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Nanatsu-no-kata, *Endō-no-kata*, and *Jōge-no-kata* —A pedagogical and qualitative biomechanical evaluation of Hirano Tokio's *kuzushi* (unbalancing) concept as part of skill acquisition for throwing techniques in *Kōdōkan jūdō*

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ORIGINAL PAPER

Abstract

Hirano Tokio (1922-1993) was a talented *jūdō* champion who developed his own pedagogical approach towards teaching and practicing *kuzushi* (unbalancing) and *tsukuri* (preparation), two critical skills for successfully applying *jūdō* throws. In his approach, Hirano emphasizes the use of rotational unbalancing preceded by strategic movements that mimic water waves. No biomechanical analysis of Hirano's wave system has previously been attempted. The purpose of this paper is to provide a detailed survey of Hirano's didactic system comparing it with traditional *Kōdōkan* teachings, and to assess its biomechanical foundations. The fluid dynamic modeling of the several kinds of waves proposed by Hirano is mathematically complicated and heavily relies on Boussinesq differential equations. Given the involvement of numerous parameters in determining the hydrodynamic behavior of water (depth, period of waves, saliency, temperatures, currents, shape of the coastal line, water density, wind) which are absent in the surroundings of a pair of two *jūdōka* moving indoors on a *tatami*, Hirano's system appears limited to a mere visualization and metaphysical interpretation of *jūdō*. The lack of empirical and experimental data available obtained in large groups of students taught according to Hirano's approach make it so far impossible to conclude whether it facilitates *kuzushi* and *tsukuri* skill acquisition. Ultimately Hirano's wave-based *kuzushi/tsukuri* does not alter the biomechanical analysis previously proposed by Sacripanti, as it still is all about general action invariants aimed to close the distance between both opponents, to break the opponent's symmetry, and to apply one of the infinite options to achieve this.

Keywords: Hydrodynamics; Jigoro Kano; judo; kata; kinematics; kuzushi; martial arts

Nanatsu-no-kata, *Endō-no-kata*, y *Jōge-no-kata* — Una evaluación pedagógica y biomecánica cualitativa del concepto de *kuzushi* (desequilibrio) de Hirano Tokio como parte de la adquisición de habilidades de proyección en el *Kōdōkan jūdō*

Resumen

Hirano Tokio (1922-1993) fue un talentoso campeón de *jūdō* que desarrolló su propia aproximación pedagógica a la enseñanza y a la práctica del *kuzushi* (desequilibrio) y del *tsukuri* (preparación), dos habilidades decisivas para la aplicación exitosa de las proyecciones de *jūdō*. En su enfoque, Hirano enfatiza la utilización de un desequilibrio rotacional precedido de movimientos estratégicos que imitan olas de agua. Hasta la fecha aún no se ha realizado un análisis biomecánico del sistema de olas de Hirano. El objetivo de este artículo es proporcionar una visión detallada del método didáctico de Hirano, compararlo con las enseñanzas tradicionales del *Kōdōkan*, y evaluar sus bases biomecánicas. El modelado de la dinámica de los fluidos en los diversos tipos de olas propuestas por Hirano es matemáticamente complicado y se fundamenta en gran medida en las ecuaciones diferenciales de Boussinesq.

Nanatsu-no-kata, *Endō-no-kata* e *Jōge-no-kata* — Uma avaliação pedagógica e biomecânica qualitativa do conceito de *kuzushi* (desequilíbrio) de Hirano Tokio como parte da aquisição das habilidades de projeção no *Kōdōkan jūdō*

Resumo

Hirano Tokio (1922-1993) foi um talentoso campeão de *jūdō* que desenvolveu a sua própria aproximação pedagógica no ensinamento e na prática do *kuzushi* (desequilíbrio) e do *tsukuri* (preparação), das habilidades decisivas para a aplicação das projeções do *jūdō*. No seu enfoque, Hirano enfatiza a utilização de um desequilíbrio rotacional precedido de movimentos estratégicos que imitam ondas. Até ao momento, não se realizou nenhuma análise biomecânica do sistema de ondas de Hirano. O objetivo deste artigo é de proporcionar uma visão detalhada do método didático de Hirano, compará-lo com os ensinamentos tradicionais do *Kōdōkan* e avaliar as suas bases biomecânicas. O modelo da dinâmica de fluidos nos diversos tipos de ondas propostas por Hirano é matematicamente complicado e fundamenta-se, em

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Debido a la implicación de numerosos parámetros en la determinación del comportamiento hidrodinámico del agua (profundidad, frecuencia de las olas, altura, temperaturas, corrientes, forma de la línea costera, densidad del agua, viento), los cuales están ausentes en el entorno de dos *jūdōka* en movimiento bajo techo sobre un tatami, el sistema de Hirano parece estar limitado a una mera visualización y a una interpretación metafísica del *jūdō*. La ausencia de datos empíricos y experimentales obtenidos en grupos numerosos de estudiantes entrenados de acuerdo al método de Hirano imposibilita concluir si este facilita la adquisición de las habilidades del *kuzushi* y del *tsukuri*. En último término el *kuzushi/tsukuri* de Hirano, basado en olas, no modifica el análisis biomecánico propuesto por Sacripanti, ya que de lo que se sigue tratando es de acciones generales invariantes orientadas a reducir la distancia entre ambos oponentes, romper la simetría del oponente, y aplicar una de las infinitas opciones para lograrlo.

Palabras clave: Hidrodinámica; Jigoro Kano; judo; kata; kuzushi; cinemática; artes marciales.

grande medida, nas equações diferenciais de Boussinesq. Devido à implicação de numerosos parâmetros na determinação do comportamento hidrodinâmico da água (profundidade, frequência das ondas, altura, temperaturas, correntes, forma da linha costeira, densidade de agua, vento), os quais estão ausentes em torno de dois *jūdōka* em movimento de baixa técnica num tatami, o sistema de Hirano parece estar limitado a uma mera visualização e a uma interpretação metafísica do *jūdō*. A ausência dos dados empíricos e experimentais obtidos em grupos numerosos de estudantes treinados de acordo com o método de Hirano impossibilita concluir se este facilita a aquisição das habilidades do *kuzushi* e do *tsukuri*. Este termo de *kuzushi*/*tsukuri* de Hirano, baseado nas ondas, não modifica a análise biomecânica proposta por Sacripanti, já que não trata de ações gerais invariáveis orientadas a reduzir a distância entre ambos os oponentes, romper com a simetria do oponente e aplicar uma das infinitas opções para consegui-lo.

Palavras-chave: Hidrodinâmica; Jigoro Kano; judo; kata; kuzushi; cinemática; artes marciais.

1.- Introduction[1]

Kōdōkan Jūdō 講道館柔道 is a Japanese form of pedagogy, created by Kanō Jigorō 嘉納治五郎 (1860-1938). Its practical study consists of *randori* 乱取 (free exercise) and ten different (*Kōdōkan*) *kata* 形 (predetermined and choreographed physical exercises). The main building blocks of *randori* and *kata* are *nage-waza* 投技 (throwing techniques) and *katame-waza* 固技 (controlling techniques); in addition, there are *atemi-waza* 当身技 (striking techniques to the body's vital points) which are permitted in *kata* only, and *kappō* 活法 (resuscitation methods) (De Crée & Jones, 2009; Kanō, 1931, Kōdōkan, 1986; Mifune, 1956).

Many *jūdō* techniques originate in *jūjutsu*, but have been refined or modified for safety and efficiency, though more recently others have been newly developed or imported from other combat sports, in order to potentially increase a competitor's scoring chances during *jūdō* contests. Understanding the fundamental principles of those techniques is instrumental to fully capture how mastering practical *jūdō* is underpinned by its maxims of *Sei-ryoku saizen katsuyō* 精力最善活用 (Optimal use of energy) (usually abbreviated to *Sei-ryoku zen'yō* 精力善用) and *Jū yoku gō o sei suru* 柔能く剛を精する (Non-resistance overcomes force) (Kanō, 2006).

In adherence to those principles, the *Kōdōkan*'s teaching approach typically explains that a *jūdō* throw consists of three sequential phases[2]: 1. *kuzushi* 崩し (unbalancing), 2. *tsukuri* 作 (preparation), and 3. *kake* 掛け (execution). Thus, these three elements are the focus of technical attention by teachers and *jūdō* books (Kōdōkan, 1986; Kudō, 1967; Mifune, Kudō, & Matsumoto, 1955-56; Sacripanti, 1987).

One of the most remarkable teachers of *jūdō* in Western Europe during its earlier stages of evolution was Hirano Tokio 平野時男 (1922-1993) (Figure 1). Hirano had arrived in Europe in 1951 and after a brief stay in Germany and France, became a significant propagator of *jūdō* in the Netherlands and Belgium (Geels, 1979; Tegelaar, 2012a; van Gasse, 2009). Hirano argued that a *jūdō* throw in fact has four phases, most commonly: 1. *kumu* 組む (gripping), 2. *tsukuri* 作り

[1] See "Notes" section.

[2] De Crée and Edmonds (2012) have previously argued that this is in fact incorrect, and that seven different phases can be recognized: 1. *Debana* 出端 (the opportunity and optimal moment to succeed), 2. *Tsukuri* 作り (preparation), 3. *Kumu* 組む (gripping), 4. *Kuzushi* 崩し (unbalancing), 5. *Kake* 掛け (execution), 6. *Nageru* 投げる (throwing), and 7. *Zanshin* 残心 (the follow through, literally, the "continuation of the spirit"). The order of phases #1 through #3 may change depending on the specific circumstance.

(preparation), 3. *kake* 掛け (execution), and 4. *nageru* 投げる(throwing), and #1 and #2 should be reversed thus *tsukuri* preceding *kumu* (Chen & Chen, 2002).

Later, Hirano also developed three formal choreographic series (*kata*) to illustrate his conceptual approach of *kuzushi* to *jūdō* throws (Tegelaar, 2012a). Most notable in his philosophy and pedagogy was the incorporation of different types of self-defined waves, and how those natural occurring phenomena could form the basis of one's dynamic *jūdō* game and strategy.

Figure 1. Hirano Tokio 平野時男 (1922-1993), at the time *Kōdōkan* 6th *dan* (later 8th *dan*), during a visit to the author's *jūdō* club, the *Royal Jūdō & Jūjutsu Academy Bushidō-Kwai Mechelen* (Belgium) in the early 1950s (probably 1952 or 1953).

As explained, Hirano Tokio was a phenomenally gifted champion and fighter, with all the accompanying attributes (physique, physiology, strategic insight, psychological determination) (Chen & Chen, 2002; Tegelaar, 2012a). His mastership of the local Western languages of the countries he taught in was, however, only minimal (Tegelaar, 2012a). For those reasons, transferring such a comprehensive and different model of *jūdō* to the point that his pupils would acquire the full extent of its resulting possibilities presented a most challenging task. When considerable communication problems exist in *jūdō*, whether it is because of tangible language issues or because students due to their cultural background lack a deeper understanding of the phenomenological basis that underpins one's didactic strategies, students tend to focus on what they think they see and try to copy it. Often though, in *jūdō* what can be seen is only the proverbial "tip of the iceberg", hence why the contribution to one's development of technical insight by copying the apparent mechanical movements will have limited success (Kanō, 2011).

It is the purpose of this paper to clarify Hirano's conceptual view of *kuzushi* and to compare Kanō's and Hirano's pedagogical approach to learning and applying *kuzushi* in *jūdō* throws from both a historic and qualitative biomechanical perspective.

2. Who was Hirano Tokio ?

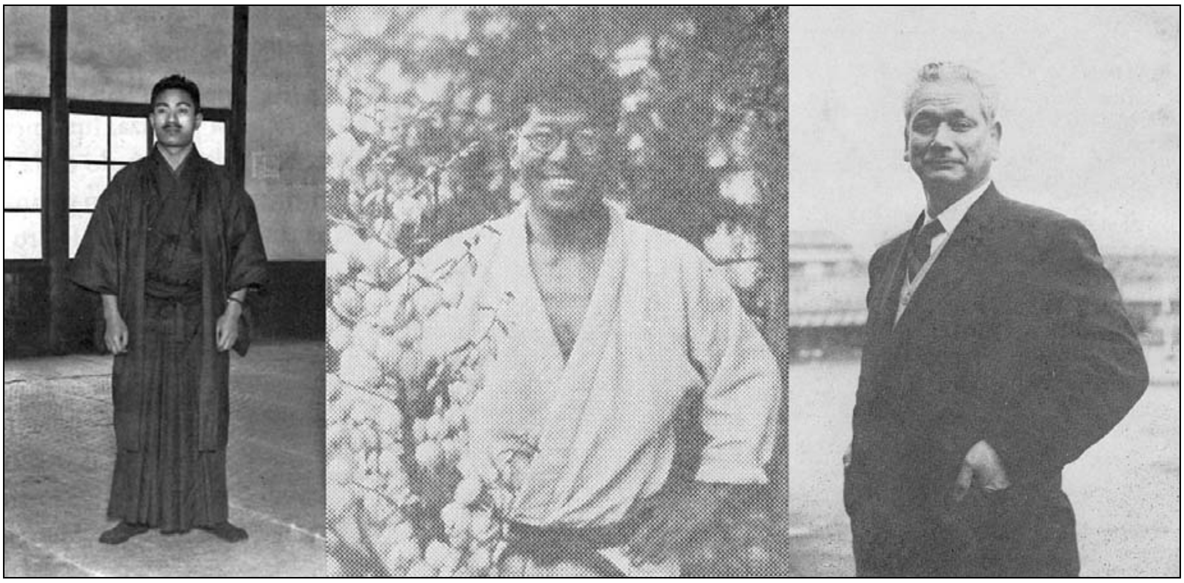
Hirano Tokio was born on 6 August 1922 in Sumoto 洲本市 on Awaji-shima 淡路島 (Awaji Island), an island off the coast of the seaport city of Kōbe 神戸 in Hyōgo 兵庫県 Prefecture (Hirano, 1972a, 1985a). He took up *jūdō* at age 12, and in November 1936 just three months after his 14th birthday he obtained his black belt 1st *dan*. In 1937 he entered the *Heian Chūgakkō*[3] 平安中学校 (Heian Junior Middle-School) in Kyōto (Hirano, 1972a, 1985a). While there, he became an *uchi-deshi* 内弟子 (in-living apprentice) of Fukushima Seizaburō 福島清三郎 (1890-1950) (Figure 2), who was later (in 1948) promoted to 9th *dan*, and who was a famous *bujutsu*[4] and *jūdō* teacher at the *Dai Nippon Butokukai* 大日本武徳会 (Great Japan Martial Virtues Association) and a professor at the *Budōsenmongakkō* 武道専門学校 (Martial Arts Vocational School) or *Busen* (Hirano, 1972a, 1985a; Shishida, 1994). In 1936 Fukushima had built an additional 80-*tatami dōjō* (a training hall the size of 80 Japanese mats, each mat having a surface of approximately 2m²), the *Gihōkai* 義方会 where he taught some of his best students. During the same time Hirano also studied *jūdō* under

[3] Since April, 2008 renamed *Ryūkoku Daigaku Fuzoku Heian Chūgakkō* 龍谷大学付属平安中学校 (Ryūkoku University Heian Junior High School).

[4] Fukushima Seizaburō-*sensei* was also qualified in *koryū jūjutsu* 古流柔術 (traditional *jūjutsu*), specifically in *Kyūshin-ryū jūjutsu* 扱心流柔術.

Morishita Isamu 森下勇[5] (1901-1985) (Figure 2), who was the principal of the *Busen* from June 1935 to March 1942, and who also was on the *jūdō* teaching faculty at the same institution and at the *Butokukai*; Morishita too was later (in 1962) promoted to 9th *dan*. While still at Kyōto, Hirano later also became an *uchi-deshi* to Ushijima Tatsukuma 牛島辰熊 (1904-1985) (Figure 2), famous for his competitive achievements and who too was a *Busen jūdō* teacher and future (1984) 9th *dan*-holder[6].

Figure 2. Hirano Tokio's 平野時男 (1922-1993) three legendary Kyōto *jūdō* instructors at the *Heian Chūgakkō* 平安中学校 (Heian Junior Middle-School), the *Dai Nippon Butokukai* 大日本武徳会 (Great Japan Martial Virtues Association), and the *Budōsenmongakkō* 武道専門学校 (Martial Arts Vocational School) or *Busen*, from left to right: Fukushima Seizaburō 福島清三郎 (1890-1950), Morishita Isamu 森下勇 (1901-1985), and Ushijima Tatsukuma 牛島辰熊 (1904-1985), all three later at different points in time promoted to 9th *dan*. Image of Morishita Isamu reproduced from Hirano (1972a, p. 68), with permission.



In 1941 Hirano graduated from *Heian Chūgakkō* and entered Takushoku University 拓殖大学 in Tōkyō (Hirano, 1985a). By then he had already developed his trademark *tai-otoshi* 体落 (body drop) throwing technique (Hirano n.d.[b], 1985a). Ushijima, one of Hirano's former Kyōto teachers and himself a formidably *jūdō* competitor, had been requested to become *jūdō* instructor of the Imperial Guard in Tōkyō. While accepting this job he decided to combine it with instructorships at a number of universities in Tōkyō amongst which also Takushoku University. In this way Hirano who was studying there was able to continue his *jūdō* training with Ushijima. In October 1941 at the age of 19, Hirano, by then a superb *jūdō* technician holding the rank of 4th *dan*, entered the half-yearly *kōhaku-shiai* 紅白試合 (red and white *jūdo* contests) at the *Kōdōkan* 講道館 in Tōkyō, where in less than half an hour time he defeated a line-up of 15 *yodan* (4th *dan*) holders, each with a different technique. After this unprecedented and hitherto unseen *batsugun* 抜群 (extraordinary performance)[7], Hirano received instant promotion to the *jūdō* rank of *godan* (5th

[5] The correct pronunciation of Morishita-*sensei*'s first name is not 100% certain. The *kanji* 勇 in 森下勇 is usually pronounced either Isamu or Yū. However, rare uncommon other pronunciations exist too. In this case, we believe the pronunciation likely to be 'Isamu'.

[6] Ushijima Tatsukuma too had a background in *Kyūshin-ryū jūjutsu* 扱心流柔術, similarly to Fukushima Seizaburō. He was a double prewar All Japan Championships winner, runner-up of the first (1929) *Shōwa Tenran Shiai* 昭和天覧試合 (Contest Before the *Shōwa* Emperor), and probably most famous as the main *jūdō* teacher of the legendary Kimura Masahiko 木村政彦 (1917-1993).

[7] The achievement was unprecedented and never repeated for such a high rank, however, there do exist *jūdōka* who defeated even more opponents but at a lower rank. Kaminaga Akio 神永昭夫 (1936-1993), at that time 18 years old, during the 1954 *kōhaku shiai* defeated 19 opponents and received *batsugun* instant promotion from 1st to 3rd *dan*. During the spring *kōhaku shiai* of the next year he defeated 12 consecutive opponents thus again receiving *batsugun* promotion from 3rd to 4th *dan*. Kaminaga, contrary to Hirano, was a heavy-weight *jūdōka*. In the history of *Kōdōkan kōhaku shiai* three

dan) (Chen & Chen, 2002; Hirano, 1972a, 1985a). Furthermore, Hirano won multiple *jūdō* titles in his native Japan, including the *Daigaku Kōsen Kojinsen* 大学高専個人戦 (All Japan Collegiate Jūdō Championships) (1941 and 1942) as well as the 1948 third *Zen Koku Kokumin Taiiku Taikai Zen Nihon* 全国国民体育大会全日本 (All Japan National Athlete Jūdō Championships) (Hirano, 1985a). In 1946 he became chief-*jūdō*-instructor of the Imperial Guard (*Kōgū Keisatsu Jūdō Shihan* 皇宮警察柔道師範), and the next year he also was promoted to the rank of *rokudan* (6th *dan*) (Hirano, 1985a).

A heavily disputed loss against Ōsawa Yoshimi[8] 大沢慶巳 (born in 1927) during the the final of the Tōkyō Championships, allegedly due to the lack of impartiality of referee Mifune Kyūzō 三船久蔵 (1883–1965), 10th *dan* of the *Kōdōkan*, infuriated Hirano who, in consequence, decided to leave Japan. He went on to play a massive role in the promulgation of *jūdō* in Europe (especially, in Belgium, France, Germany, and the Netherlands). In 1948 Hirano arrived in Europe via Antwerp in Belgium and settled in Germany, where he became a *jūdō* instructor at the recently (1947) founded *Deutsche Sporthochschule Köln* (German Sport University Cologne). His wife and daughter joined him in Germany in February 1952. In February 1953, he became the technical director of the *Belgische Amateur Judo Associatie* (BELAJA) in Flanders, and after its merger with the Walloon *Association Fédérale Belge de Judo et Ju Jitsu* (AFBJJ) into the *Belgian Judo Federation* (BJB) on 18 October 1959, he would share the same position with Abe Ichirō, at the time also 6th *dan* and technical director of the AFBJJ. In 1964, Hirano was promoted by the *Kōdōkan* to 7th *dan*, and at the end of June 1966 he left Europe with his family to return to Japan. In 1967 he became *jūdō* instructor at Takushoku University, a position he held until 1982 (Hirano, 1985a). Hirano Tokio, then 8th *dan*, passed away on 26 July 1993 due to cirrhosis and cancer of the liver.

3. The history of *kuzushi* in *Kōdōkan jūdō*

Kanō-*shihan* created *Kōdōkan jūdō* in 1882 although it would take many further decades to consolidate his *jūdō* into a refined system of physical and mental education and self-defense (Kanō, 1932; Kōdōkan, 1986; Maruyama, 1939; Oimatsu, 1976). Kanō did not create his *jūdō* from scratch. Rather, he largely compiled material from other existing Japanese martial arts schools molding it into something that was more than just a practical art for self-defense. The two main schools where he obtained his ideas were *Kitō-ryū* 起倒流 and *Tenjin Shinyō-ryū* 天神真楊流 both schools of traditional Japanese *jūjutsu* 柔術 (the art of giving way), and created in the early 17th and 19th century, respectively (De Crée, 2014; De Crée & Jones, 2009; Kanō, 2006; Kanō, 1932; Kōdōkan, 1986; Maruyama, 1939; Oimatsu, 1976).

These two schools were very different, with *Tenjin Shinyō-ryū* being Kanō's main inspiration for *atemi* 当見 (strikes aimed at the body's vital points) and *katame-waza* 固技 (controlling techniques), whereas *Kitō-ryū* delivered most of Kanō's inspiration for throws and for his concept of *Jū yoku gō o sei suru* 柔能く剛を精する (Non-resistance overcomes force), although the latter can be traced even further towards the roots of historic *sumō* 相撲 wrestling (De Crée, 2014; Kanō, 2006). More specifically, Kanō also obtained his concept of *kuzushi* or "breaking balance" from *Kitō-ryū jūjutsu*, where it is dealt with in the traditional *makimono* 巻物 (scroll) *Hontai-no-maki* 本體之巻 (Scroll of Proper Body Position) and *Chi-no-maki* 地之巻 (Scroll of the Earth) (Figure 3).

While practicing *Kitō-ryū jūjutsu* the young Kanō realized, around 1885, during *midare-dori*[9] training with his master Iikubo Kōnen 飯久保恒年先生[10] the important role of *breaking one's*

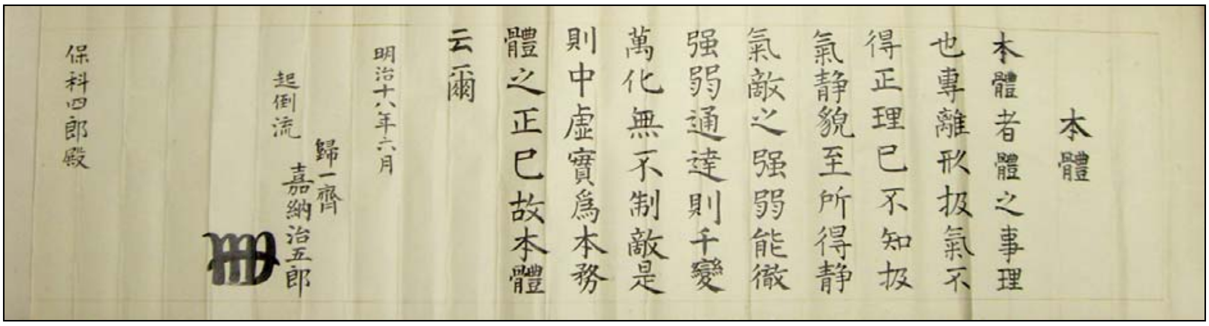
people have defeated even more opponents in a line-up than Kaminaga. Ōuchi Ken'ichi and +100 kg heavy-weight *jūdōka* Ōnoko Arata 大鋸新, in 1958 and 2003, respectively, defeated 24 opponents without a single break in-between contests. The absolute record is held by Yoshino Kentarō (*kanji* not known), who during the 1934 *kōhaku shiai* defeated a line-up of 27 consecutive opponents hence like Kaminaga receiving *batsugun* promotion from 1st to 3rd *dan*, and also following up this achievement by defeating another 11 opponents the year after and receiving *batsugun* promotion from 3rd to 4th *dan*.

[8] Ōsawa Yoshimi currently, since January 2006, is a rare *Kōdōkan* 10th *dan*-holder.

[9] *Midare-dori* was *Kitō-ryū jūjutsu*'s equivalent of what we know today in *jūdō* as *randori*. *Kitō-ryū kata* were often practiced in *midare-dori* form, thus with the opponent seriously resisting *tori* and avoiding the latter establishing control over him (De Crée, 2014).

opponent's balance to effect better throwing techniques and ensure a more efficacious execution of these techniques. This is particularly so between two fighters with similar physique and force. In such cases breaking the balance of one's adversary is crucial to obtain results (Sacripanti, 2012b, p. 6).

Figure 3. A *Hontai-no-maki* 本體之巻 (Scroll of Proper Body Position) scroll issued by Kanō Jigorō-*shihan* in his function as holder of *menkyo kaiden* 免許皆伝 (Holder of the License of Full Transmission) of *Kitō-ryū Takenaka-ha* 起倒流竹中派 branch to Hoshina Shirō 保科四郎 (former name of Saigō Shirō) in the 6th month of the 18th year of Meiji 明治 (June 1885) (From the library of Lance Gatling, Tōkyō, reproduced by kind permission, all rights reserved – February 2009).



Thus, even in classical Japanese *jūjutsu* one is taught how to use to one's advantage the condition in which the body of an opponent has lost equilibrium, the so-called *kuzure-no-jōtai* 崩れの状態 (state of imbalance). During dynamic combat situations, this balance is sometimes spontaneously lost by one's opponent, while at other times one will positively cause the destruction of the opponent's balance hence putting him into a particularly vulnerable posture (Kanō, 2006; Sacripanti, 2012b, p. 6).

When between 1903 and 1915 the very first *jūdō* books in Japanese appeared, such as "*Jūdō*" by Uchida Ryōhei 内田良平 (1903) and "*Jūdō Tai'i*" 柔道大意 (A synopsis of *jūdō*) by Arima Sumitomo 有馬純臣 (1904), the concept of *kuzushi* was already very developed in *Kōdōkan jūdō* and hence explained to the reader. The same is true for the first *jūdō* books in Western languages such as Arima Sumitomo's 1906 book in English "*Jūdō. Japanese physical culture. Being a further exposition of jujitsu and similar arts*" (Arima, 1906), and Sasaki Kichisaburō's 佐々木吉三郎 book in Hungarian "*Djudo. A Japán dzsiu-dzsicu töké-letesitett módszere*" (The Japanese jūjutsu skills method) (Sasaki, 1907), or Yokoyama Sakujirō 横山作次郎 and Ōshima Eisuke's 大島英助 1908 book "*Jūdō kyōhan*" 柔道教範 (Learning text of jūdō) in Japanese (Yokoyama & Ōshima, 1915) and its 1911 French translation by Yves Le Prieur (Yokoyama and Ōshima, 1911).

4. Kanō Jigorō's concept of *kuzushi* in *Kōdōkan jūdō*

The first known record of Kanō Jigorō discussing *kuzushi* was in his famous May 1889 lecture[11] for the *Dai Nippon Kyōikukai* 大日本協育会 in Hitotsubashi Kanda 一橋神田 (De Crée, 2014; Kanō, 2006). Therein Kanō mentioned that he had experienced *kuzushi* through the *Kitō-ryū* school, while also realizing that the *Kitō-ryū kata* from a theoretical point of view were far more difficult than the often more directly practical *kata* of *Tenjin Shin'yō-ryū*, *jūdō*'s other parent school (Kanō, 1932, 2006; Maruyama, 1939; Oimatsu, 1976). The concept was then more formally introduced into *Kōdōkan jūdō* in writing in the June 1927 issue of the *Kōdōkan* magazine *Sakkō* 作興. In subsequent years, it was then extensively dealt with on a regular basis in the *Kōdōkan*'s old

[10] Later, in *Kōdōkan* writings Iikubo Kōnen-*sensei* 飯久保鍬吉恒年先生 started being referred to as "Iikubo Tsunetoshi", for as of yet still unknown reasons. Iikubo himself was a *deshi* of Takenaka Tetsunosuke 竹中鉄之助一清 and taught at the *Kōbusho* 講武所, which was the Tokugawa clan's *budō* training place as well as at the *Eishōji* 永昌寺 temple in Tōkyō, where Kanō had started his *Kōdōkan* school of *jūdō* (De Crée, 2014).

[11] The exact date was May 11th, 1889 (Kanō, 2006, Kanō-sensei Denki Hensankai, 1984).

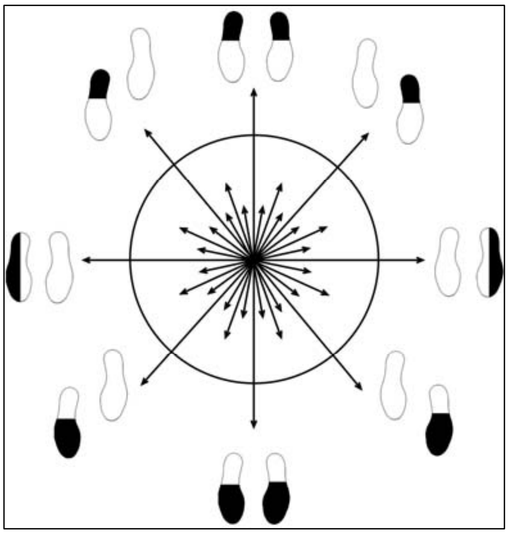
periodicals such as *Yūkō-no-katsudō* 有効の活動 (The Efficiency of Movement) and *Jūdō*, be it explicitly or less explicitly. Similarly, it took up a central place in Kanō's many lectures about *Kōdōkan jūdō* in Japan or abroad, and also in Kanō's *Jūdō kyōhon jōkan* 柔道教範 上潘 (A textbook of *jūdō*), published in 1931 and the first and only full textbook which Kanō ever wrote about *jūdō*, (Kanō, 1931; Kanō-sensei Denki Hensankai, 1984).

"… if an opponent pushes, you must pull in the same direction; if he pulls, you push him in the same direction". This quote represents the *Kōdōkan* concept of *yawara* or *jū* (Kanō, 1931, 1932; Kanō-sensei Denki Hensankai, 1984; Kōdōkan, 1986). Applying these forces becomes much more energetically efficient if you also result in unbalancing your opponent. In that case, the minimal force applied by you will amplify that imbalance, so that easy application of a lever would enable you to control your opponent and succeed in throwing him with ease. For Kanō this essentially represents "the proper use of force" a concept which he thoroughly researched and used as a base for constructing *Kōdōkan jūdō*'s *gō-no-kata*, likely the oldest choreographed *jūdō* exercise (De Crée & Jones, 2009).

Tsukuri in its classical form exists in two forms: *aite-no-tsukuri* 相手の造 (preparing of the opponent) and *jibun-no-tsukuri* 自分の造 (preparing oneself)[12]. This preparing of the opponent consists of destroying the opponent's balance before performing a technique and thus intends to put him in a posture that facilitates the application of a technique. Simultaneously, "the one acting" (*tori*) must be in a posture and position in which it is easy to apply a technique. This is the "preparing of oneself" (Kudō, 1967; Sacripanti, 2012b, p. 7).

In teaching the basic skills of *kuzushi*, Kanō adopted a didactic model which pre-existed in *Tenjin Shin'yō-ryū jūjutsu* and that was called *Roppō-no-kuzushi* 六方の崩 "Six directions of unbalancing", but which he himself later expanded and renamed as *Happō-no-kuzushi* 八方の崩 or "Eight directions of unbalancing" (Figure 4) (Kōdōkan, 1986; Mifune, Kudō, & Matsumto, 1955-56). What really is meant, are straight horizontal directions parallel to the *tatami*. Linguistically in Japanese, the term *happō* in this context also often means "all directions", thus in the sense of covering everything over a 360° radius, thus not literally just eight.

Figure 4. Schematic representation of *Happō-no-kuzushi* 八方の崩 or "Eight directions of unbalancing"; after Sacripanti, 2012, p. 8, with permission.



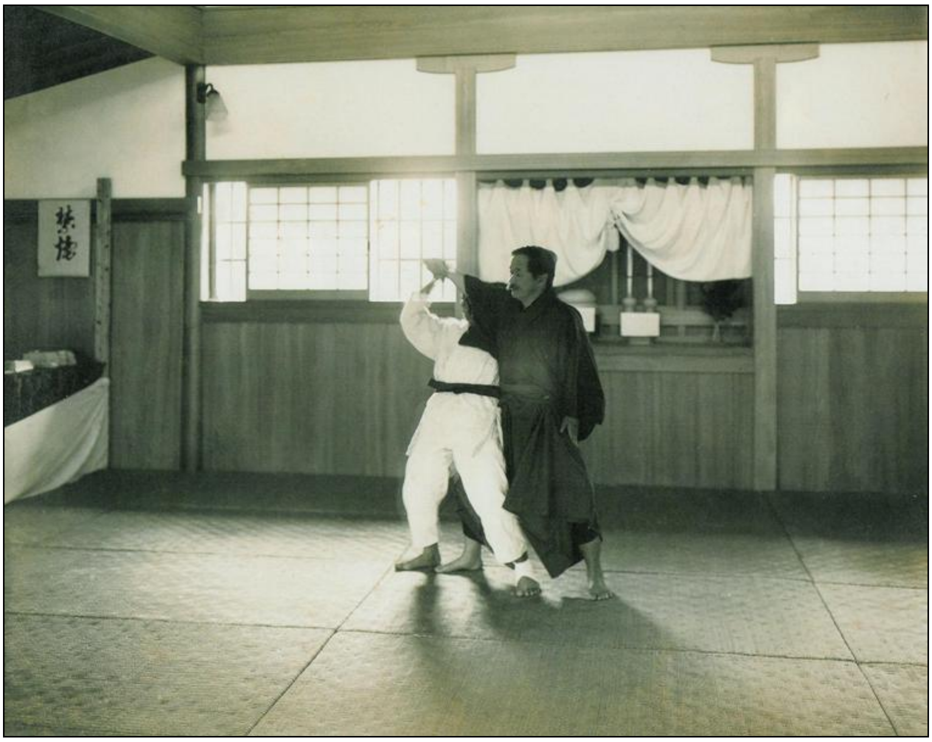
However, in reality, *kuzushi* clearly entails much more than just horizontal directions. There is also a vertical component. This also illustrates the difficulty in skills transfer of *kuzushi* when teaching *jūdō* to students. For example, left-front *kuzushi* is recommended for a simple-entry fundamental performance of basic *koshi-waza* 腰技 (hip techniques) such as the throw *harai-goshi* 払腰 (sweeping hip) and several *te-waza* 手技 (hand techniques), such as the throw *tai-otoshi* 体落 (body drop). Yet, despite the same direction, the *kuzushi* for both throws is very different. In fact, if considering just a single throw, say *tai-otoshi*, while varying the *hairi-kata* 入方 (ways of entering), for example, *tsuri-komi* 釣込 (lift-and-pull entry) *vs. mawari-komi* 回込 (spinning entry), already then the *kuzushi* is quite different (Hirano, n.d.[b]).

The *happō-no-kuzushi* model postulates only two dimensions instead of three, and does not account for all those very important differences. Consequently, someone mastering *happō-no-*

[12] In the West, most *jūdōka* are not familiar with these separate forms of *tsukuri*. This can create some confusion particularly when some authors place the *tsukuri*-phase following the *kuzushi*-phase, whereas others prefer putting *kuzushi* prior to *tsukuri*. When using the full terminology this confusion is prevented since typically preparing the opponent precedes *kuzushi*, but preparing oneself may indeed well come after the *kuzushi* phase.

kuzushi will still experience significant problems in their skill acquisition to apply *kuzushi* to any throw in a dynamic or realistic situation. Unfortunately, the *Kōdōkan jūdō* syllabus does not have other models to teach this *kuzushi* except for perhaps one example, the *ri-no-kata*, such as especially *Koshiki-no-kata*[13]. Unfortunately, *Koshiki-no-kata* is so complicated that the exercise is taught only at the most advanced level, a level which the majority of people in *jūdō* will never reach (Figure 5). Even then, the sheer difficulty of this exercise for many advanced *jūdōka* prevents any comprehension beyond a mere mechanistic perception, so that, sadly and for that reason, it does in most cases not significantly contribute to their understanding of *kuzushi*.

Figure 5. Kanō Jigorō-*shihan* (*tori*) with Yamashita Yoshitsugu 山下義韶 (1865-1935), 7th *dan* (later 10th *dan*) (*uke*), performing *Ko-daore* 虚倒 (Fall in a void), the seventh technique of *Koshiki-no-kata* 古式の形 at the occasion of the opening of the *Jundōkan* 順道館 in Kōbe 神戸, Hyōgō Prefecture 兵庫県, on April 30th of 1916.



5. Biomechanical appreciation of Kanō Jigorō's *kuzushi* system

A number of authors have looked into the biomechanical properties of *kuzushi* (Ikai, 1958; Imamura, Hreljac, Escamila, & Edwards, 2006; Imamura, Iteya, & Ishii, 2007; Okada, 2008; Sacripanti 2010a, 2010b, 2012a; Sannohe, 1986; Tezuka, 1983; Trilles, Blais, & Cadière, 2010) in *jūdō*. Especially the work of Sacripanti in this area has been extensive. According to Sacripanti, from a physics viewpoint, it is noted that

> Kanō used *kuzushi* to synthesize the transfer of action in biomechanical elements, *i.e.* the barycentric throwing of the opponent's body outside both the optimal trapezoid surface and the supporting base. The action of *kuzushi* takes advantage of a human body's erect position, 'a physics position of unstable equilibrium', by introducing everything that permits throwing that body after an unbalance, namely, through an appropriate barrier (*e.g.*, *tai-otoshi* 体落 (body

[13] *Koshiki-no-kata* 古式の形, before 1901 by Kanō referred to as *Kitō-ryū-no-kata* 起倒流の形, was taken over virtually integrally by Kanō from his *Takenaka-ha* 竹中派 branch of *Kitō-ryū*, as he had learnt it from his *Kitō-ryū* teacher Iikubo Tsunetoshi-*sensei* 飯久保鍬吉恒年先生. The exercise is originally contained in *Kitō-ryū*'s *Jin-no-maki* 人の巻 (The scroll of Man) where the first series of techniques is grouped under the name *Omote-kata* 表形 (the fundamental, visible forms) and the second, depending on the lineage, as either *Ura-kata* 裏形 (the applied, hidden forms) or *Mudan* 無段 (the non-stepwise application). The whole *kata* is in *Kitō-ryū* usually referred to as *Kitō-ryū kumi-uchi-no-kata* 起倒流組討の形.

> drop), *hiza-guruma* 膝車 (knee wheel)) or through merely causing a hyper-extension of the body in a space (*e.g.*, *uki-otoshi* 浮落 (floating drop), *sumi-otoshi* 隅落 (corner drop)). (…) (Sacripanti, 2012b, p. 7)

The question about the direction of forces and their proper use prompted Kanō to consider the development of dynamic actions with a purely straight and two-dimensional symmetry. Even if we only consider two-dimensional linear symmetry, and because of its complexity exclude specific three-dimensional issues, then the number of unbalance directions is infinite, more precisely, "*an infinity of the power of continuum*" (Sacripanti, 2012b, p. 8). The *Happō-no-kuzushi* directional principle is therefore only satisfactory on the condition that each of the eight fundamental and straight directions proposed by Kanō is considered as "*representative vector*" of a group or more exactly of a *class of directions* (Sacripanti, 2010a, 2012b). We must therefore approach *Happō-no-kuzushi* as a didactic example depicting what is essentially an 'innumerable' number of horizontal straight directions of unbalance now divided into eight classes.

One of the major flaws in Kanō's description of *kuzushi* is that it is based on an erroneous physics assumption in the sense that the human body is considered to be a rigid object (Yokoyama & Ōshima, 1915, 1911), which it is not. In reality, the human body is flexible and is segmented with various articulations, hence the considerable conceptual gap between the theoretical explication of the *happō-no-kuzushi* horizontal two-dimensional directions concept, and how it can be practically applied in *shiai* or in the novice *jūdōka*'s skill acquisition (Sacripanti, 2010a, 2012a, 2012b).

In reality, the body's center of mass (COM) changes its position both inside and outside the body, thus altering the subject's stability even though it may not be totally unbalancing their body (Sacripanti, 2012b, p. 12). Sacripanti points out that

> In *jūdō*, we are used to consider balance while being in a neutral standing situation, that is, a position of unstable equilibrium, assuming that the COM of the athlete is still more or less under the navel from a perspective of the body's well-known three planes of symmetry (frontal, sagittal and transverse). If the opponent's body is rigid, you can easily apply Kanō's unbalancing concept; if, however, the opponent's upper body part turns or bends to the side, you cannot. In this case, the COM shifts and changes position, and, consequently, both the body's stability and mobility are altered. (…) (Sacripanti, 2012b, p.12).

An expert *jūdōka* is able, through the proper application of *debana* (opportunity) to use these situations to gain an advantage. However, nothing within the *Kōdōkan* didactical system other than "practice, practice, practice" provides clear guidelines or tools to help the novice *jūdōka* acquire these essential skills. In reality, what it really reduces to is the "breaking of symmetry" of the opponent's balance (Sacripanti, 2012b, p.13).

By bending or turning one's body one can break the symmetry of the opponent's body position. In doing so, one reduces the opponent's mobility by shifting its COM either inside or outside of his body hence increasing his instability. Many modern *jūdōka* often with limited technical skills try to achieve this through grip fighting and blunt pulling and pushing, whereas well-known exemplary technicians such as Mifune Kyūzō 三船久蔵 (1883-1965), Okano Isao 岡野功 (born in 1944) or Hirano Tokio 平野時男 (1922-1993) achieve this through an optimal approach of recoiling action/reaction or *hazumi* 弾み (Clause, 2003; Hirano, 1966; 1972a; Mifune, 2005; Okano n.d.; Okano & Satō, 1973). As Sacripanti points out though, neither the novice nor the expert *jūdōka* usually has any conscious knowledge about the role of the "breaking of symmetry" concept, or the biomechanical objective of *kuzushi* (Sacripanti, 2012a, 2012b, p. 13). When someone's symmetry is broken, his body's stability is diminished hence limiting his ability to shift and compensate thus making it easier for the opponent to apply a successful throw.

From a biomechanical view, successful *kuzushi* involves, or … at least is closely intertwined with a twofold process, namely the *debana*[14] 出端 (the opportunity and optimal moment to

[14] Sacripanti uses *hazumi* to refer to perfect timing, however, *hazumi* 弾み does not really signify "perfect timing", but "the use of recoiling of the body to promptly and explosively act when that opportunity presents itself"; the opportunity itself though is called *debana* 出端.

succeed), and a final contact or body collision or clash called *butsukari*[15] 打つかり. These two steps immediately precede the *kake* or execution of the throwing phase and the *nageru* or actual throwing phase[16]. Proper and effective use of such situation is often called *handō-no-kuzushi* 反動の崩し (Litt.: "reactive/recoiling unbalancing") (De Crée, 2014; Sacripanti, 2010a, 2012b).

"The sublimity of *jūdō* techniques lies not in the action of performing techniques, but rather in the skill with which the anticipating work, *i.e.* the preparatory phase is completed" (Sacripanti, 2012b, p. 7-8).

Tsukuri (preparation) is really aimed at bringing an opponent in an ideal position to be thrown with minimal energy. Even though the possibilities of *tsukuri* solutions may be infinitive, they all share as a common goal shortening the distance between the two *jūdōka*. Sacripanti pointed out that from a biomechanical point of view the number of actions that simultaneously aim to maximally reduce distance while expending minimal energy, is limited to three classes or "Action invariants" (Sacripanti, 2010a, b, 2012a, b). According to Sacripanti, each of these classes is defined by what is known in classical Newtonian physics as the *Principium of Jacobi Minimum* (or *Least*) *Action*, and can be reduced to the *Hamilton–Lagrange Equation* and to the *Hamilton Action Principle*:

$$S(q,\, t) = \int L(q,\, \dot{q}, t)\, dt$$

In this equation, S is the action of a physical system (*i.e.* the chosen throw), L is the Lagrangian (the system's energy) component, and q is the generalized Lagrange coordinate, while the dot denotes the time derivative, and t is time. When considering the external energy of the system (gravitational field) one may conclude that:

$$S(q,t) = W(q) - Et = L(q,\dot{q})$$

$$\delta S(q,t) = \delta\int_{t_1}^{t_2} L(q.\dot{q})dt = \delta\int_{t_1}^{t}\left[\frac{\partial L}{\partial q} - \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}}\right)\right]\partial q dt = 0 \Rightarrow$$

$$\frac{\partial L}{\partial q} - \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}}\right) = 0$$

… where W is the potential energy within the external field, E is the kinetic energy, and t is time.

For a non-conservative system we must write:

$$\frac{\partial L}{\partial q} - \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}}\right) + Q = 0$$

… with Q being the heat emitted.

A conservative field is where the line integral depends solely on the end points of a trajectory, whereas a non-conservative field is when the line integral depends both on the end points and on the trajectory between them. The net work that is carried out by a conservative field on an object that follows a closed loop is zero. This is an alternative way of expressing that a conservative field stores energy without loss, *i.e.*, if an object gives up a certain amount of energy to a conservative field in traveling from point A to point B, then the field returns this energy to the object without loss when it travels back to point A. However, if an object gives up energy to a non-conservative field when moving from A to B, then the field returns only part of this energy to the object when traveling back to A. Gravitational fields, but also static electric and magnetic fields are

[15] Sacripanti uses the term *ikioi* 勢い to refer to this body collision. However, body collision in *jūdō* is actually *butsukari* 打つかり whereas *ikioi* 勢い simply points out that an action is done "vigorously and forcefully".

[16] We are adhering here to the seven phases of a *jūdō* throw as proposed by De Crée and Edmonds (2012), in response to what these authors considered the incompleteness of the three stages suggested by the *Kōdōkan*: *debana* 出端 (the opportunity and optimal moment to succeed), *tsukuri* 作り (preparation), *kumu* 組む (gripping), *kake* 掛け (execution), *nageru* 投げる (throwing), and *zanshin* 残心 (the follow through, litt. the "continuation of the spirit").

probably the most typical examples of a conservative field. An example of a non-conservative field would be represented by an object moving over a rough horizontal surface, such as a *jūdōka* moving over a *tatami*. In that case, frictional force would continuously drain energy from the object as it moves over the surface, energy which then is dissipated as heat.

Considering *Hamilton's Principle*[17], the true evolution of S(q,t) is an evolution for which the action is stationary (a minimum, a maximum, or a saddle point). However, since *jūdō* is all about maximal efficiency, one in fact strives for a minimum, *i.e.* the so-called *Principle of Minimum Action* (Sacripanti, 2010a, 2012a). The Action Invariants, mentioned in the previous paragraph, in *jūdō* refer to the minimal path in time that the body needs to shift in order to achieve the best *kuzushi* and *tsukuri* position for every *jūdō* throw. Generally, this applies to a conservative field; if, however, we consider a non-conservative field (see above), then one also needs to include a factor Q, *i.e.* the heat emitted, although the quick succession of *jūdō* techniques during *randori* or *shiai* is such that temperature variations within the couple formed by both *jūdōka* are negligible and adiabatic (Sacripanti, 2010c, 2012b). The succession of throws in *randori* or *shiai* represent applications of the principle of minimum action, which has lead to them being referred to as *Action Invariants*, and which are both summarized as follows:

- The principle of minimal action is represented by the athlete's (= the *jūdōka*'s) energy consumption, while the best outcome is represented by the applied *jūdō* technique.
- The principle of minimal action is represented by the athlete's (= the *jūdōka*'s) movement trajectory in order to achieve optimal positioning for carrying out the throw, while the best outcome is determined by the applied *jūdō* technique.

6. Hirano Tokio's concept of *kuzushi* in *jūdō*

In practical terms, many *jūdōka* seriously struggle with technically mastering a number of throws because of the difficulty in learning correct *kuzushi*, which is a highly coordinative process requiring substantial neurological and motor skills. Hirano Tokio fully recognized these problems and applied an entirely new and original approach. Firstly, to Kanō's essentially two-dimensional model of directions of *kuzushi* contained in the *happō-no-kuzushi*, he added a third dimension, namely a vertical one. He also identified seven different ways of using the arms to realize a fully three-dimensional model of *kuzushi*: and included those in a didactic set of forms which he called *Jōge-no-kata* 上下の形 (Forms of up- and downward movement) (Hirano, 1972a). The seven vertical forms of *kuzushi* contained therein are:

1. *Katate-sabaki* 片手捌 (Single-handed preparation)
2. *Ryōte-sabaki* 両手捌 (Double-handed preparation)
3. *Taiko-tataki* 太鼓叩 (Drumbeating)
4. *Tobi-agari* 跳上 (Jumping up) (see Figure 6)
5. *Ayumi-ashi* 歩足 (Normal walking)
6. *Hiza-mage* 膝曲 (Knee-bending)
7. *Sutemi* 捨身 (Sacrificing)

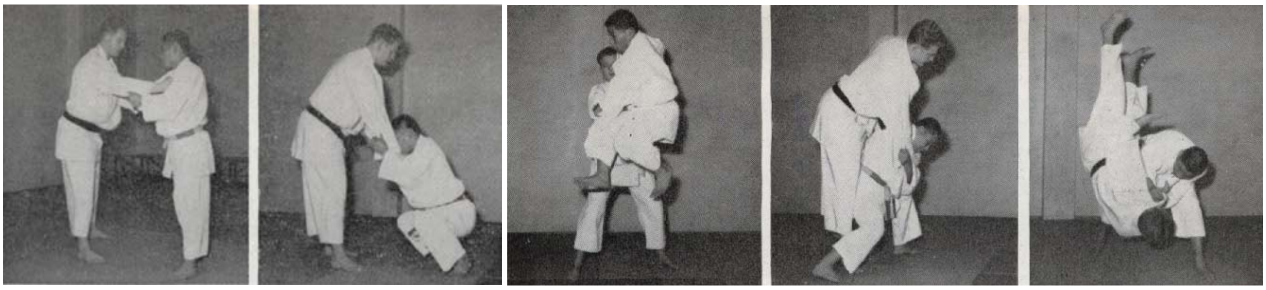
These *kuzushi* movements are typically preceded by an explosive pull downwards followed by a *suri-ashi* 摺足 sliding step that leads to a *tsuri-komi*-like 釣込 upwards pulling. These strong pulses sent to the opponent will elicit a response which *tori* learns to anticipate, and which he then optimally follows up with one (or multiple) of the above 7 *kuzushi* options.

[17] *Hamilton's principle* is William Rowan Hamilton's (1805-1865) formulation of the principle of stationary action. It states that the dynamics of a physical system is determined by a variational problem for a functional based on a single function, the Lagrangian, which contains all physical information concerning the system and the forces acting on it. The variational problem is equivalent to and allows for the derivation of the differential equations of motion of the physical system.

Furthermore, Hirano felt that contrary to what the majority of *jūdōka* does today, gripping should not be a predetermined starting point, but should be a logical consequence (following Kanō's maxims) after *tsukuri* (Chen & Chen, 2001; Hirano, 1972a, 1985; van Gasse n.d.), with that *tsukuri* simply representing that what the opponent is doing, either out of his own initiative or in response to waves sent out by *tori* in a pulsatile fashion. One can argue whether Hirano truly distinguishes a separate *kuzushi* phase or not, since the opponent as a result of his own movements will always have a relative imbalance somewhere, which the ensuing choice of gripping then will simply reinforce. Importantly, Hirano's *tsukuri* always contains a solid action/reaction response that involves considerable *hazumi* 弾み (rebound, recoil, spring, reaction). To do so, Hirano also makes ample use of a myriad of *hairi-kata* 入方 depending on the situational circumstances (Hirano n.d.[a, b]), and which includes, amongst others:

- *Tsuri-komi* 釣込 (lift and pull entry)
- *Mawari-komi* 回り込 (spinning entry)
- *Tobi-komi* 飛込 (jumping entry)
- *Handō* 反動 (reactive entry)
- *Oi-komi* 追い波 (chasing entry)
- *Hiki-dashi* 曳出し (pulling open entry)

Figure 6. Hirano Tokio demonstrating his famous *Tobi-agari* 跳上 (Jumping up) entry in combination with his immensely successful *tai-otoshi* 体落 (body drop); From Hirano (n.d.[b]), with permission.



One approach that increases or facilitates the effect of *kuzushi* is to apply it in a rotational trajectory, since a subject endures greater difficulty in recovering from sideways or rotational loss of balance than from a straight forward or backward imbalance (Sacripanti, 2010c, 2012a, b). The concept of *tai-sabaki* 体捌 is integral to *Kōdōkan jūdō* and considered important as clearly shown in the historic footage in which Kanō Jigorō demonstrates his *toku'i-waza* 得意技 (specialty): *hidari uki-goshi* 左浮腰 (left floating hip throw) (Figure 7), although its biomechanical relationship to *kuzushi* is not commonly explained within the *Kōdōkan* syllabus. Note that, particularly, in *Daitō-ryū aikijūjutsu* 大東流合気柔術 and *aikidō* 合気道 these circular pathways and *tai-sabaki* are constantly emphasized.

In rotational *kuzushi*, the *kuzushi* actions form straight-line tangents on an otherwise circular path or movement (Figure 8).

Rotational unbalancing almost invariably is integrated with a more dynamic form of *jūdō*, hence it is no surprise that Hirano Tokio proposed a didactic form of rotational flows, unlike *Kōdōkan* where the didactic approach of rotational *kuzushi* is really limited to a reassurance that *tai-sabaki* is important and that mastership in it will come with practice. Instead, Hirano proposed *Endō-no-kata* 円動の形 (Forms of circular motion) (Tegelaar, 2012a). He distinguished 6 such forms:

1. *Dai-en* 大円 (Large circle)
2. *Katate-dai-en* 片手大円 (Single-handed large circle)
3. *Ryōte-sho-en* 両手小円 (Double-handed small circle)
4. *Naname-en* 斜円 (Diagonal circle)

5. *Ito-sabaki* 意図捌 (Surprise turn)
6. *Kaiten-en*[18] 回転円 (Rotating circle)

Figure 7. Kanō Jigorō demonstrating his *toku'i-waza* 得意技 (specialty): *hidari uki-goshi* 左浮腰 (left floating hip throw) on Yamashita Yoshitsugu 山下義韶 (1865-1935), one of his most loyal and senior students.

Figure 8. Schematic representation of rotational *kuzushi* (unbalancing); after Sacripanti 2012b, p. 9, with permission.

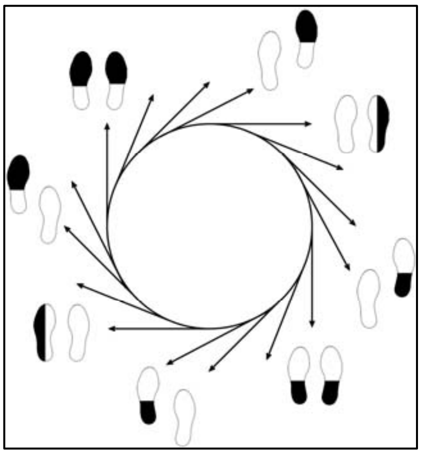
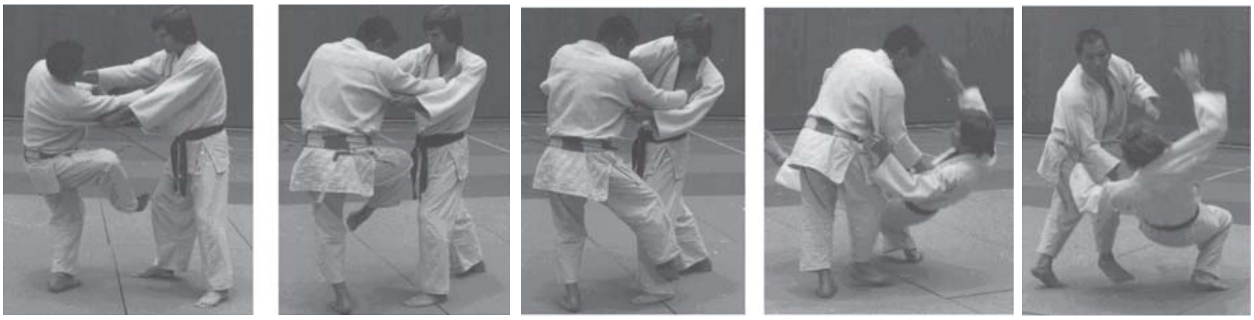


Figure 9. Hirano Tokio showing a *Konpasu-en* コンパス円 (compass circle) entry to apply *ko-soto-gari* 小外刈 (minor outer-reap throw). From Tegelaar, (2012a), with permission.



Jōge-no-kata and *Endō-no-kata* are forms neither intended nor suited for ceremonial demonstrations complete with *reihō* 礼法 (formal bowing etiquette). They are practical forms that serve as the grammar of pure technical skill, exactly as *kata* 形 (forms) were intended to be.

These methods for rotational unbalancing can be applied to several throwing techniques (Figure 10), although they are particularly suited to some. Hirano devised such methods mostly based on his own *tokui-waza* 得意技 (preferred technique), which included *ō-soto-gari* 大外刈 (major outside reap), *ō-soto-otoshi* 大外落 (major outer drop), *ippon-seoi-nage* 一本背老投 (one-point back-carry throw), *ō-uchi-gari* 大内刈 (major inner reap), *tai-otoshi* 体落 (body drop), and *uchi-mata* 内股 (inner thigh). For example, the "large-circle" method is particularly suited for *uchi-mata*, whereas the "singled-handed large circle" is particularly suited for *ippon-seoi-nage*; on the other hand, the "diagonal circle" works particularly well with *ō-soto-otoshi*.

One of the major difficulties in *jūdō* is choosing the right moment of opportunity (*debana* 出端) to initiate a certain throw, and thus also to initiate the appropriate *kuzushi*. However, one should not just wait passively until this moment occurs spontaneously. A *jūdōka* has ways to create or provoke such opportunities, or increase the frequency at which they occur, for example, by increasing the tempo of the fight. Hirano, however, goes one step further by attempting to visualize a number of *tsukuri/kuzushi* strategies that could effectively be applied to each throw, and that thus precede the seven vertical or the six rotational *kuzushi* forms which we discussed in the previous

[18] Also the term *Konpasu-en* コンパス円 (compass circle) appears to have been used by Hirano to refer to the sixth type of circular entry (Figure 9).

paragraphs. Hirano postulated that in addition to those forms of *kuzushi* there existed seven different types of water waves *nami* 波 or *handō* 反動 (reactions) that provided the basis on which he modeled seven different "*tsukuri-kuzushi* entities" (Hirano, 1972b; Tegelaar, 2012a, 2012b). These would exist separately from the chosen entry of the throw, with the waves producing the *debana* or right moment of opportunity.

Figure 10. Hirano Tokio-*sensei* during a visit to the author's original *jūdō* club, the *Jūdō and Jūjutsu Club Arsenaal Mechelen* in 1955, demonstrating his mastership of rotational *kuzushi*, here performed on 4 adversaries. Hirano was known on occasions to show the same application on no less than 10 adversaries at the same time.

Hirano collected the different kinds of water waves or *nami* 波 which he postulated in a *kata* he devised and that he later named *Handō-no-kata* 反動の形 (Forms of reactions) (Hirano, 1972b, pp. 220-221). The types of waves included in this *Handō-no-kata* are named as follows:

1. *Ōnami* 大波 (large or surging wave)
2. *Yoko-shibuki* 横繁吹 or 横沫 (sideways splash)
3. *Uchi-age* 打上 (up-shooting wave) or "*Juwa*[19]*-kudaki*" じゅわ砕き (squashing wave)
4. *Oinami* 追い波 (overtaking wave) / *Uchi-gaeshi*[20] 打返 (branding)
5. *Tatsumaki* 竜巻き (waterspout)
6. *Nami-no-hana* 波の花 (foaming wave) / *Saka-maki*[21] 坂巻き (clapotis[22] wave)
7. *Uzumaki* 渦巻き (whirlpool)

[19] A Swiss source (Soave & Goetz, 2007) suggests that the name of the third technique would be "*Juwa-kudaki*" or "*Jūwa-kudaki*" with as translation provided "Großer Felsen". It is unclear exactly which Japanese word is meant, as there does not exist a commonly used Japanese word with that pronunciation. Likely the name is a misunderstanding with the German translation "Großer Felsen" coming from the English "Big rock", but with the word 'rock' here indicating … a rocking or shaking movement rather that 'rock' in the sense of a large stone. A word for 'rocking' in Japanese is '*yura*', and maybe what is intended here might be '*yura-kudaki*' 揺砕 (violent tremor till the point of breaking or squashing wave).

[20] A Swiss source (Soave & Goetz, 2007) suggests that the name of the fourth technique would be "*Uchi-gaeshi* 打返" with as translation provided "branding".

[21] A Swiss source (Soave & Goetz, 2007) suggests that the name of the sixth technique would be "*Saka-maki* 坂巻き" with as translation provided '*Sturmwelle*' (Storm wave or clapotis wave).

[22] The term 'clapotis' is derived from the French '*clapotis*' which refers to a sound made by the sea, called '*clapoter*' and '*clapotement*', which is defined by most French dictionaries as a … "particular sound produced by a slightly agitated sea". In hydrodynamics the term 'clapotis' has come to mean a non-breaking standing wave pattern, often caused by the reflection of a succession of traveling surface waves from a near vertical shoreline like a breakwater, seawall or steep cliff. In more mainstream literature the term often simply implies a large standing wave (Figure 11).

Figure 11. A clapotis or large standing wave, *i.e.* a non-breaking standing wave pattern, often caused by the reflection of a succession of traveling surface waves from a near vertical shoreline like a breakwater, seawall or steep cliff.

Figure 12. Hirano Tokio-*sensei* demonstrating his *nami* 波 [wave] concept as forming the basis of *kuzushi/tsukuri* as applied in his *Handō-no-kata* 反動の形 [Forms of Reactions].

Hirano would demonstrate these in ceremonial *kata* form, showing how very large movements from one side of the mat would develop all the way to the other side and result in the best choice of *kuzushi* and a particularly efficient throwing technique (Hirano, 1966, 1985b, 1986; Tegelaar, 2012a, 2012b). The demonstration is reminiscent of *Itsutsu-no-kata* 五の形 (The Five Forms), a formal series of five techniques which Kanō Jigorō imported from *Tenjin Shin'yō-ryū jūjutsu*'s 天神真楊流柔術 *Kuden gohon* 極意口伝五本 (The Five Oral Transmissions) as a way to pay his respect to his teachers and one of the parent schools of *Kōdōkan jūdō*, as well as to edify *jūdō*'s unwritten most advanced teachings (De Crée, 2014).

Such large and continued movements are perhaps more of a metaphysical nature having in that way a strict energy-efficiency (Figure 12). However, their application certainly can produce valuable results, as illustrated by Hirano's extremely dynamic and efficient *jūdō*. The best way perhaps is to compare it with a sonar system. The *jūdōka* sends out a pulse, a wave, and depending on what happens to that pulse or wave (does it stop? is it returned? does it diminish? is it absorbed? and if so, after what time interval and with how much power?), he will choose an efficient response optimizing rotational *kuzushi*. When these principles are applied in a throw or *randori* they are much more subtle to the extent that one will often not actually observe these waves in the dynamic arm movements of the person creating them.

One starts a wave (in reality often a series of subtle pushing or pulling action) and your opponent will do something in response with that: resist, give in, ignore it, whatever. The way the opponent does this —resisting, giving in, or ignoring it— will depend on his physique, his *jūdō* level, the extent to which he feels threatened, etc. Thus he may block in an exaggerated way, or he may be very skilled and evade it. All these are ways to deal with waves, just like waves of the ocean (at least in the way Hirano philosophically perceived this, irrespective if hydrodynamically this is correct). For example, they can break on rocks in the sea, they can dissipate, they can return and drag you with them, and they can even rotate in the case of a whirlpool or waterspout.

In this way Hirano devised that he could transmit several types of waves and that the opponent could deal with those waves in a set number of ways. Depending on how the opponent responded, the logical answer would be a particular *kuzushi* and throw. The waves that one initiated, would not be merely pushing actions, but could be an entire throw with which one attacked because there too the opponent would react in a limited number of ways, such as for example: he is thrown, he blocks, he evades, he attempts to counter it, foreward, backward, left, right, etc (Kanō, 2011).

As such, Hirano's ideas are original, pedagogically very different from Kanō's and also interesting. However, one of the aspects that Hirano did not really address was that ... he himself also possessed incredible stamina, speed, and was extremely talented in *jūdō*. This then raises the question how effective and realistic the approach is from a didactic point of view in terms of skill transfer when it has to be applied by ordinary or average *jūdōka* and not world-class athletes blessed with extraordinary skills or capabilities ? During *randori* Hirano did not tend to make those large preparatory movements you see in his *kata*. In such situations, those movements really could be so short that he could apply them while not making any movements greater than a few centimeters, before he had gained all the information he needed to follow up with a devastating *ippon* scoring throw.

7. Biomechanical appreciation of Hirano Tokio's *kuzushi* system

Recall that, according to Sacripanti (2010), Kanō's fundamental maxim of *Kōdōkan jūdō*, *i.e.*, his principle of *Sei-ryoku saizen katsuyō* 精力最善活用 (Optimal use of energy) in the biomechanics of *jūdō* can be clarified by the *Jacobi form of the least action*, which if expressed mathematically is:

$$\Delta \int_{\rho_1}^{\rho_2} \sqrt{E + W(\rho)}\ d\rho = 0$$

with *E* being the kinetic energy and *W* being the potential energy.

We have indicated previously that there exist three types of *General Action Invariants,* which cover the whole plethora of actions of the body meant to reduce the distance between both *jūdōka* and to optimize one's own body position relative to that of the opponent in order to succeed in performing a chosen throw (2010). Sacripanti proposed that these *General Action Invariants* included in the *kuzushi-tsukuri* phase are:

1. Reducing the distance between both opponents using no rotation.
2. Reducing the distance between both opponents using a complete (0°to180°) clockwise or counterclockwise rotation.
3. Reducing the distance between both opponents using a half (0° to 90°) clockwise/counterclockwise rotation.

In the above list which reflects on the trajectory completed by the entity formed by both *jūdōka*, the first class of *General Action Invariants* consists of a nearly straight line, which preferably would be sideways (frontal plane) for simple reasons of efficiency, namely that the human body appears less skilled to resist or recover from a sideways unbalancing attack (Sacripanti, 2012b).

When considering the other classes of General Action Invariants, *i.e.* those that include either half or complete rotations, Sacripanti proposed[23] that the movement produced by the *jūdōka* shows similarities to the rolling of a body according to an inertial ellipsoid (without slipping) trajectory on a specific plane. The *jūdōka*'s body is cylindrical and symmetrical, and the inertial ellipsoid becomes an ellipsoid of revolution. The curve created by the point of contact on the inertial ellipsoid is then a circle around the athlete's axis of symmetry, and the curve on the transversal plane formed by the *tatami* also represents a circle (Sacripanti, 2010a, b, c, 2012a, b). Unfortunately this description is only accurate if the entity formed by both athletes moves freely as one, *i.e.* has no opposing interaction. In reality, *jūdōka* complete complex three-dimensional trajectories that include frictions which exist between both *jūdōka* and between them and the *tatami*, and there are also push-pull actions between both *jūdōka*, thus making an accurate calculation of their force-time evolution in space extremely difficult (Sacripanti, 2010a, 2012b).

However, at least the entity formed by both *jūdōka* is isolated from external forces. After all, the external gravity force is stopped by the *tatami*, and the entity formed by both *jūdōka* is subjected to the random push/pull forces that occur internally within the system consisting of both *jūdōka*, and to the friction between their feet and the *tatami*. When the random push-pull forces are subtracted, then this system follows a *Langevin-type Equation*, as previously demonstrated by Sacripanti (2010, 2012):

[23] This suggestion was based on the Poinsot geometrical description of a free forces motion of a body (Sacripanti, 2010, 2012).

$$F = -\mu v + m v \sum_j (\pm 1)_j \delta(t - t_j) = F_f + F_y$$

… where F is the total force acting on the system, -μ is the friction coefficient acting against the direction of the total force, v is the system's velocity, δ is Kronecker's delta which is a function of two integers that in some point of space is 1 if the variables are equal and 0 otherwise; t and t_j are two generic time integers of the Kronecker delta. If so, then the total force is composed by two terms with F_f representing the friction force $-\mu v$ and F_y being the stochastic force contribution (or term) that is the sum of all the push/pull contributions which in the end and over a long time interval average zero because the push/pull contributions do not have any specific preferred direction and are random.

Trilles, Blais, and Cadière (2010) on the other hand proposed the Newtonian mathematical form, in which only *tori*'s (the one attacking) actions and movements are considered:

$$-\vec{F}_{T/U} + \vec{P}_T + \vec{R}_{ground/T} = \frac{d}{dt}(M_T \cdot \vec{V}_{GT})$$

or

$$\vec{F}_{T/U} = \frac{d}{dt}(M_T \cdot \vec{V}_{GT}) - \vec{P}_T - \vec{R}_{ground/T}$$

$$\vec{F}_{T/U} = \frac{d}{dt}(\sum_{i=1}^{15} m_i \vec{V}_{Gi_T}) - \vec{P}_T - \vec{R}_{ground/T}$$

In this way attention is devoted to the possible variations in function of time of the movements produced by the various segmental articulations in generating the force or the actual action ($F_{T/U}$) of *tori* on *uke*, on the weight (P_T) and the ground reaction force $R_{ground/T}$. The coordination required between the various body segments[24] accordingly can be evaluated taking into account the vectorial sum of their individual movement (Sacripanti, 2010a, 2012b).

While the possible choices of *tsukuri/kuzushi* actions are infinite, Hirano-*sensei* proposed some unusual and apparently quite efficient ways of *tsukuri/kuzushi* many of which made optimal use of rotational dynamics. Some of these *tsukuri* may have very particular biomechanical properties. For example, Hirano's infamous *Tobi-agari* 跳上 (jumping up entry) (see Figure 5) from a physics point of view is different from conventional entry because it eliminates the friction that is otherwise produced by the soles of both feet turning on the *tatami*. However, the method requires the additional energy of having to jump up and temporarily move against the Earth's gravity (9.81 m/s^2 at sea level), as well as air resistance and overcoming a certain pulling force applied by the opponent's grip; elastic energy storage in the muscle may positively contribute to the height of the jump, but still an unknown amount of work will be put into the action of jumping upwards:

$$W = \int \vec{F} \cdot d\vec{s}$$

However, the amount of work created by having to jump up could well outweigh that what is gained by canceling out the friction between the feet and the *tatami* during normal movement. If indeed greater, then strictly speaking it would not longer be an application of Kanō's best application of energy principle.

Trilles, Blais, & Cadière (2010) have studied the contribution of the different segments of the body to rotation and different types of entry including *tobi-komi* 飛込 (jumping entry). Between 65-70% of the rotation relies on the lower limbs, with trunk and head representing about 22%, and the remaining approximately 10% being represented by the upper limbs. During *tobi-komi* entry

[24] Trilles, Blais, and Cadière (2010) postulate the existence of fifteen different segments which the *jūdōka* uses in generating his movements, namely: head, hands, forearms, upperarms, trunk, pelvis, thighs, lower legs, and feet. According to these authors the articulations involved in connecting these segments can essentially be reduced to fourteen: between head and trunk (1), between upperarms and shoulders (2), between upperarms and forearms (2), between forearms and hands (2), between trunk and pelvis (1), between pelvis and thighs (2), thighs and lower legs (2), between lower legs and feet (2).

this is somewhat different, with a higher contribution of the trunk and head than in many other types of entry. At the point after *tori* has reached his highest point and is descending, the upper limbs contribute to almost 60% of the rotation and the trunk and head to 40% with the contribution of the legs having fallen back to near zero percentage contribution. Time of entry with *tobi-komi* is generally about 10-20% longer than when for example using *hiki-dashi*[25] 曳出し (pull out entry), likely because of the longer distance (one has to add an upwards distance in addition to a lateral displacement) covered during *tobi-komi*. Trilles, Blais, & Cadière found for *hiki-dashi* a *tsukuri* phase which lasted approximately 0.70 s, and an overlapping *kuzushi* phase of 1.40 s, and a *kake* phase of approximately 0.30 s, totaling about 1.70 s, whereas for *tobi-komi* entries the same authors found a *tsukuri* phase of 0.64 s and an overlapping *kuzushi* phase[26] of 1.40 s, but a longer *kake* phase of approximately 0.50 s totaling about 1.90 s (Trilles, Blais, & Cadière, 2010).

In addition, these authors note that in case of *tobi-komi* during the descending phase tori is particularly well suited to rapidly and forcefully bringing his center of mass below that of *uke*, and may add the momentum caused by his own mass to bring the opponent out of balance. Therefore, the longer time does not imply it would be less successful.

Figure 13. Artist's impression of *Sanbon-me* 三本目, the third technique from *Itsutsu-no-kata* 五の形 (The Five Forms), which according to current *Kōdōkan* claims would represent the natural phenomenon of a whirlpool and how it can be applied to *jūdō* techniques. Note that there is actually no historic foundation to this claim, not in *Kōdōkan*, and not in its parent school *Tenjin Shin'yō-ryū jūjutsu*'s 天神真楊流柔術 from which the *kata* was imported (De Crée, 2012, 2014) (Art work created by Jan de Wringer, Amsterdam, reproduced by kind permission of the author, all rights reserved – 2011).

[25] A *hiki-dashi* 曳出し "pull-out entry" implies that you step away from your opponent while pulling him towards you to close the distance in preparation of entering a throw, instead of moving towards him.

[26] We note that the division into *kuzushi* and *tsukuri* (and other phases) is a pedagogical approach, as explained in De Crée and Edmonds (2012). However, according to some authors, in terms of muscle activation and contraction those two phases cannot be separated. For example, already in 1978, Matsumoto et al, found that "in all the *nage-waza* (throwing techniques), the movements of the *tsukuri* and the *kake* have already begun at the time when the electrical discharge of the gastrocnemius muscles was observed at the inception of the *kuzushi*, indicating that the series consisting of *kuzushi*, *tsukuri*, and *kake* starts simultaneously." (Matsumoto, et al., 1978, p. 38). However, the solidity of this conclusion was not clear since the study contained only a single pair of *jūdōka*. In such cases it becomes difficult to conclude whether the observation should be attributed to *jūdō* itself or to the specific *jūdō* style of that athlete. Nevertheless, findings by Trilles, Blais & Cadière (2010) seem to point in the same direction as these authors too appear to use the term "overlapping *kuzushi* phase". From a biomechanical point of view the whole motion pattern consists of measurable time-steps that are not strictly connected with a *kuzushi*, *tsukuri* or *kake* phase, as they clearly overlap each other.

Very characteristic and unusual in Hirano's didactic and practical approach of *tsukuri/kuzushi* is his heavy reliance on postulated water waves. With the exception of the fourth technique of *Kōdōkan jūdō*'s *Itsutsu-no-kata* 五の形 there is virtually no precedent for this in *jūdō*. *Itsutsu-no-kata* 五の形 (Figure 13) is, however, one of *Kōdōkan*'s two most advanced *kata*, and generally very poorly understood due to its reliance on metaphysical, naturalistic, and Taoist principles. While this *kata* is a *ri-no-kata* 理の形 (Theoretical Forms), meaning that it is one of mainly theoretical importance, Hirano's system as subsequently conceived in his *Handō-no-kata* 反動の形 —also known under the names *Nanatsu-no-kata* 七の形, *Nami-no-kata* 波の形 or *Hirano-no-kata* 平野の形[27] (Kanō, 2011) — is far more applied and practically oriented.

No prior scientific study of Hirano's postulated waves has, however, been attempted, and such study is timely to: further define the nature and meaning of those waves as part of *tsukuri/kuzushi*, establish whether these different categories of waves truly exist and differ, and whether hydrodynamic modeling deserves a place in understanding and improving *jūdō* technique, especially *tsukuri/kuzushi*.

8. Physics and fluid dynamic principles of standard wind (surging wave, clapotis, branding) and non-wind (whirlpool, waterspout, *tsunami*) propagated water waves

Most generally in physics waves are defined as a disturbance or oscillation that travels through space-time, accompanied by a transfer of energy from one point to another, often with no permanent displacement of the particles of the medium, meaning that this occurs with little or no associated mass transport. When waves are of a mechanical nature, they propagate through a medium with deformation of that medium. In the case of waves that occur in the sea or the ocean the waves can be either wind- or non-wind-generated, and represent perturbations where the medium they propagate through is water. Wind-generated waves are generated by the wind passing over the surface of the sea or the ocean (Janssen, 2004; Philips, 1957, 1977; Young, 1999). The majority of waves postulated by Hirano in his *Handō-no-kata* are standard or wind-propagated water 'waves'; such is the case for the *ōnami* 大波 (large or surging wave), the *yoko-shibuki* 横繁吹 or 横沫 (sideways splash), the *uchi-age* 打上 (up-shooting wave), the *oinami* 追い波 (overtaking wave) or *uchi-gaeshi* 打返 (branding), and the *nami-no-hana* 波の花 (foaming wave) or *saka-maki* 坂巻き (clapotis wave). To examine to what extent the didactic value of these postulated waves in *jūdō* is a reflection of how they exist in real life rather than being of a merely metaphoric nature, we need to devote some attention to the hydrostatic foundations and physics behind the origin of these wind-propagated waves.

Many of the waves we see on a pond or non-deep parts of the ocean are so-called "shallow water waves". When waves travel into areas of shallow water, they begin to be affected by the bottom of the sea. The free orbital motion of the water is disrupted, and water particles in orbital motion no longer return to their original position. As the water becomes shallower, the swell becomes higher and steeper, ultimately assuming the familiar sharp-crested wave shape. After the wave breaks, it becomes a wave of translation that is intensified by the eroded bottom of the sea or ocean (Dean & Dalrymple, 1991; Holthuijsen, 2007; Jansen, 2004; Lamb, 1994; Munk, 1950; Philips, 1977; Young, 1999).

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[27] Using the term *Hirano-no-kata* to refer to Hirano's *Handō-no-kata* is a misnomer. Nevertheless, this error is committed frequently. "*Hirano-no-kata*" implies "the (one) *kata* made by Hirano", which is confusing and misleading even though grammatically in Japanese, the term also means "the (various) *kata* made by Hirano" (thus plural). The average non-Japanese-speaking *jūdōka* does not realize this, and neither is the term really meant in that way since most people do not know that there exist multiple *kata* conceived by Hirano Tokio. The second term in use, and much more common is "*Nanatsu-no-kata*", thus "Forms of Seven" or "Seven Forms". There are, however, problems with this term too. Like "*Itsutsu-no-kata*" ("Forms of Five" or "Five Forms"), "*Nanatsu-no-kata*" is a temporary name that merely refers to the number of techniques it contains. Mifune Kyūzō, for example, uses the 'probable' name of "*Nanatsu-no-kata*" for "*Itsutsu-no-kata*" anticipating its expansion from five to seven or even ten forms (Mifune, 1956). For that reason, historically and from a scholarly viewpoint using that name for Hirano's *Handō-no-kata*, is undesirable; an even stronger argument evidently is that there is no credible evidence that Hirano ever formally assigned that name to this *kata*; rather he formally named it "*Handō-no-kata*" (Hirano, 1972b).

Both air pressure differences between the upwind and the leeside of a wave crest, as well as the friction on the water surface by the wind, cause the water to go into the shear stress hence triggering the growth of the waves (Dean & Dalrymple, 1991; Holthuijsen, 2007; Jansen, 2004; Lamb, 1994; Miles, 1957; Munk, 1950; Philips, 1977; Young, 1999). The height of a water wave is determined by wind speed, the duration of time the wind has been blowing, the 'fetch', *i.e.* the distance over which the wind excites the waves, and by the depth and topography of the sea floor (which can either amplify and focus or disperse the waves' energy). Generally, the larger the wave, the more powerful it is, however, amplitude is not the only criterion that matters. Wave power is also determined by wave speed, wave length, and water density. The oscillatory motion of the waves is the highest at the surface and diminishes exponentially with depth, with the exception that for so-called 'clapotis' or "standing waves", if they occur near a reflecting coast, the wave energy will also continue and be present as pressure oscillations at great depth, even leading to the production of small or micro-seismic events (Dean & Dalrymple, 1991; Holthuijsen, 2007; Jansen, 2004; Lamb, 1994; Munk, 1950; Philips, 1977; Reynolds, 1877; Young, 1999).

These considerations suggest that the factors and mechanics involved in the generation of wind-propagated water waves are of a totally different nature than the mechanics used by humans practicing *jūdō* and who are mimicking the external appearance of these waves in an environment that does not involve any water or other or forces of nature. In other words, as far as wind-propagated water waves are concerned these appear to be used or referred to by Hirano merely in a metaphorical sense.

It is also possible to create a variety of artificial waves in water including circular waves, plane waves, reflection, refraction, diffraction and interference waves, and even inertial waves, by putting objects of different shapes at different depths. However, this cannot be what Hirano intended in his vision.

In his total of seven different water waves Hirano also included a number of nonstandard or non-wind-propagated water 'waves'. For example, the fifth type of water 'wave' which Hirano defined is the *tatsumaki* 竜巻き (waterspout). In reality a waterspout is not a water wave. A waterspout is a funnel-shaped or tubular column of relatively weak rotating cloud-filled air or wind usually extending from the underside of a towering cumulus or cumulonimbus cloud down to the surface of an ocean or lake. The rotation occurs at low levels in the atmosphere, so the resulting vortex does not extend very far up into the cloud, and the phenomenon is largely confined to the region below cloud base (Dean & Dalrymple, 1991; Lamb, 1994). While most waterspouts closely resemble weak tornadoes, it is debated whether they actually are tornadoes or not. They are really an anomaly of nature, attributable to the deviation in the mechanism of their formation. They form when cold air moves over warm water, and they churn at speeds up to 350 km/h, but quickly dissipate when rain begins to fall from their host cloud. The atmospheric conditions are obviously such that they are impossible to be created by an individual human being on a *tatami*...

The last wave which Hirano defined is the *uzumaki* 渦巻き (whirlpool). A whirlpool is a swirling body of water that is not directly caused by wind but by the meeting of opposing water currents, although the currents themselves, if occurring at the surface, are mainly wind-driven and influenced by the Coriolis effect, although vertical and ocean-bottom currents are caused mainly by density differences as a result of differences in temperature and salinity (Dean & Dalrymple, 1991; Holthuijsen, 2007; Lamb, 1994). For example, cold, salty waters coming from the poles sink to the ocean bottom and move to opposite poles where they will again surface, although vertical upwelling currents can also because by winds blowing from the coastline. Whirlpools may occur both in shallow or deep water (Figure 14).

Whirlpools really represent the inertia of water. When trying to move a large body of water, the water molecules start moving in a tangent because of their inertia, with the activated force being centrifugal force. However, the deeper one goes, the more gravity acts on the water, and this gravity exerts a pressure proportional to how much water is above it; thus the deeper one goes the higher the pressure. This pressure is pushing against the outward pressure created by the rotation of the water, and forces the water back to the center, but proportional to the depth. Thus, the deeper the water the more pressure and gravity that will be present.

Therefore, at depth, the water will push objects caught in the whirlpool to the middle of it, while at the surface such objects will initially be pushed outwards (Dean and Dalrymple, 1991; Holthuijsen, 2007; Lamb, 1994).

Figure 14. A whirlpool occurring in shallow river water.

A whirlpool technically is a free vortex or line vortex in which the tangential velocity *v* varies inversely with the distance *r* from the center of rotation so that the angular momentum *rv* is uniform everywhere throughout the flow; the vortical motion (vorticity) is zero everywhere except at the center-line, and the velocity at which a one circulation $r = 0$ is completed has an identical value everywhere, though the time to complete that rotation will be longer when further away from the center (Bradt, 2001). In other words, the fluid near the center of the vortex completes one revolution in a shorter time than the fluid far from the center.

The speed of the fluid also decreases as the distance from the center increases. A leaf floating in a free vortex will maintain an orientation that remains constant, even though it is moving around the center of the vortex. If there is a free surface present then it will sharply dip (as r −2) as the center line is approached (Bradt, 2001).

The tangential velocity of a whirlpool vortex is given by:

$$v_\theta = \frac{\Gamma}{2\pi r}$$

In the above mathematical expression Γ is the circulation and r is the radial distance from the center of the vortex.

It is also possible to integrate the non-conservative force exerted by a whirlpool on an object such as a boat. If the radial component is negligible, and the azimuthal force a function of radius, thus a force with only an azimuthal component F_θ, it can be expressed as (Bradt, 2001):

$$F = F_\theta \hat{u}_\theta = +k\,r^{-1}\hat{u}_\theta$$

In the above equation $\hat{u}_\theta$ is a unit vector in the azimuthal direction, k is a constant, and the '+' indicates that the force is in the positive azimuthal direction.

If one integrates the quantity F·ds around a circular path C_2 at a constant radius r_0 (See Figure 15), then:

$$W = \oint_{C_2} F \cdot ds = \int_0^{2\pi} F_\theta\, r_0\, d\theta = \int_0^{2\pi} +k r_0^{-1} r_0\, d\theta = k r_0^{-1} r_0 \int_0^{2\pi} d\theta = +2\pi k$$

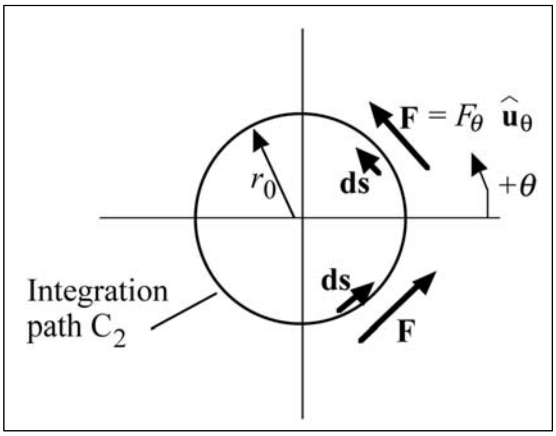
The outcome will not be zero as work is done by the non-conservative force that carries the object around its circular trajectory in the direction of the force vector. Because of this, the work W, as performed by the force, will be positive (Bradt, 2001).

We assume that the object moves in a positive counterclockwise direction, which is also what we assumed for the force component F_θ and for the direction of increasing angle θ. Therefore the counterclockwise direction of the angular displacement in this case will also be positive, which is also reflected by the limits on the integral. These limits imply that the object moves from θ = 0 to θ = 2π; if, on the other hand the positive direction had been defined as clockwise, the integration limits for counterclockwise displacements would have been, for example, 0 to −2π or 2π to 0 (Bradt, 2001).

For any azimuthal force F_θ, independent of θ, the integration can be rewritten as:

$$W = \oint_{C_2} F \cdot ds = F_\theta \, r_0 \int_0^{2\pi} d\theta = F_\theta 2\pi \, r_0 \quad (F_r = 0)$$

Figure 15. Schematic drawing of a vector field showing a force with only an azimuthal component F_θ, and indicating the non-conservative force exerted by a whirlpool on a boat (from Bradt, 2001, p. 11).



Thus, the integral becomes quite simple if the Force F is azimuthal and axially symmetric. In this way it presents in a transparent way the work performed by the force that moves the object around the circle, which simply is the constant azimuthal force multiplied by the distance around the circle (Bradt, 2001).

The same concerns would apply to for *tsunami* 津波 which obviously also create waves, although to be fair, it is not one of the waves conceptualized in Hirano's *jūdō*. However, *tsunami* are neither wind- nor object-propagated transverse waves. Instead, a *tsunami* is a pressure wave with a longitudinal mode, which travels at very high velocities or approximately 700 km/hr. Although it travels as a pressure wave in the open ocean, the wave is reflected partially upwards when it reaches a continental shelf.

This has the effect of converting it into a transverse wave as water moving along is now pushed upwards. This is a very nonlinear process and nontrivial to model. This pushing up of the water does initially cause water at the shore to recede outwards. The wave which seconds later reaches shore is much more slow-moving, and a large part of that wave energy is converted into the towering wave front that consequently will sweep in (Dean & Dalrymple, 1991; Holthuijsen, 2007; Lamb, 1994). Because such phenomena involve gigantic natural forces they are irrelevant here when discussing interplay between two humans.

A more in-depth analysis of the physics and the mathematical expression of fluid dynamic properties of water waves[28] and their different forms are beyond the scope of the present paper and beyond what is necessary to understand in order to seriously examine the physics that might underpin Hirano's wave-based *tsukuri/kuzushi* system.

9. Hydrodynamic principles of water waves and their possible biomechanical application in Hirano's *tsukuri/kuzushi* phase

Thus, of the seven waves defined by Hirano only five are real wind-propagated water waves, whereas two of them (the whirlpool and waterspout) are not really waves but arise as the result of other factors, which in the case of whirlpools has to do with conflicting currents of water, and in the case of waterspouts with conflicting currents of air. It should be obvious from the reflection on the physics behind all these phenomena, which we have presented in the previous paragraphs, that none of the many contributing factors, such as density of water, salt concentration, depth of water, height of waves, temperatures of water, and geography of the ocean bottom are involved at all in

[28] Investigating the physical properties of water waves is not a simple affair and their mathematical representation is rather complicated. The shallow water equations are derived from equations of conservation of mass and conservation of momentum (so-called "Navier-Stokes equations") and are often called "shallow water equations" or "Saint Venant equations" (Dean & Dalrymple, 1991; Lamb, 1994; Peregrine, 1972; Philips, 1977). These were named after Adhémar Jean-Claude Barré de Saint-Venant (1797-1886), a French mathematician and mechanics expert, who devised a number of hyperbolic partial differential equations that describe the flow below a pressure surface in a fluid. Later, in 1872 the French mathematician and physicist Joseph Valentin Boussinesq (1842-1929) in a paper (Boussinesq, 1872) proposed a number of specific differential equations that further approximated water waves that are weakly non-linear and fairly long, equations which today are often referred to as Boussinesq equations (Dean & Dalrymple, 1991; Holthuijsen, 2007; Lamb, 1994; Philips, 1977; Peregrine, 1972).

jūdō interactions between two people who are not even immersed in water. Therefore it is also not possible to truly biomechanically apply to *jūdō* the hydrodynamic behavior of water as it does in wind-propagated water waves or in water behavior due to other meteorological phenomena. Rather, Hirano's water wave-based modeling of *tsukuri/kuzushi* represents a metaphysical-pedagogical approach and visualization aid. Despite these limitations, the discrepancy between what a true hydrodynamic analysis of those waves shows us, and how Hirano was able to incorporate his ideas in his *jūdō*, it did not prevent him from becoming a hugely successful champion fighter who was able to defeat much heavier and stronger *jūdōka*, thanks to his supreme mastership of *tsukuri*, *kuzushi* and other factors essential in effecting *jūdō* throws.

As Sacripanti had already demonstrated, the potential choices of *tsukuri/kuzushi* actions are infinite (Sacripanti, 2010a, b, 2012b). The choices of *tsukuri/kuzushi* proposed by Hirano-*sensei* are often unusual and apparently quite efficient partly because of their optimal use of rotational dynamics and Newton's Third Law of action/reaction. However, to quantify or measure exactly how much more efficient they are than other selected examples of *tsukuri/kuzushi* is a rather complicated task as it would need to isolated the *tsukuri/kuzushi* method itself from the skills of the *jūdōka* and require a good replicability of those forms of *tsukuri/kuzushi.* So far, Trilles, Blais, and Cadière (2010) are some of the few researchers to have compared different forms of *tsukuri/kuzushi*, such as notably *hiki-dashi* vs. *tobi-komi* entries. Even then, the outcomes were limited to quantification of velocities and forces and not necessarily to efficiency in terms of success of breaking symmetry. Moreover, it did not appear that their approach was able to separate the forms of *hiki-dashi/tobi-komi* from the skills of the performer, meaning that another performer might have a completely different distribution of forces and velocities depending on his skill in the chosen movements.

Visualization is a useful tool in learning motor skills, and perhaps whether what one visualizes being scientifically correct or not may be secondary to that what one is attempting to achieve. If one succeeds in optimally applying general action invariants or breaking the symmetry of the opponent because one imagines one applies a movement as a *tsunami* or tornado or animal, it probably does not matter that in reality —both in terms of force, acting mechanisms or nature— what one is doing has materially nothing to do with the image one is referring to. As to the success of Hirano's pedagogical system and whether it facilitates skill acquisition more than the traditional *Kōdōkan* didactical approach, is hard to say because of a lack of hard data that have compared this in longitudinal studies. Rather the approach may better work in some simply because they might see a role model in Hirano-*sensei* and are fascinated by his system or its originality, which may motivate them to train harder or differently. One major problem is that of those who had the privilege to train under Hirano, virtually no one properly understood his approach. This was likely the consequence of a relative lack of experience still among many Western *jūdōka* in those days, and because of communication challenges with Hirano-*sensei* due to limitations in his mastering of non-Japanese languages. Thus, foremost before being able to better evaluate the value of Hirano's didactical approach one would need instructors who properly and comprehensively understand his system and are willing to devote time and effort into teaching their students in that way.

10. Conclusions

The fluid dynamic modeling of the several kinds of waves proposed by Hirano is mathematically complicated involving classic Boussinesq differential equations (Boussinesq, 1872; Dean & Dalrymple, 1991; Peregrine, 1972). Numerous parameters which determine the hydrodynamic behavior of water (depth, period of waves, saliency, temperatures, currents, shape of the coastal line, density of the water, wind) are absent in the surroundings of two *jūdōka* indoors on a *tatami*, hence Hirano's system appears limited to a mere visualization and metaphysical interpretation of *jūdō*.

The lack of empirical data available obtained in large groups of students taught according to Hirano's approach, make it so far impossible to conclude whether it facilitates *kuzushi* and *tsukuri* skill acquisition, with one major difficulty being separating Hirano's system from the skills of the individual. Hirano's success in competitive *jūdō* may as well be explained by him being exceptionally gifted and skilled rather than by his use of the wave system itself. Ultimately Hirano's wave-based *kuzushi/tsukuri* does not alter the biomechanical analysis proposed by Sacripanti, as it still involves general action invariants aimed to close the distance between the opposing *jūdōka*, to break the opponent's symmetry, and to apply one of the infinite options to achieve this.

Notes

1. Preliminary data from this study were presented in part at the 5th European Science of Judo Symposium on April 23rd, 2014 in Montpellier, France, organized by the European Judo Union (EJU).
2. Japanese names in this paper are listed by family name first and given name second, as common in traditional Japanese usage and to maintain consistency with the order of names of Japanese historic figures.
3. For absolute rigor, long Japanese vowel sounds have been approximated using macrons (*e.g. Kōdōkan*) in order to indicate their Japanese pronunciation as closely as possible. However, when referring to or quoting from Western literature, the relevant text or author is cited exactly as per the original source, with macrons used or omitted accordingly.

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Carl De Crée is a Senior Research Professor in Exercise Science and Sports Medicine, who at the time this manuscript was written, was affiliated with the University of Rome. Currently at Ghent University, Belgium, he is also a senior scholar in Chinese and Japanese Studies, which he efficiently combines with his expertise as an exercise physiologist and sports medicine specialist. Having conducted research on *jūdō* since 1981, he has established a reputation as one of the foremost *jūdō* scholars. He is one of only a few technical *jūdō*-experts holding an EJU Level-6 Specialized Judo Teacher & High-Performance Coach qualification and a Master's degree in *Jūdō* from the University or Rome. He also holds a Trainer-A in *jūdō* qualification from the Flemish

Trainer School, an International Judo Coach qualification and a Judo Master Teacher Class A Certificate from the United States Judo, Inc. He is research-active in all aspects of *jūdō* including medical, physiological, historical, philosophical, technical, nutritional, and pedagogical. He is a former international *jūdō* competitor and his expertise has been sought by world elite-class *jūdō* athletes. He currently holds a 7th *dan* black belt in *jūdō* and the title of *kyōshi*, and is the Instructor-in-Chief of the Royal Judo & Karate Academy Bushido-Kwai Mechlin, Belgium's oldest *jūdō* club. E-mail: prof.cdecree@earthlink.net. Http://www.carldecree.net.