A kinematic comparison of the judo throw Harai-goshi during competitive and non-competitive conditions

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Abstract
The purpose of this study was to compare the kinematics of kuzushi/tsukuri (KT) phases of the harai-goshi throw under competitive and non-competitive conditions. A third degree black belt subject served as the tori (thrower) for both conditions. Two black belt participants ranked as first degree and fourth degree served as the uke (faller) for the competitive and non-competitive conditions, respectively. Two video cameras (JVC 60 Hz) and a three dimensional motion analysis system (Vicon-Peak Performance Technologies, Inc., Englewood, CO) were used to collect and analyze peak velocity for the center of mass (COM) of uke and tori and peak angular velocity of tori’s trunk (TAV). Data were smoothed using a 4th order zero lag Butterworth filter with a cut-off frequency set by the Peak software optimization technique. All variables were normalized by time as a percentage of the KT phase. In general, the COM directional velocity patterns were similar between conditions. Uke’s defensive efforts during the competitive condition created differences in timing and magnitude of peak COM and TAV velocities. During competition, tori created larger peak COM velocities onto uke which indicated greater throwing power. Peak velocities for tori’s COM were larger during the non-competitive condition since uke’s resistance was minimal. Findings of the competitive condition suggested that mediolateral COM movement towards tori’s pulling (left) hand can be an ideal set-up movement prior to execution. Tori’s TAV was also greater during the competitive condition. Two distinct TAVs were observed, a counterclockwise TAV created by tori turning their hips during the entrance of the throw and a clockwise TAV created by the shoulders turning to complete the 180 degree body turn with the simultaneous leg sweep. It is thought that the counterclockwise rotation aids in producing a pre-stretch of trunk muscles which helps to create greater trunk rotation power.

Key words: Biomechanics, Harai-goshi, kinematics, judo, throw, velocity.

Introduction
Judo continues to be one of the most popular sports in the world. Up to 187 national affiliates under the International Judo Federation (IJF) are currently participating in international competition. Medal winners at the recent 2004 Olympic Games in Athens, Greece, were comprised of 19 different countries. The biomechanical approach to studying judo is consistent with judo’s basic philosophy of “maximum efficiency with minimum effort” or emphasizing proper mechanics and technique over muscular strength. Determining the proper mechanics of judo, however, presents a challenge, particularly because success in judo is largely determined by the actions of the opponent as well as oneself. A number of contact sports are similar to judo in this respect and likewise have not been studied extensively.

The harai-goshi is considered a popular throw among competitors. It is classified as a forward hip throw where the opponent is thrown forward and over the hip with a prominent leg sweep to the opponent’s outside leg (Figure 1). The execution of the throw is further characterized by the thrower, or tori, pulling the opponent, or uke, forward and sideways via two distinct ground reaction forces created by the positioning of the right foot followed by the left foot.

Judo’s philosophy of “maximum efficiency with minimum effort” has generated considerable interest in the early phases of a throw or the time in which the opponent’s balance is manipulated. All judo throwing techniques are comprised of three main phases: kuzushi the preparatory phase defined as breaking an opponent’s balance or simply to prepare them for a throw, tsukuri the process of fitting into the throw, and kake the air phase describing the execution of the throw itself. For most throwing techniques including harai-goshi, the kuzushi and tsukuri phases are difficult to separate. It is agreed that kuzushi always precedes tsukuri but the point at which kuzushi ends and tsukuri begins remains somewhat subjective (Harrison, 1952; Imamura et al., 2006; Kano, 1986; Kim and Shin, 1983; Koizumi, 1960).

Harter and Bates (1985) studied the ground reaction forces (GRF) associated with the harai-goshi throw. A tri-modal peak anteroposterior GRF pattern indicating a pull-push-pull effort by tori was found during the throw. Tezuka et al. (1983) also measured the GRF of harai-goshi and found similar results. Pucsok et al. (2001) correlated kinetic and kinematic characteristics of harai-goshi. They found a significant relationship between anteroposterior GRF of the supporting foot and horizontal velocity of the sweeping leg. Yabune (1994) found a greater rear supporting foot GRF for advanced judo players. In general, GRF studies have all found a pushing force by tori during the initial supporting foot ground contact, which likely plays a key role during the tsukuri phase.

Imamura et al. (2006) analyzed momentum at the center of mass (COM) of uke (faller) during all three phases for the harai-goshi throw. The study was able to show trends in uke’s momentum in the anteroposterior and mediolateral directions. In the anteroposterior direction,
mining which factors are necessary to achieve an baseline data that may assist judo practitioners in dete-

rminative situations, this study will also be useful in providing kinematics of under real-life conditions. It was hypothesized that the throw under a real-life competitive condition and a simu-

ted laboratory condition. The study described this movement as a slight resistance to tori’s pull. The study alluded that this slight resistance is a necessary occurrence, freezing uke momentarily so that tori may execute tsukuri (fit-in) with greater effectiveness. Furthermore, it was also suggested that this slight resistance is present in all throws and, therefore, may serve as a biomechanical descriptor for the kuzushi phase.

To date, biomechanical analyses of the harai-goshi throw have been isolated to laboratory conditions. In most cases the throw was performed from a stationary position and tori’s motions were restricted by the use of force platforms. Furthermore, in all cases uke was a passive faller offering no conscious resistance to tori’s throwing efforts. Though this type of throwing, called nage-komi, is common practice in judo training, it may not be completely revealing as to what tori is doing during the kuzu-

shi/tsukuri phases to successfully throw an opponent under real-life conditions.

The purpose of this study was to compare the kinematics of kuzushi/tsukuri phases of the harai-goshi throw under a real-life competitive condition and a simulated laboratory condition. It was hypothesized that the two conditions will exhibit similar kinematics since the outcome of both conditions is a perfect throw or what competitors refer to as an ippon throw. Because very little is known about the biomechanics of judo during competitive situations, this study will also be useful in providing baseline data that may assist judo practitioners in determining which factors are necessary to achieve an ippon throw during competition.

Methods

A third degree black belt subject (age = 32 y; mass = 89 kg; height = 1.78 m) served as the tori for both competitive and non-competitive conditions. Due to the difficulty involved with collecting data of ippon throws during competitive conditions, the study was not able to use the same uke for both conditions. Two different black belt participants, ranked as first degree (age = 21 y; mass = 78 kg; height = 1.77m) and fourth degree (age = 38 y; weight = 89 kg; height = 1.75m), served as the uke for the competitive and non-competitive conditions, respectively.

Data for the competitive condition were collected at a local judo tournament. The subject executed the harai-goshi throw for an ippon score (a score representing a perfect throw) approximately two minutes into the four minute match. For the non-competitive condition, data were collected at a local practice facility under a controlled environment. The subject was instructed to perform the harai-goshi throw with an adequate combination of maximal effort and proper technique. Thus, the subject performed the throw with maximal effort while maintaining their balance (staying on at least one foot and no more than one hand touching the ground) after the throw was executed. This procedure was designed to simulate the throw under ideal conditions, where uke began each throw in a stationary position and elicited no conscious resistance to tori’s efforts. The procedure is similar to typical throwing practice, referred to as nage-komi.

Two video cameras (JVC 60 Hz) were used to collect the data for both conditions. For the non-competitive condition an LED was used to synchronize the cameras. For the competitive condition cameras were synchronized by tori’s initial right foot touch during the kuzushi/tsukuri phase of the throw. The cameras were positioned approximately 90 degrees apart for both conditions. Directions for the throw were adjusted such that uke began the throw facing the positive x (anteroposterior) direction and his right shoulder facing the positive z (mediolateral) direction. The upward direction was designated as positive y (vertical). Power spectrum analysis consistent with the Nyquist Theorem indicated that 60 Hz was adequate collection frequency for judo movements.

A three dimensional motion analysis system (Vicon-Peak Performance Technologies, Inc., Englewood, CO) and the DLT (Direct Linear Transformation) procedure were used to analyze three-dimensional kinematic data. Two different scaling factors were used, a twenty point cube and a twelve point cube for the non-competitive and competitive conditions, respectively. For the competitive condition, the contest area was divided into four different calibration areas to ensure that the action occurred within a calibrated volume of space. Since judo requires that all participants wear a judo uniform (judo gi), joint markers could not be used for either condition. Therefore, manual digitization of 18 body points (top of head, chin, shoulders, elbows, wrists, knuckles, hips, knees, ankles, metatarsal heads) for both tori and uke were performed for all trials. A single researcher who was experienced with the sport of judo digitized all trials to minimize digitizing error between the

Figure 1. Illustration of the harai-goshi throw with the first four pictures describing the kuzushi/tsukuri phase (Source: Imamura et al., 2006).
two conditions. The digitized data were smoothed using a 4th order zero lag Butterworth filter with a cut-off frequency set by the Peak software optimization technique. Center of Mass (COM) calculations were based on anatomical parameters from Clauser et al. (1969) and computed by the motion analysis software into a virtual point. COM variables included peak linear velocity of uke and tori in the anteroposterior, mediolateral, and vertical directions. Peak angular velocity of tori’s trunk was determined by measuring the angular displacement between shoulder-to-shoulder and hip-to-hip segments within the XZ plane. All variables were normalized by time to determine when these variables occurred during the kuzushi/tsukuri phase.

**RESULTS**

The kuzushi/tsukuri phase (KT) occurred over a span of 0.83 and 0.68 seconds for the competitive and non-competitive conditions, respectively. In general, uke’s center of mass (COM) peak velocities were greater during the competitive condition, while tori’s COM peak velocities were greater during the non-competitive condition (Tables 1 and 2).

**Movement of Uke**

Movement of uke’s COM along the anteroposterior axis occurred exclusively in the forward direction. Both conditions demonstrated a gradual increase in forward COM velocity, however, peak velocity of the non-competitive condition occurred at 83% of KT while peak velocity of the competitive condition occurred at 100% of KT and continued to increase into the kake phase (Figure 1a).

Movement along the vertical axis differed temporally between conditions. For the competitive condition, peak COM velocity occurred in the downward direction at 43% of KT followed by the upward direction at 95% of KT. The non-competitive condition depicted opposite results with peak upward velocity occurring before peak downward velocity at 62% and 86% of KT, respectively (Figure 1b).

Movement along the mediolateral axis depicted a similar temporal pattern between conditions. Peak COM velocity to uke’s left occurred at 79% and 68% of KT for the competitive and non-competitive conditions, respectively. Peak velocity to uke’s right occurred later in KT just before the beginning of the kake phase at 93% and 90% for the competitive and non-competitive throw, respectively (Figure 1c).

**Movement of Tori**

For tori’s movement along the anteroposterior axis, the COM did not move in the positive direction during the non-competitive trial. Initially, there was a negative forward movement towards uke followed by a 180 degree turn and a negative backwards movement towards uke. For the competitive condition, tori exhibited a positive peak forward COM velocity during the competitive trial near 55% of KT. Both conditions depicted a backwards peak velocity later in the phase at 81% of KT (Figure 2a).

Movement along the vertical axis depicted an upward-to-downward peak COM velocity pattern during both conditions. Differences were present in the timing of the movement with the competitive condition exhibiting the upward-to-downward pattern at 19% and 41% of KT compared to 45% and 73% of KT for the non-competitive condition, respectively (Figure 2b).

For movements along the mediolateral axis, tori’s peak COM velocity to uke’s left occurred late during KT at 84% and 100% KT for the competitive and non-competitive conditions, respectively. For the competitive condition peak velocity to uke’s right occurred at 32% of KT. For the non-competitive condition, tori’s COM did

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**Table 1. Comparisons of peak linear velocity of uke’s COM in the anteroposterior [X: forward (+) and backward (-)], vertical [Y: up (+) and down (-)], and mediolateral [Z: uke’s right (+) and uke’s left (-)] directions as well as occurrences of these variables as a percentage of kuzushi/tsukuri phase.**

<table>
<thead>
<tr>
<th></th>
<th>Competitive peak velocity (m·s⁻¹)</th>
<th>% of Phase</th>
<th>Non-competitive peak velocity (m·s⁻¹)</th>
<th>% of Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>COM X</td>
<td>1.19</td>
<td>100</td>
<td>.94</td>
<td>83</td>
</tr>
<tr>
<td>COM Y</td>
<td>.58</td>
<td>100</td>
<td>.15</td>
<td>62</td>
</tr>
<tr>
<td>COM Z</td>
<td>-.80</td>
<td>42</td>
<td>-.23</td>
<td>85</td>
</tr>
<tr>
<td>COM W</td>
<td>.82</td>
<td>95</td>
<td>.33</td>
<td>95</td>
</tr>
<tr>
<td>COM Z</td>
<td>-.09</td>
<td>78</td>
<td>-.17</td>
<td>58</td>
</tr>
</tbody>
</table>

**Table 2. Comparisons of peak linear velocity of tori’s COM in the anteroposterior [X: forward (+) and backward (-)], vertical [Y: up (+) and down (-)], and mediolateral [Z: uke’s right (+) and uke’s left (-)] directions and peak angular velocity of the trunk in the counterclockwise (CCW) and counterclockwise (CW) directions as well as occurrences of these variables as a percentage of kuzushi/tsukuri phase.**

<table>
<thead>
<tr>
<th></th>
<th>Competitive peak velocity (m·s⁻¹)</th>
<th>% of Phase</th>
<th>Non-competitive peak velocity (m·s⁻¹)</th>
<th>% of Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>COM X</td>
<td>.16</td>
<td>55</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>COM X</td>
<td>-.17</td>
<td>81</td>
<td>-.70</td>
<td>81</td>
</tr>
<tr>
<td>COM Y</td>
<td>.15</td>
<td>19</td>
<td>.80</td>
<td>45</td>
</tr>
<tr>
<td>COM Y</td>
<td>-.50</td>
<td>41</td>
<td>.074</td>
<td>73</td>
</tr>
<tr>
<td>COM Z</td>
<td>.39</td>
<td>32</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>COM Z</td>
<td>-.31</td>
<td>84</td>
<td>-.63</td>
<td>100</td>
</tr>
<tr>
<td>Trunk CCW</td>
<td>365 deg/s</td>
<td>17</td>
<td>105 deg/s</td>
<td>23</td>
</tr>
<tr>
<td>Trunk CW</td>
<td>-266 deg/s</td>
<td>52</td>
<td>-183 deg/s</td>
<td>47</td>
</tr>
</tbody>
</table>

NA = did not occur.
Kinematic analysis of Harai-goshi

Figure 2. Uke’s center of mass velocities (m·s⁻¹) along the (a) anteroposterior, (b) vertical, and (c) mediolateral axes during competitive and non-competitive conditions as a percentage of kuzushi/tsukuri (KT).

not move to uke’s right during the entire KT phase (Figure 3b).

Tori’s peak trunk angular velocities (TAV) were greater during the competitive throw (Table 2). Peak TAV representing a counterclockwise (CCW) movement of the hip segment relative to the shoulder segment, with the left hip and shoulder serving as the angle vertex, was found early at 17% and 23% of KT for the competitive and non-competitive conditions, respectively. Likewise, peak TAV representing a clockwise movement (CW) was found later in KT at 52% and 47% for competitive and non-competitive conditions, respectively (Figure 4).

Discussion

For this study the harai-goshi throw was executed for an ippon (perfect throw) by the same thrower (tori) under competitive and non-competitive conditions. It was expected to observe similarities in execution between conditions but it was immediately clear that there were some differences. A longer total time for the KT phase as well as a large number of directional changes in uke’s COM movement indicated a vigorous attempt by uke to defend the throw during the competitive situation. Not surprisingly, the defensive effort by uke is most likely the root of
One of the most important aspects of harai-goshi during KT is to pull uke forward. The data in this study substantiated this action with uke’s COM velocity moving forward along the anteroposterior axis during both competitive and non-competitive conditions. Differences occurred with how the pull was performed. The competitive condition indicated an initial movement by tori’s COM away from uke, followed by a movement towards uke, and then again away from uke. This pattern reflected the same pull-push-pull pattern via ground reaction force measurements found by Harter and Bates (1985). Even though the non-competitive condition indicated only a movement towards uke, it is likely that tori pulled uke forward in both conditions. During the competitive condition the resistance from uke required tori to pull with greater contribution from whole body momentum. Conversely, the non-competitive condition enabled tori to simultaneously pull and step into a stationary uke using less whole body momentum in the process. From a peak velocity standpoint, tori’s COM was found to be generally slower during the competitive condition. This was the result of uke’s defensive effort and large inertial component, resulting in an overall decrease in tori’s COM velocity. Moreover, uke’s peak COM velocity was found to be generally greater during the competitive condition indicating greater pulling power by tori during competition.

As mentioned previously, tori’s movement along
the anteroposterior direction during the competitive condition was consistent with the pull-push-pull ground reaction force pattern found by Harter and Bates (1985). The push force reflected tori’s backwards movement towards uke. In this study, both conditions exhibited peak COM velocities for tori in the backwards direction near 81% of KT. These findings suggest that regardless of condition there is an effort by tori to push backwards during the later stage of KT, namely tsukuri, to generate sweeping power and enhance collision with uke. This is also consistent with the findings of Pucsok et al. (2001) who found a significant relationship between anteroposterior ground reaction forces for the left (supporting) foot and the horizontal velocity of the sweeping (right) leg. Furthermore, it can be considered an advanced trait, since rear GRF forces during harai-goshi were found to be greater with advanced judo players (Yabune, 1994).

The defensive effort by uke was most influential on velocities along the vertical axis. During the competitive condition there was a large downward peak COM velocity (-80 m/s) measured for uke early in the KT phase (42%). This indicated an attempt by uke to quickly lower their COM to maintain stability and defend the throw, which was not seen during the non-competitive condition. This defensive posture likely influenced uke’s vertical velocity by allowing tori to generate large impulse against a resistance. Once the defense was breached uke’s upward velocity increased dramatically and continued to increase into the throwing phase (kake phase). Uke’s defensive posture during the competitive condition most likely affected forward velocity in the same manner which was also found to increase dramatically into the kake phase.

Despite uke’s defensive effort along the vertical axis, tori exhibited a similar upward to downward peak COM velocity pattern between conditions. This pattern represents tori’s orthodox throwing technique, where there was an attempt to pull uke upward then downward with a simultaneous leg sweep (Harrison, 1952; Kano, 1986; Kim and Shin, 1983; Koizumi, 1960). This procedure occurred much more quickly during the competitive condition with tori’s peak upward and downward velocities occurring at 19% and 41% of KT respectively compared to the non-competitive trial at 45% and 73% of KT respectively. Thus, the execution of the throw occurs faster during competition, however, due to the defensive efforts by uke the actual outcome of the throw is delayed, as represented by the longer total KT time.

Imamura et al. (2006) found a form of resistance to tori’s pulling efforts by uke during the harai-goshi throw. This resistance was found to be very small and occurred in the opposite direction of tori’s pulling right hand along the mediolateral direction. Because the resistance was too small to be considered an effective defense by uke, it was thought to be a key event during a successful throw, where the resistance froze uke into a stationary position which, in turn, allowed tori to execute an effective tsukuri and properly fit into the throw. The resistance in this study was represented by uke’s movement to their left or negative velocity. Both conditions demonstrated this movement during the KT phase, with the competitive condition showing only a small velocity in this direction. When comparing the two conditions it was evident that tori pulled uke to their right during competition. This directional movement illustrates a distinct difference on how the harai-goshi is performed when it is executed during movement and from a stationary position. Since the non-competitive condition did not demonstrate any movement of either tori or uke’s COM to the right, it can be assumed that movement to the left is more representative of the throw itself, while movement to the right is more representative of uke and tori’s movement before the throw is executed. This can be a likely explanation as to why uke’s resistance to their left was not more readily seen in velocity data of the competitive situation. More importantly, these findings suggest that competitive judo players may try to strategically create movements to uke’s right before executing harai-goshi.

General conclusions concerning the two conditions indicated that the competitive condition created greater velocities onto uke. Tori’s peak trunk angular velocity (TAV) was the only tori measurement that reflected this trend with the competitive condition eliciting greater TAV in both directional rotations. There were two distinct TAVs that occurred during KT. The first was a counterclockwise (CCW) TAV that represented tori stepping into the throw as the hips begin to turn 180 degrees. The sec-

![Trunk Angular Velocity](image-url)

**Figure 4.** Trunk angular velocities (deg/s) during competitive and non-competitive conditions as a percentage of kuzushi/tsukuri (KT), with the counterclockwise direction considered positive and clockwise considered negative.
ond was a clockwise (CW) TAV that represented the subsequent rotation of the upper body 180 degrees (recall that the harai-goshi requires tori to turn 180 degrees). The CW TAV also includes the execution of the sweep. There was a third smaller TAV in the CCW direction which was likely created by the collision with uke’s body.

Though all TAV measurements were greater for the competitive condition, the patterns were the same. The CCW to CW pattern indicated an attempt by tori to pre-stretch muscles in the CCW direction to enhance muscle contraction in the CW direction. It is conceivable that a greater pre-stretch of muscles can lead to greater contractile forces in this case. Uke’s defense may also play a role in this process. Since tori attempts to rotate against a greater resistance a greater pre-stretch can be attained. This may also necessitate the need for the slight resistance by uke along the mediolateral axis, which was found in this study as well as Imamura et al. (2006). Just as the resistance may improve tori’s ability to execute tsukuri, it may also enhance the pre-stretch of tori’s trunk muscles to improve contractile forces during CW rotations. If this resistance theory is true, a judo player should seek to find the point at which the opponent’s resistance is minimal enough to overcome yet strong enough to enhance pre-stretch of muscles and subsequent kuzushi/tsukuri in the form of body collision.

**Conclusion**

As expected, a number of kinematic characteristics for the harai-goshi throw were similar between competitive and non-competitive conditions. It was clear, however, that a number of differences were present, particularly in the timing and magnitude of certain characteristics. Most, if not all of the differences, can be associated with the movement of tori and uke prior to the throw and the defensive efforts of uke, both of which occurred during the competitive condition. It was deduced that movement towards uke’s right can be an effective precursor to the harai-goshi throw and should be considered as an ideal time to execute the throw. In general, COM directional velocity patterns were similar between conditions and consistent with the pull-push-pull pattern found by previous kinetic studies. Trunk rotation velocity patterns were also similar between conditions but magnitudes were much larger during competition. There are indications from this study and previous studies that a defensive effort by uke allows for a more effective kuzushi and tsukuri. From biomechanics perspective, larger inertial characteristics from uke would conceivably lead to greater generation of impulse by tori, leading to greater changes in the throw’s velocity.

**References**


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Key points

- COM directional velocity patterns were similar between conditions and were consistent with the findings from previous kinetic studies.
- Uke’s defensive efforts during the competitive condition created differences in timing and magnitude of peak COM and TAV velocities.
- Mediolateral COM movement towards tori’s pulling (left) hand can be an ideal set-up movement prior to execution.
- It is thought that the counterclockwise rotation aids in producing a pre-stretch of trunk muscles which helps to create greater trunk rotation power.

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