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Research article

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 anterposterior and mediolateral directions. In the anteroposterior direction,

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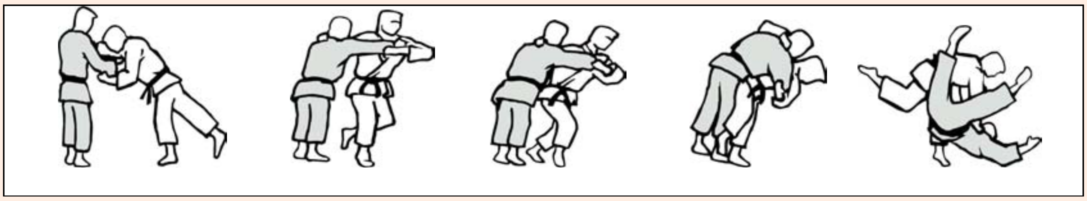

Figure 1. Illustration of the *hara-goshi* throw with the first four pictures describing the *kuzushi/tsukuri* phase (Source: Imamura et al., 2006).

uke depicted forward momentum during both the *kuzushi* and *tsukuri* phases indicating a pulling force from *tori*. *Uke's* momentum dropped significantly between the *tsukuri* and *kake* phases indicating a collision between the two bodies. In the mediolateral (sideways) direction there was a propensity for *uke* to move away from the direction of *tori's* throwing side, or right hip, during the *kuzushi* phase. 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 *kuzushi/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

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.

	Competitive peak velocity ($m \cdot s^{-1}$)	% of Phase	Non-competitive peak velocity ($m \cdot s^{-1}$)	% of Phase
COM X	1.19	100	.94	83
COM Y	.58	100	.15	62
COM Y	-.80	42	-.23	85
COM Z	.82	95	.33	95
COM Z	-.09	78	-.17	58

two conditions. The digitized data were smoothed using a 4^{th} 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

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.

	Competitive peak velocity ($m \cdot s^{-1}$)	% of Phase	Non-competitive peak velocity ($m \cdot s^{-1}$)	% of Phase
COM X	.16	55	NA	
COM X	-.17	81	-.70	81
COM Y	.15	19	.80	45
COM Y	-.50	41	0.74	73
COM Z	.39	32	NA	
COM Z	-.31	84	-.63	100
Trunk CCW	365 deg/s	17	105 deg/s	23
Trunk CW	-266 deg/s	52	-183 deg/s	47

NA = did not occur.

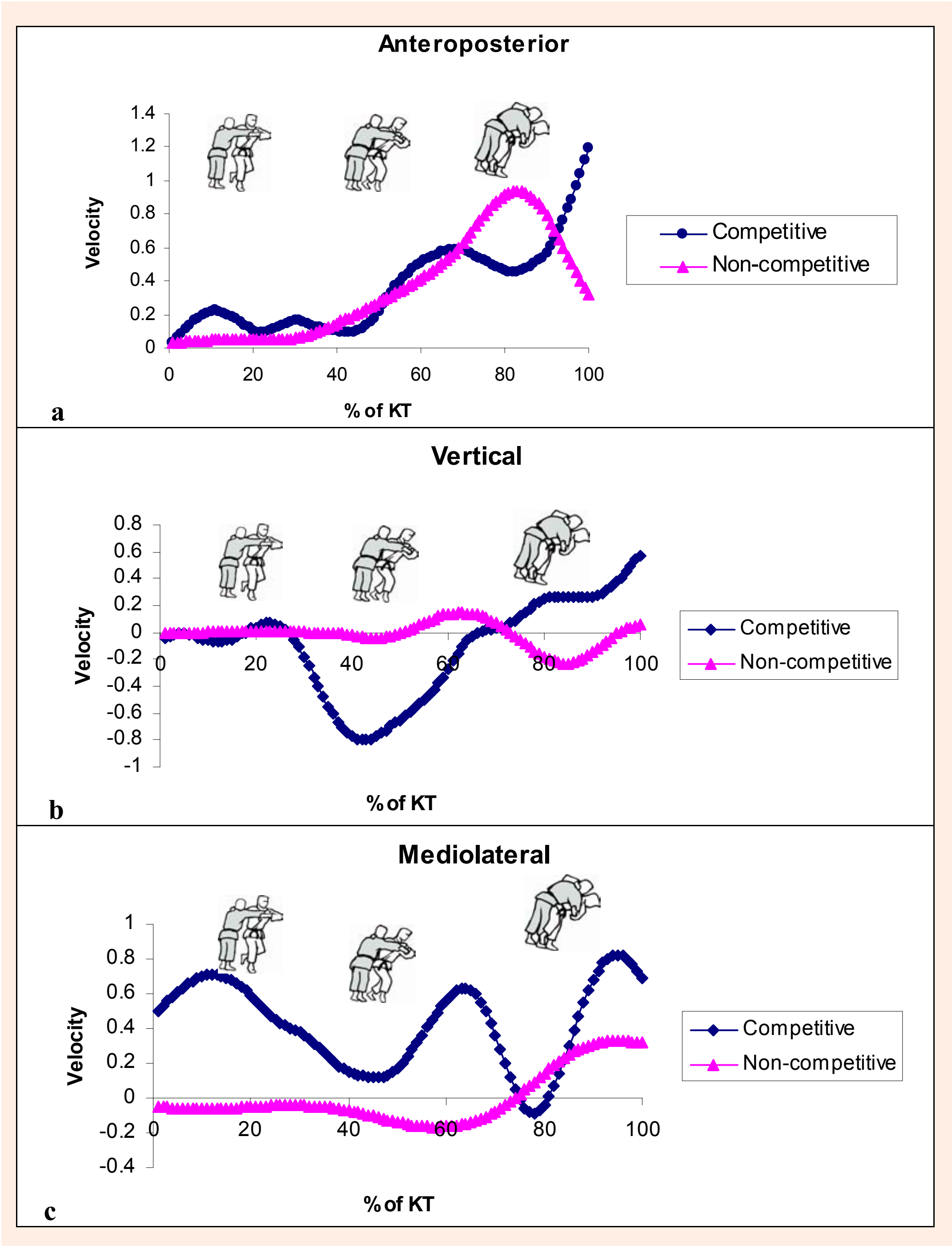

Figure 2. ***Uke's*** **center of mass velocities (m·s^{-1}) along the (a) anteroposterior, (b) vertical, and (c) mediolateral axes during competitive and non-competitive conditions as a percentage of *kuzushi/tsukuri* (KT).**

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

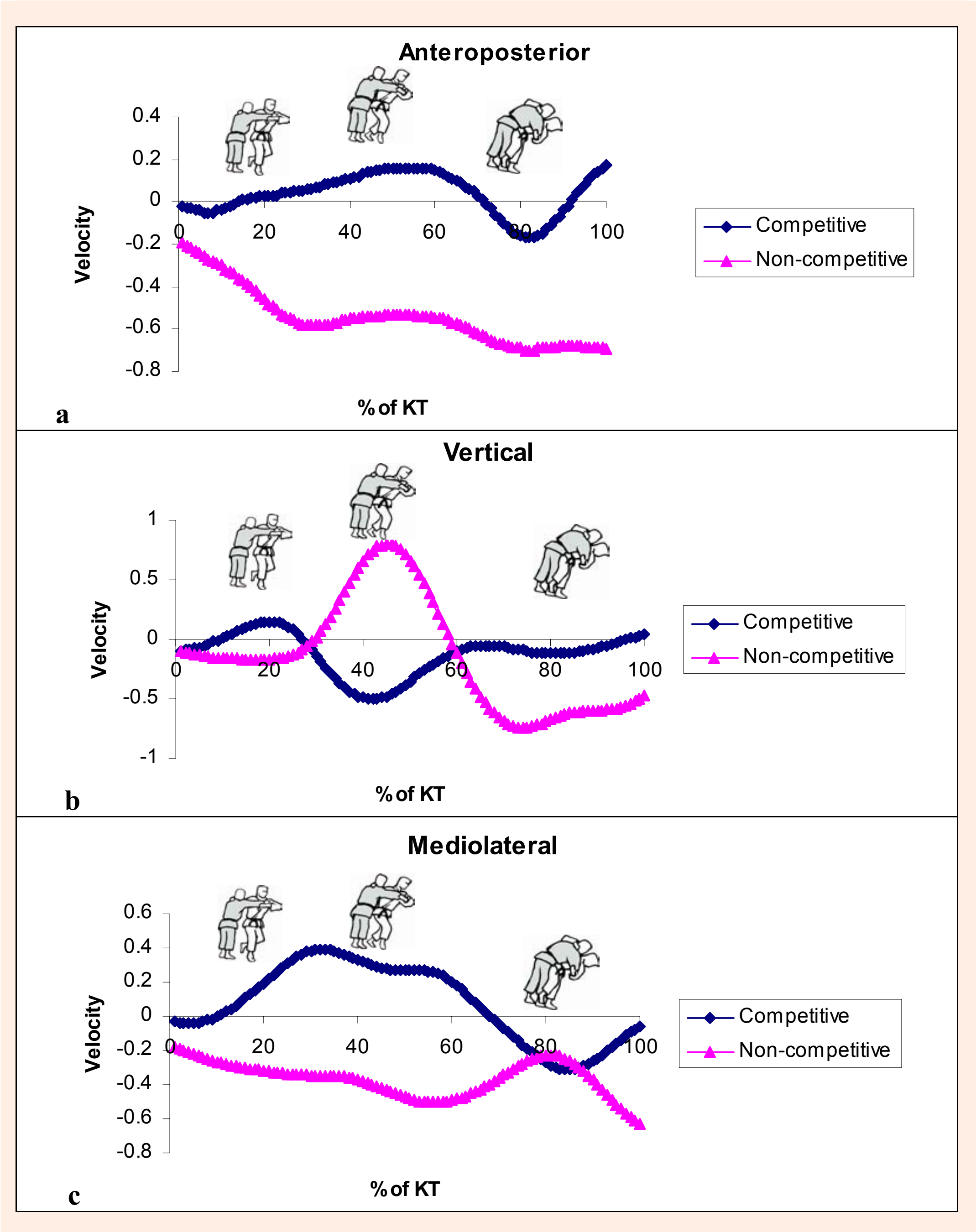

Figure 3. ***Tori's*** **Center of mass velocities (m·s^{-1}) along the (a) anteroposterior, (b) vertical, and (c) mediolateral axes during competitive and non-competitive conditions as a percentage of *kuzushi/tsukuri* (KT) phase**

a number of kinematic differences between conditions.

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

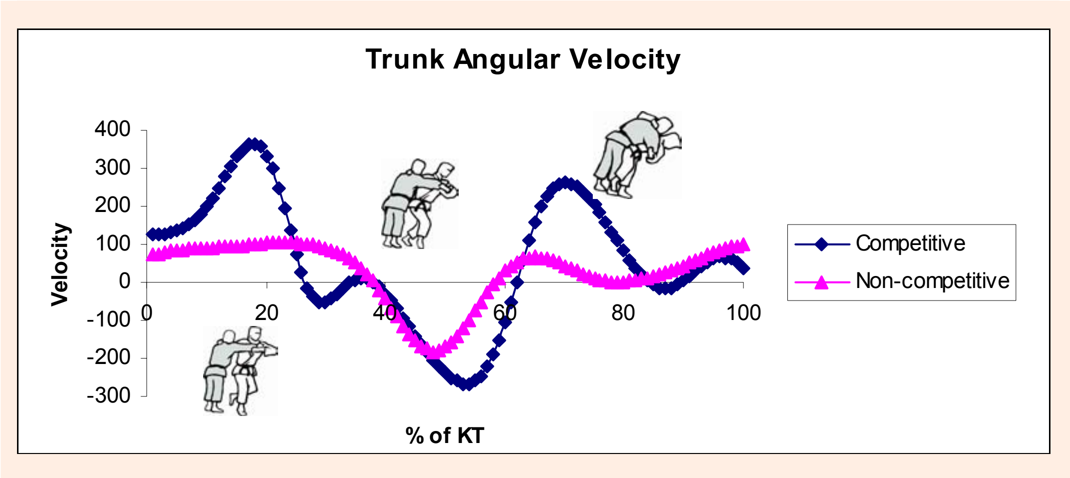

Figure 4. Trunk angular velocities (deg/s) during competitive and non-competitive conditions as a percentage of *kuzushi/tsukuri* (KT), with the counterclockwise direction considered positive and clockwise considered negative.

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 second 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.

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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 execuation.
- 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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