# 4. 大外刈のバイオメカニクス

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# 4. The Biomechanics of *Osoto-gari*

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要約

これまでに柔道の技について解説した多くの書物があるが、技を定量的に分析した研究はまだまだ少ない。我々は、バイオメカニクス的な分析は投げの本態を定量的に解明するために役立つと考えている。そこで、本研究の目的は柔道の柔能制剛という理合いをふまえて、大外刈をバイオメカニクス的な手法で分析することである。

これまでに行ってきた3つの柔道のバイオメカニクス的研究における大外刈の解析データを利用し、大外刈の投げをバイオメカニクスの観点から再考した。結果は以下の通りであった。

A. 取の分析

1) 刈り足の足関節の形について：刈り足の速度、即ち股関節の角速度は足関節の底屈位と背屈位では差がなかった。また、底屈位・背屈位とも刈る時には膝関節の動きが伴ったことから、刈り足は足関節の屈伸に関わらず、むしろ膝関節の動きを用いた鞭的な効果（キネティックリンクパターン）を発揮するような動作が重要であると考えられる。
2) 熟練者（有段者）と未熟練者（無段者）の大外刈の比較について：熟練者ではピーク角速度が股関節、膝関節・足関節の順に現れた。そして、熟練者の足関節の底屈速度のみが未熟練者と比較して速かった。これは、熟練者は刈り足を一本の棒（剛体）とするのではなく、鞭効果を利用するような動作をしているからと考えられる。一方、股関節と膝関節の角速度には差はなかったが、熟練者の体幹の速度は有意に大きかった。このことから、取にとっては刈り足よりも受に上体を密着させる体幹の動きが重要であると考えられる。
3) 取の重心は、崩し・作りの局面では前方向（負）の運動量を示したが、掛けの局面で急激に正の運動量に変化した。また、崩しの局面で上方向への重心移動は期待したほど顕著では

なかった。さらに、崩し・作りの局面では取りの重心は引き手方向へ移動した。これらのことから、取の重心は崩し・作りの局面では前方および引き手方向へ動き、掛けの局面では上体の衝撃により短時間に運動量の方向が逆転するという特徴がみられた。

B. 受の分析

受の重心は、崩し・作りの局面では前方向、上方向、取りの引き手に引かれる方向に動いたが、掛けの局面では後ろ方向、下方向、取の引き手と反対方向に動いた。このことから、受は崩し・作りの局面において一旦投げられる方向とは反対方向に動かされるという特徴がみられた。

## Introduction

Judo continues to be one of the most popular sports in the world. Recent information from the International Judo Federation (IJF) indicated that 178 National Federations over 5 continents are currently practicing judo. Since its inauguration into the Summer Olympic Games in Tokyo (1964), the popularity of judo has grown and has attracted worldwide attention as a competitive international sport.

Despite its amenity to biomechanical analysis, few studies concerning the biomechanics of judo have been written in English (Harter & Bates, 1985; Imamura & Johnson, 2003; Minamitani, Fukushima, & Yamamoto, 1988; Pucsok, Nelson, & Ng, 2001; Serra, 1997; Sacripanti, 1989; Tezuka, Funk, Purcell, & Adrian, 1983). The *osoto-gari* (major outer leg reap) is one of the most popular throwing techniques used by judo competitors. Despite its simplistic nature, many experts consider the throw easily learned but very difficult to master (Daigo, 1994; Yamashita, 1991).

From a qualitative perspective, a successful *osoto-gari* is executed when *tori* (*thrower*) creates simultaneous pushing and pulling forces onto the body of *uke (faller)*. The pushing force is directed towards the upper body of *uke*, while the pulling force (from *tori's* sweep) is directed towards the lower body. These forces produce a rotational motion onto the body of *uke*, a motion much like that of a pinwheel (Figure 1). Most experts agree that an effective rotation of *uke's* body is a clear reflection of the throw's success (Daigo, 1994; Yamashita, 1992).

Biomechanical analysis of *osoto-gari* is necessary to develop a greater understanding of the mechanical nature behind the throw, which up to now has been studied mostly through qualitative means. The following is a quantified presentation of some of the biomechanics underlying the *osoto-gari* throw, with an emphasis on factors that contribute to judo's general philosophy of "maximum efficiency with minimal effort".

## Methods

The biomechanical data that were reviewed for this manuscript originated from video motion analysis (Imamura, 1996; Imamura & Johnson, 2003; Imamura, Hreljac, Escamilla, & Edwards, 2004). All video footage was collected at 60 Hz. All throws were executed to insure a combination of maximal effort and proper technique by *tori* under non-competitive situations (*nagekomi*). In addition, no conscious resistance by *uke* was given during the throws. A Peak Performance Inc. Motus motion analysis software (Englewood, CO, USA) was used to determine kinematic variables such as angular velocities for hip, knee, and ankle joints in two-dimension and location of center of mass as well as linear velocities of the center of mass in three-dimension. Statistical analysis used for the Imamura and Johnson (2003) study was a one-way MANOVA (p=.05) to determine differences between black and novice groups.

## Kinematic Analysis of *Tori*

The *osoto-gari* throw, as well as all throws in judo, are separated into phases. The founder of modern judo, Jigoro Kano (1860-1838), developed phases with the intent of developing judo through analytical thinking. There are three main phases: *kuzushi* is the preparatory phase defined as breaking an opponent's balance or simply to prepare them for a throw, *tsukuri* is the process of fitting into the throw, and *kake* is the acceleration phase describing the execution of the throw itself. For the *osoto-gari* throw, *kuzushi* begins with the onset of *tori's* leg drive from the sweeping (right) leg, allowing the supporting (left) leg to move towards *uke* and ends with *tori's* sweeping leg moving up to *uke's* body. *Tsukuri* immediately follows *kuzushi* and begins with *tori's* sweeping leg passing *uke's* body and ends with *tori's* sweeping leg making sweep contact. *Kake* immediately follows and begins with sweep contact to *uke's* body and *uke's* legs subsequently striking the ground. Figure 2 illustrates the different phases of *osoto-gari.*

There has been much attention given to the sweeping aspect of *osoto-gari.* Imamura (1996) and Imamura and Johnson (2003) studied two-dimensional peak angular velocities of *tori's* sweeping leg just prior to contact as well as peak trunk angular velocities for both *tori* and *uke*. The first study by Imamura (1996) compared black belt subjects performing two different types of sweep based on foot position. The foot placed in a plantarflexed position (toes pointed downward) prior to sweep contact is considered the orthodox method while the foot placed in a dorsiflexed position (toes pointed upward) the unorthodox method (Figure 3). The unorthodox method was made famous by the legendary champion Masahiko Kimura (1917-1994) who believed that sweeping power was enhanced by dorsiflexing the foot (Daigo, 1994).

Biomechanically, Kimura's style can potentially shorten the length of one's sweeping leg by decreasing the moment of inertia and increasing angular velocity about the hip thereby increasing sweeping power. However, it was found that there was no significant difference in hip angular velocity between the two styles. Furthermore, it was found that subjects had a tendency to move their knee during the sweep. The knee movement altered the moment of inertia characteristics about the hip affecting the results of the study, but more importantly indicated that subjects were using the sweeping leg as a linked segment rather than a single rigid one.

Imamura and Johnson (2003) further investigated the *osoto-gari* two-dimensionally from the perspective that skilled judo players will use their sweeping leg not as a rigid segment but as a coordinated linked system. In this study 10 black belt subjects were compared to 10 novice subjects. The study found temporal differences in the pattern of sweep from the hip to ankle: time of peak hip extension angular velocity, time of peak knee flexion angular velocity, and time of peak ankle plantarflexion angular velocity. Figure 4 illustrates the ability of black belt subjects to create peak velocity and momentum from their larger muscles first (i.e. hip muscles) and then transferring momentum to smaller muscles of the knee and ankle in a linked fashion. In a sense, the action of the sweeping leg for *osoto-gari* can be compared to the action of a throwing arm for pitching where muscles are contracted in a sequential manner to obtain optimal final momentum in distal segments, a concept referred to as kinetic link.

The study also found a significant difference in peak angular velocity for the ankle but not for other joints of the sweeping leg. This indicated that the only major difference in sweep velocity between black belt and novice subjects came from the ankle, particularly plantarflexion. Thus, large plantarflexion activity during the sweep can be considered a skilled trait and perhaps a key component to a successful kinetic link system.

Other findings of the study further suggest that the *osoto-gari* sweep is not necessarily the most important aspect of the throw. While there were no significant differences in hip and knee angular velocities for the sweeping leg between novice and black belt subjects, the study did find significant difference in trunk angular velocity as *tori* made chest to chest contact or impact with *uke*. Black belt subjects were able to produce greater trunk angular velocity than novice subjects indicating that the upper body impact during *kuzushi* and *tsukuri* is a very skilled trait and should be considered important if not more important than the sweep. Table 1 presents two-dimensional average angular velocities for black belt subjects executing *osoto-gari*.

A three-dimensional analysis of *osoto-gari* was performed by Imamura, Hreljac, Escamilla, and Edwards (2004) to investigate the center of mass (CM) momentum for both *tori* and *uke* during *kuzushi* and *tsukuri*. Four black belt subjects served as *tori* for this study, while a different black belt subject was used as *uke* and accepted the throws for all subjects. The study was able to determine forward-backward (x), up-down (y), and side-to-side (z) momentum for *tori* and *uke*.

As would be expected, *tori* was found to increase forward momentum from *kuzushi* to *tsukuri* phases as *uke* is pushed backwards. This momentum continues to increase until *kake* where it decreases sharply and changes direction. The abrupt change in forward to backward momentum is due to the collision created by the upper body impact between *tori* and *uke*. This is consistent with previous findings of Imamura and Johnson (2003) who found large peak trunk angular velocities for tori during *osoto-gari*.

Within the up-down direction, *tori's* momentum was found to move slightly upward during *kuzushi* and then slightly downward during *tsukuri*. From a biomechanical standpoint one would expect *tori* to lift *uke* upward to reduce frictional resistance from *uke's* feet prior to sweep contact. Though momentum values did indicate upward momentum during *kuzushi*, they were considered relatively small with high variance. Therefore, two assumptions can be made. The first is that upward momentum for *tori* during kuzushi may not be as important as one would expect and, second, whether it is important or not, upward momentum is most likely influenced by the relative height of *uke* and *tori* and should be accounted for in future studies.

Within the side-to-side direction, *tori* was found to direct their momentum towards the pulling hand for both the *kuzushi* and *tsukuri* phases. This is expected as most judo players will pull *uke* sideways so that *uke's* weight is shifted onto the leg that will be swept. Figure 5 illustrates all directional average momentum and standard deviation for *tori* during *osoto-gari*.

### Kinematic Analysis of *Uke*

Analyzing *uke's* motion can be viewed as analyzing the product of *tori's* throw. Furthermore, it can reveal the position and movement of *uke* prior to the throw and likewise further investigate the meaning of *kuzushi* and *tsukuri*. Three-dimensional analysis indicated that *uke's* CM had forward and upward momentum and momentum towards the pulling hand during the kuzushi phase. The *tsukuri* phase indicated a continuation of forward and upward momentum as well as momentum towards the pulling hand, while *kake* depicted momentum backwards, downwards, and away from *tori's* pulling hand.

Since the *osoto-gari* tosses the uke backwards, one would expect *uke* to move backwards in all phases. However, this was not the case as *uke's* momentum increased from *kuzushi* to *tsukuri* in the forward direction. It was not until *kake* that *uke* moved backwards. From these results, it is likely that *tori* pulls *uke* towards them while stepping into the throw during both *kuzushi* and *tsukuri*. The results for *tori* also demonstrated forward momentum indicating a prelude to a collision between *tori* and *uke*. Similar to what was seen in *tori's* momentum was a sharp change in *uke's* momentum following body impact. This once again indicated an importance for *tori* to create a large collision or impact onto *uke.*

*Uke's* forward momentum during *kuzushi* and *tsukuri* can be attributed to *uke's* reaction to *tori's* push, a concept referred to as "reaction resistance". Reaction resistance occurs as a result of *uke* attempting to maintain balance during the *kuzushi* phase. This is most likely a subconscious movement by *uke* thus the term "*reaction* resistance". It is thought that "reaction resistance" is a necessary occurrence during *kuzushi*, in that, without a slight resistance from *uke*, *tori* cannot perform *tsukuri* very well. Therefore, it is also possible that *uke* creates a slight resistance reaction to *tori's* push which allows *tori* to properly fit into the throw. Furthermore, it is likely that some form of reaction resistance occurs during every throw during the *kuzushi* phase.

Imamura and Johnson (2003) indicated very little movement of *uke* in the up-down direction during *osoto-gari.* The three-dimensional study indicated a pattern of upward momentum during the *kuzushi* and *tsukuri* phases, however the values were small with a large variance. This substantiates previously mentioned findings with CM momentum results of *tori*, in that, *uke's* upward momentum does not seem to be an important aspect of the throw. However, it should be emphasized that height differences between *tori* and *uke* were not taken under account with these measurements and could have affected the results.

Within the side-to-side direction there was no indication of a "resistance reaction" from *uke.* Rather *uke's* body moved towards *tori's* pulling hand with the greatest momentum being created during the *tsukuri* phase. Thus, *tsukuri* tends to be a particularly important phase for this throw. This is in agreement with Imamura and Johnson (2003) who found chest to chest contact and upper body angular velocity to be an important aspect of *osoto-gari.* Figure 6 illustrates all directional average momentum and standard deviation for *uke* during *osoto-gari.*

## Conclusion

The *osoto-gari* is comprised of *tori* generating two forces onto the body of *uke.* The first force targets the upper body, pushing *uke* backwards. The second force targets *uke's* leg, sweeping the lower body forward. When these forces are successfully integrated *uke's* body rotates about its center and falls to the ground.

There has been much attention given to the *osoto-gari* sweep (major outer leg reap) as the name implies. Research has found that the sweep is a skilled trait. Experienced judo players (black belts) have developed the skill to use their sweeping leg as a linked system to build optimal momentum via kinetic chain. In particular, experienced players are much more active with ankle plantarflexion than novice players in an effort to maximize all segments and muscles of the leg.

Research has also indicated that the *osoto-gari* sweep may not be the most important aspect of the throw. Experienced judo players will use upper body impact or collision to push *uke* backwards and towards their pulling hand. While novice players were shown to exhibit similar angular velocities of the sweeping leg as compared to experienced players, they were considered very poor in creating upper body velocity and impact. Because impact is a very important aspect of *osoto-gari*, it is important that judo players develop large momentum prior to the *kake* phase. Likewise, individuals that are heavy and fast are likely to produce the best momentum necessary to execute *osoto-gari* well.

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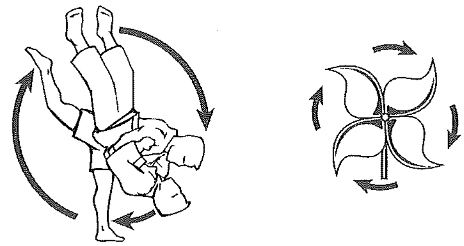

**Figure 1. The rotational motion of the *uke's* body is similar to that of a pinwheel's motion.**
**Source: Imamura, R.T. & Johnson, B.F. (2003). A kinematic analysis of a judo leg sweep: major outer leg reap – osoto-gari. *Sports Biomechanics*, 2(2), 191-201.**

図1. 受の身体の回転動作は風車に似ている　Imamura, R.T. & Johnson, B.F. (2003) から引用

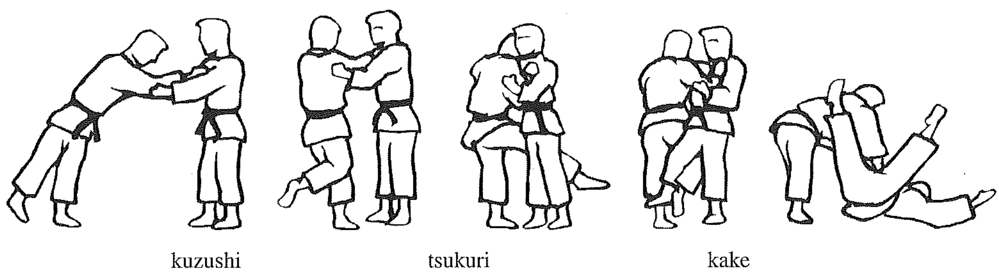


**Figure 2. Three main phases for the *osoto-gari* throw: *kuzushi*, *tsukuri*, and *kake*.**
**Source: Imamura, R.T., Hreljac, A., Escamilla, R.F., Edwards, W.B. (2004). *A three-dimensional analysis of center of mass for three different judo throwing techniques.* Manuscript submitted for publication.**

図2. 大外刈の3つの主要局面：崩し・作り・掛け　Imamura, R.T., et al. (2004) から引用

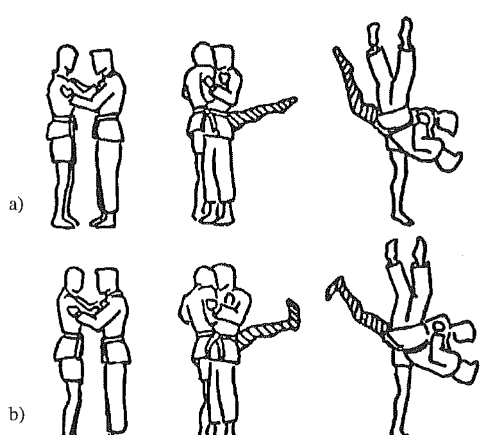


**Figure 3. Two styles of osoto-gari sweep, a) orthodox style with the toes pointed outward and ankle plantarflexed b) unorthodox style with toes curled-up and ankle dorsiflexed.**

図3. 大外刈の刈り足の2つのスタイル；a) 足関節底屈位でつま先を伸ばした標準的なスタイル，b) 足関節背屈位でつま先を上に向けた特別なスタイル

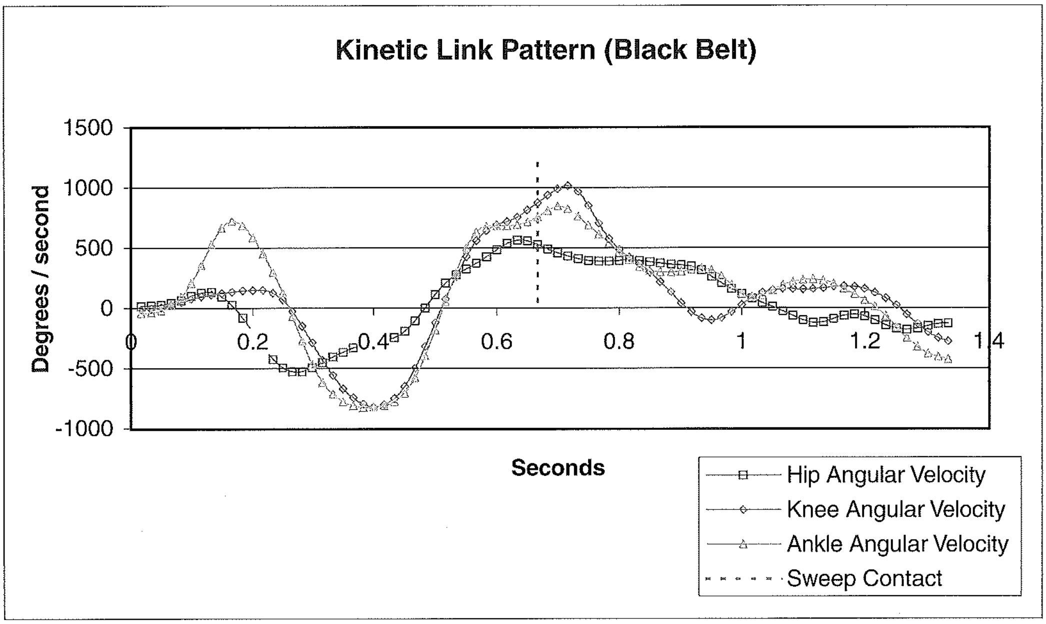


**Figure 4. Typical sweep pattern for a black belt subject depicting a kinetic link pattern.**

図4. キネティックリンク（鞭的な効果）を示す有段者の典型的な刈り足パターン

**Table 1. Mean, standard deviation, and significance values ($p<0.05$) for the following variables: peak *tori* angular velocities for trunk flexion (TTRK), hip extension (THIP), knee flexion (TKNEE), and ankle plantarflexion (TANK); peak *uke* angular velocities for the trunk (UTRK) and leg (ULEG) with respect to the vertical axis.**
**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.**

表1. 取の体幹（TTRK），股関節伸展（THIP），膝関節屈曲（TKNEE），そして足関節底屈（TANK）のピーク角速度と受の垂直軸に対する体幹（UTRK）と脚（ULEG）のピーク角速度の平均と標準偏差（＊:p<0.05） Imamura, R.T. & Johnson, B.F.（2003）から引用

| Variable | Group | N | Mean (deg/s) | Std. Deviation | Probablity Values |
|---|---|---|---|---|---|
| THIP | black belt | 10 | 508.26 | 50.70 | 0.11 |
| | novice | 10 | 435.79 | 126.36 | |
| TKNEE | black belt | 10 | 833.29 | 127.89 | 0.453 |
| | novice | 10 | 756.47 | 289.52 | |
| TANK | black belt | 10 | 746.74 | 134.63 | 0.011＊ |
| | novice | 10 | 552.49 | 169.87 | |
| TTRK | black belt | 10 | 334.69 | 35.92 | 0.043＊ |
| | novice | 10 | 299.37 | 36.78 | |
| UTRK | black belt | 10 | 394.14 | 117.33 | 0.016＊ |
| | novice | 10 | 284.32 | 57.31 | |
| ULEG | black belt | 10 | 611.71 | 83.32 | 0.954 |
| | novice | 10 | 608.78 | 133.99 | |

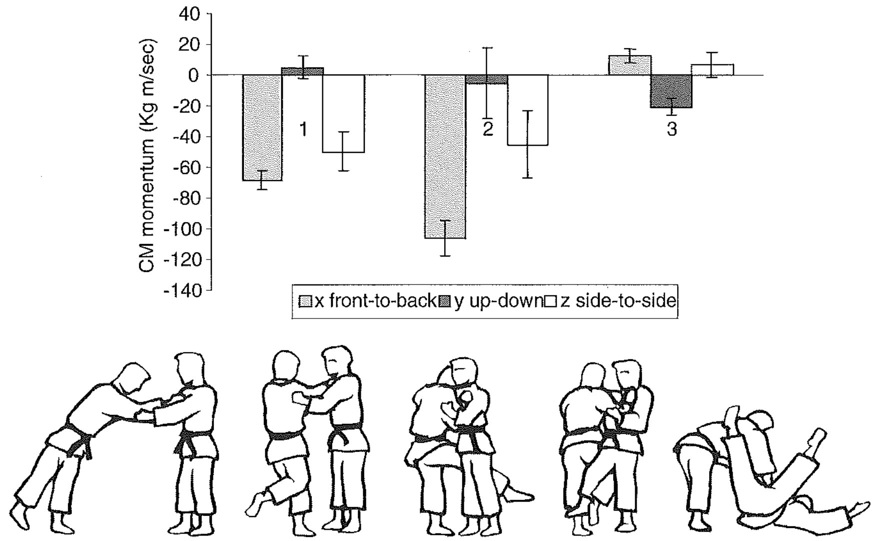


**Figure 5.** ***Tori's*** **directional momentum (forward-back(x), up-down(y), side-to-side(z)) for three phases (1 =** ***kuzushi*****, 2 =** ***tsukuri*****, 3 =** ***kake*****) of** ***osoto-gari*****.** ***Tori's*** **forward and left side momentum are considered negative in this case.**

図5. 崩し・作り・掛けの3局面における取の重心の運動量（前後（x), 上下（y), 横（z)). 取からみて前方向と左方向の運動量が負となる

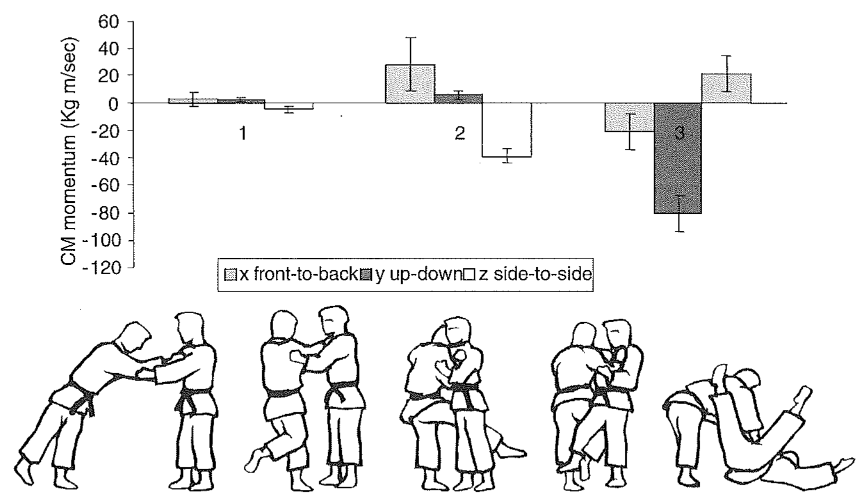


**Figure 6.** ***Uke's*** **directional momentum (forward-back(x), up-down(y), side-to-side(z)) for three phases (1 =** ***kuzushi*****, 2 =** ***tsukuri*****, 3 =** ***kake*****) of osoto-gari. Uke's forward and left side momentum are considered positive in this case.**

**Source: Imamura, R.T., Hreljac, A., Escamilla, R.F., Edwards, W.B. (2004) .** ***A three-dimensional analysis of center of mass for three different judo throwing techniques.*** **Manuscript submitted for publication.**

図6. 崩し・作り・掛けの3局面における受の重心の運動量（前後（x), 上下（y), 横（z)). 受からみて前方向と左方向の運動量が正となる Imamura, R.T., et al. (2004) から引用