Figure 2. The stick apparatus was comprised of a stick for balance and a hanging judo belt to provide a non-resistance target for the sweeping leg.

図2 棒の装置は刈り脚にとって抵抗のない目標とするためにバランス棒に柔道の帯を吊した。

Results

Peak power is presented relative to a percentage of throw time. Throw time was broken down into two phases, an entrance phase and sweeping phase. Ankle, knee, and hip movements during peak power were also listed. Both subjects created peak power while executing hip flexion during the entrance phase and hip extension during the sweep phase. Peak power was

表1 最大の力学的パワー値が開始局面 (Power 1) と刈り局面 (Power 2) で測定され、その時の全体の投げに対する割合も計測された。足関節底屈または背屈はそれぞれPF, DFと定義された。膝と腰の屈曲または伸展はそれぞれF, Eと定義された。

Table 1. Peak mechanical power measured in watts(w) during the entrance phase (Power 1) and sweeping phase (Power 2) relative to total throw time (%Time). Ankle plantarflexion or dorsiflexion defined as PF or DF, respectively. Knee and hip flexion or extension defined as F or E, respectively.

Black Belt	Power 1		Power 2	
	(w)	% Time	(w)	% Time
Ankle	25.78 (PF)	25%	33.82 (PF)	85%
Knee	146.98 (E)	14%	526.36 (F)	32%
Hip	800.63(F)	10%	1036.8 (E)	35%
Novice	Power 1		Power 2	
	(w)	% Time	(w)	% Time
Ankle	5.4 (DF)	18%	5.33 (DF)	59%
Knee	43.53 (F)	43%	113.16 (F)	60%
Hip	175.57 (F)	15%	338.91(E)	58%

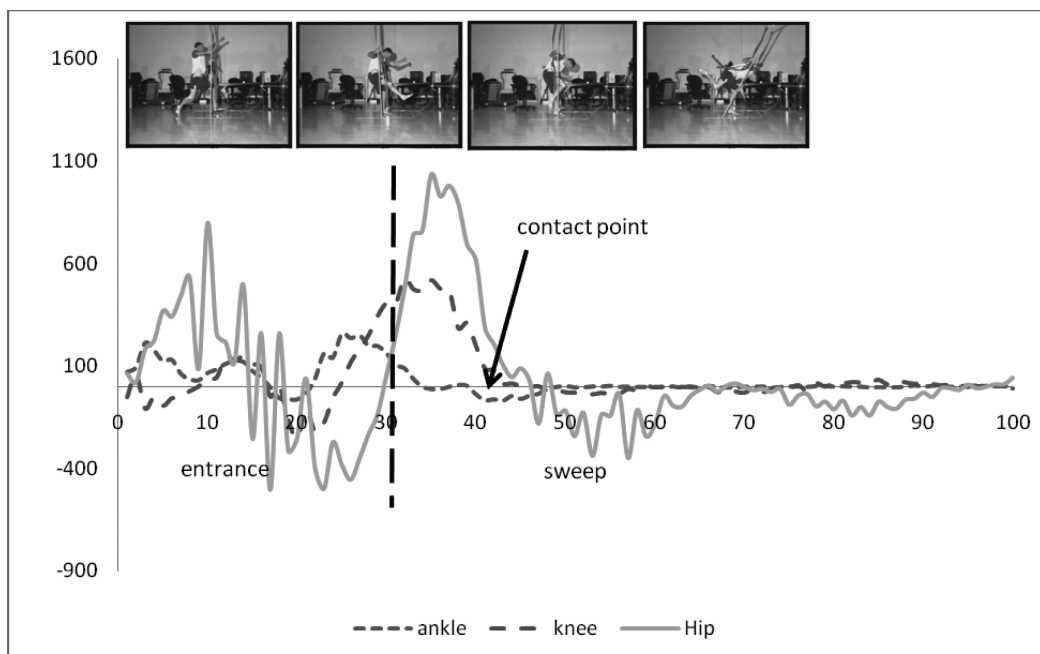


Figure 3. Mechanical power relative to total throw time (0-100%) for the black belt subject. Positive power is considered concentric contraction, while negative power eccentric contraction. Contact point was estimated at 40% of throw time. *Ankle power is magnified times 10 for visual purposes.

図3 熟練者の全投げ時間の相対値と力学的パワー。正のパワーは短縮性収縮、負のパワーは伸張性収縮と考えられる。刈り脚の接触点は投げ時間の40%と推定された。見やすくするために足関節パワーは10倍の大きさにしてある。

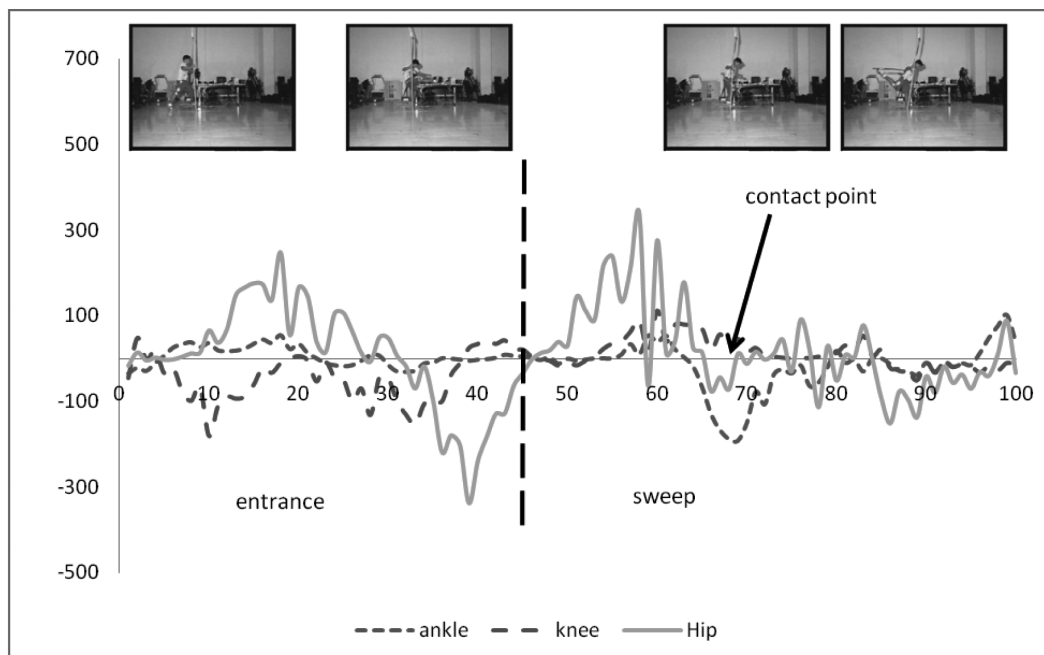


Figure 4. Mechanical power relative to total throw time (0-100%) for the novice subject. Positive power is considered concentric contraction, while negative power eccentric contraction. Contact point was estimated at 68% of throw time. *Ankle power is magnified times 10 for visual purposes.
 図4 未熟練者の全投げ時間の相対値と力学的パワー。正のパワーは短縮性収縮，負のパワーは伸張性収縮と考えられる。刈り脚の接触点は投げ時間の68%と推定された。見やすくするために足関節パワーは10倍の大きさにしてある。

created during different ankle and knee movements between subjects. The black belt created knee extension during the entrance and knee flexion during the sweep, while the novice created knee flexion for both phases. For the ankle, the black belt depicted peak power while executing ankle plantarflexion for both phases, while the novice executed dorsiflexion for both phases. Table 1 summarizes the results for both the black belt and novice subjects. It should be noted that only positive power (acceleration power created from concentric contraction) is listed in the table.

Figures 3 and 4 illustrate the mechanical power relative to a percentage of throw time for both the black belt and novice subjects. Sweep contact was estimated to be at the lowest vertical position of the ankle. The sweep contact occurred much sooner for the black belt subject (40%) compared to the novice (68%) indicating a faster entrance and sweep. The sequence of using larger more proximal muscles before smaller more distal muscles (kinetic link) was only seen during the black belt subject's entrance phase. For the sweeping phase there were no indications of a kinetic link for either subject.

Discussion

The results indicate that the black belt subject created greater sweeping power for each joint during both the entrance and sweeping phases of the *osoto-gari*. This is not in agreement with previous findings from Imamura and Johnson (2003), where differences were only found for ankle contribution. The temporal data does not indicate the use of a kinetic link during the sweep phase for either subject, however, they do indicate that the black belt was using a kinetic link during the entrance phase.

For the entrance phase, the black belt depicted peak power during hip flexion, knee extension, and ankle dorsiflexion at 10%, 14%, and 25% of the total throw time, respectively. The novice depicted hip flexion, knee flexion, and ankle dorsiflexion at 15%, 48%, and 18% of throw time, respectively. The percentages show a kinetic link pattern of power output from the larger more proximal joint muscles to the smaller more distal muscles for the black belt but not for the novice subject. In addition, the novice demonstrated peak power during knee flexion, which can be considered counterproductive during the entrance phase.

In terms of the actual sweep, there is little indication of a kinetic link pattern for either subject. As previous research by Imamura and Johnson (2003) has suggested, ankle contribution was the most noticeable difference between subjects, with the black belt demonstrating larger power contribution from ankle plantarflexion. In terms of sequence, the black belt demonstrated peak power from knee flexion before hip extension at 32% and 35% of throw time, respectively. Since the peak plantarflexion power measured at 85% of throw time occurred after the estimated sweep contact time (40%), it is safe to assume that peak plantarflexion for the sweep actually occurred during the tail end of the entrance phase. In this regard, peak plantarflexion power occurred early for the sweep at 25% of throw, preceding peak sweeping power for both hip extension and knee flexion. In light of these findings, it is possible that the black belt subject used plantarflexion, not only for additional sweeping power, but to place the sweeping leg in an optimal position. As the name of *osoto-gari* implies (major outer leg reap) the sweeping leg is positioned like a reaping tool, or sickle, to optimally create contact force to *uke's* leg.

Unlike other activities in which a kinetic link is applied, the *osoto-gari* requires the leg to be rigid at contact. In this respect, joint positioning and power are both emphasized and, perhaps, working together to optimize each other. For example, the gastrocnemius muscle can be considered a major contributor to the sweeping motion. In terms of muscle function, the gastrocnemius is a natural concentric contractor for both knee flexion and ankle plantarflexion. Thus, when the gastrocnemius creates muscle force it will naturally position the knee into flexion and the ankle into plantarflexion. In this way, the muscle creates effective power at the knee and ankle and, at the same time, provides the sweeping leg with better positioning to simulate a reaping motion.

Perhaps the most telling difference between the black belt and novice subjects, was the speed in which the throw was executed. The percentage of throw time indicated that the black belt reached sweep contact (40%) much earlier than the novice (68%). This suggests that more experienced judoka spend less time during the entrance, which can be considered a practical

advantage during competitive situations. Likewise, the data suggest that more experienced judoka can generate faster sweeping motions with greater power. These findings are consistent with Narazaki et al. (2007) who found execution speeds for *osoto-gari* much faster for skilled judo players as compared to novice.

Conclusion

The study provides a viable means to investigate the mechanical power generated by the *osoto-gari* sweep. Overall, the study reaffirms the common notion that more experienced judoka are able to execute *osoto-gari* faster and with more power than novice judoka. Ankle contribution continues to be a major difference between skill levels. While previous studies have alluded to the possibility of ankle power being a product of a kinetic link system, this study did not substantiate that notion. Rather, it is believed that the ankle not only contributes to overall sweeping power but also plays a role in placing the leg in an optimal sweeping position.

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