"IDO MOVEMENT FOR CULTURE. Journal of Martial Arts Anthropology",
Vol. 12, no. 4 (2012), pp. 7–11

KINESIOLOGY

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Kinematic characterization of the Capoeira Bencao Kick

Submission: 11.10.2011, acceptance: 24.08.2012

Key words: combatives, martial arts, capoeira, kinematical analysis, front kick, bencao

Abstract
The martial art capoeira is gaining popularity in the Czech Republic; still we lack some professional information base about it. We did a 3D kinematical analysis of the basic capoeira kick - bencao. The subject was an advanced capoeira instructor who performed the kick three times with the right and three times with the left leg. For scanning the picture we used two high-frequency synchronized digital cameras SIMI MOTION Version 7. We evaluated kinematical characteristics of 13 body points. The kick was done from the basic capoeira movement - ginga. In the preparation phase the centre of gravity in the body was in the lower position – 0.74±0.03 m above the mat. From this point the position of the centre of the gravity was elevating and in the moment of hitting the target it reached the position 0.98±0.02 m. The total time period of kick doing, including the preparatory and main phase, was 0.62±0.03 s. Maximal speed reached by the ankle of the kicking leg was 7.96±0.5 $m.s^{-1}$. This speed was recorded at the moment of initiating the main phase, when the knee of the kicking leg formed an angle of 97.92±6.1° and started tightening actively. With the use of 3D kinematical analysis we managed to concretize the most important spatio-temporal characteristics of the bencao kick performed with a high quality.

Introduction

Capoeira is a Brazilian martial art that has been developing on the American continent since the 16th century. The origins of capoeira can be traced back to the culture of slaves transported to Brasilia in the context of colonization of the newly discovered American continent at the end of the 15th century.

Considerable debate exists among practitioners and historians as to whether capoeira is the New World development of an African martial art or a system originating in the New World with African influences. There are even suggestions that some of the kicking techniques are derived from French savate via European seamen who manned the cargo vessels that docked in Brazilian ports [Green 2001].

The interpretation of the name of the martial art of capoeira is not uniform as well. Various etymologies of the name capoeira are offered in the scholarly literature. Green [2001] states that the root "ca" or "caá" from Native Brazilian languages refers to forests or woods. This linguistic stem is often used to connect the origins of the term and the art to which it refers to African slave originators who, the oral traditions of the art maintain, escaped to or practiced in the bush from the sixteenth through the nineteenth centuries. The etymology of the name and the origin of capoeira was deeply studied by Araújo [2004a, 2004b] and Jaqueira [2008]. Beyond any shadow of a doubt, if we take a look at all the considerations put forward by the authors that tried to explain it through the Tupi-Guarani language, where the term capoeira means thicket [Araújo 2004a].

Primarily capoeira relies on striking techniques, although some grappling maneuvers, especially takedowns utilizing the legs in either tripping or scissoring motions, and weapon techniques complete the repertoire of the capoeirista (practitioner or "player" of capoeira) [Green 2001]. There are many styles and clubs (grupo) of capoeira nowadays (Capoeira Regional, Capoeira Angola etc.).

Biomechanical analyses of combat sport kicking techniques have been reported before. For instance, Robertson *et al.* [2002] compared the front kick (Japanese: *mae geri*, Korean: *ap chàgi*) performed from a so-called open (kicking leg in the back) and a closed stance (both legs next to each other in parallel about shoulder width apart) in one karate (*karateka*) and one taekwondo participant (*t'aekwŏndo-in*). The authors revealed that due to the larger range of motion, the kick from the open stance produced larger foot velocities.

Andrzejewski and Elbaum [2005] investigated the front kick in karate as well and compared kicking with the dominant and non-dominant limbs in an experienced karateka. The authors reported that the kinematics of the non-dominant leg was similar to those of the dominant limb, but the timing of each joint segment was different, while the linear and angular velocities were slower. Due to the speed with which techniques are performed, it was suggested that traditional views of how optimal techniques should be executed may be flawed, necessitating the use of biomechanical equipment to assist in improving performance.

As far as is known, no scientific information about capoeira kicks is currently available. For the purposes of this study, then, it was decided to analyze a technique that was basic, typical to the sport as well as relatively easy to execute. The bencao kick met these criteria. The current investigation is part of a wider research effort at Masaryk University aimed at biomechanical analysis of various sports, including martial arts and combat sports [e.g. Kalichova 2011; Reguli 2009, 2008, 2007; Sebera *et al.* 2008; Zvonar, Psalman 2008].

Description of the bencao kick

Starting position: the kick starts from the basic stance ginga. Active phase: The kick starts with the hind leg going forward with the knee up; as the knee goes up, the shoulders and back are pushed backwards with the stretched leg and the torso forming an obtuse angle. With the kick, a dynamic take-off from the standing leg as well as a skip forwards are performed. While finishing the kick, the stretched leg is forced into the target.

The result phase: the standing and stretched leg form a right angle, the stretched leg and the torso an obtuse angle, the shoulders and back are pushed backwards, the stretched leg is forced into the target and the standing foot is slightly bent down for higher stability (Vanilson Alessandro De Abreu, personal communication, May 5, 2010). The kinogram of the bencao kick is shown in Figure 1.

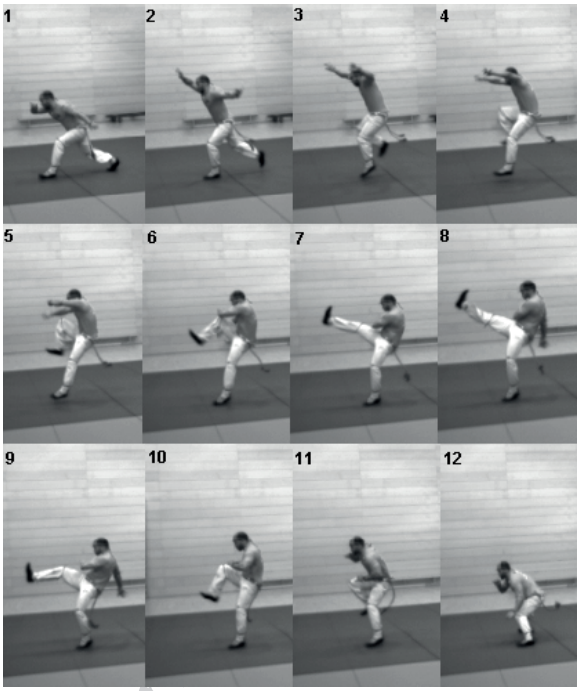

Figure 1. Kinogram of the bencao kick – microphases 1-12

From a biomechanical point of view, the velocity of the ankle when hitting the target is one of the essential factors that determines the efficacy of the kick [e.g. Sprague 2002; Kim *et al.* 2006]. With this parameter, the length of the path the ankle moves and accelerates are very closely related. After hitting the target, the velocity of the ankle decreases sharply because together with the collision with the target, the kinetic energy is transformed into internal energy of the striker and the opponent as a consequence of tissue deformation.

Methods

A 3D kinematical analysis of the capoeira bencao kick was done. Institutional ethical approval was obtained before testing started. The subject was an advanced capoeira instructor from "Grupo Candeiras", who teaches the sport in the Czech Republic. He performed the bencao kick three times with the right and left leg each. To preserve the unique movement typical of the sport, the kick was performed with the subject interspersing each attempt with the basic capoeira movement – ginga. We analyzed the motion (kick) from the initial position, which was determined by the moment, when the hind leg heel started rise from the ground (Fig. 1, microphase 1).

Two high-frequency (200 Hz) synchronized digital cameras SIMI MOTION Version 7 (SIMI Reality Motion Systems GmbH, Unterschleissheim, Germany) were used to record the kick. The data were sent directly to the software of the same brand,

where they were processed. Characteristics of 13 body points were assessed that were marked with retro reflexive balls: right and left ankle, right and left knee, right and left hip, right and left shoulder, right and left elbow, right and left wrist, and forehead. From the recorded data, angles, trajectories, paths and velocity parameters of individual segments were evaluated as well as the overall centre of gravity of the body.

Results

On the basis of 3D kinematic analysis the characteristics of key phases of the bencao kick were evaluated. We present data which was calculated as the average of all six monitored trials (Table 1).

In the preparation phase (Fig 1, microphase 1), the knee joints of both lower limbs formed an angle of 140±8.1°, the angle of the elbow raised forward formed an angle of 70.4±6.2° and the limb swinging backward, 152±7.7°. The centre of gravity of the body in the lowest position was 0.74±0.03 m above the mat. From this point, the position of the centre of gravity was elevated during the forward skip. After landing, the centre of gravity decreased and the capoeristas finished his kick. At the moment of hitting the target, the centre of gravity reached 0.98±0.02 m.

The total time of kicking, including the preparatory and main phases, was 0.62±0.03 s. During this time period the centre of gravity covered a distance of 0.85±0.03 m. Figure 2 shows how, during the course of kicking at the second attempt of kicking with the right leg, the position of the centre of gravity in the vertical axis was changing. The vertical line represents the moment when the capoeristas finished the kick, thus hitting the imaginary target.

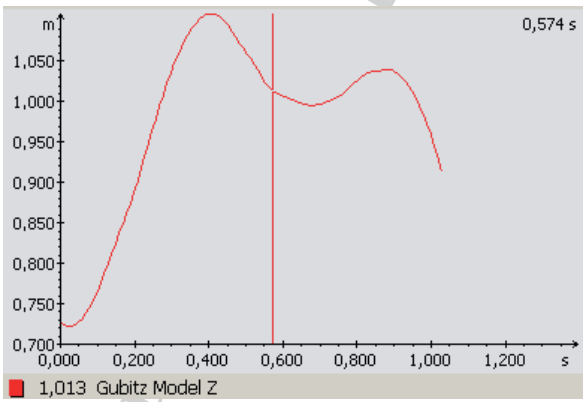

Fig. 2. Movement of the centre of gravity in a vertical axis at the second attempt of kicking with the right leg

For the quality of performance of this skill the kicking limb seems to be essential. The interest was mainly in the characteristics of the ankle. The maximal speed reached by this anatomical point was 7.96±0.5 m.s^{-1}, which was recorded at the moment of initiating the main phase (Fig. 1, microphase 4),

Tab. 1. Table of results

	kick – left 1	kick – left 2	kick – left 3	kick – right 1	kick – right 2	kick – right 3	mean	SD
preparation: knee forw. - angle (°)	149.1	138.7	141	156.3	132.3	122.5	**140**	**11.0**
preparation: knee back. - angle (°)	134.4	143.3	140	136.9	141.1	143.6	**140**	**3.3**
preparation: elbow forw. - angle (°)	62	68.1	68.8	72.6	82.4	68.2	**70.4**	**6.2**
preparation: elbow back. - angle (°)	155.7	141	152.6	151.9	165.3	145.6	**152**	**7.7**
preparation: COG - height (m)	0.742	0.74	0.81	0.739	0.726	0.7	**0.74**	**0.03**
COG - distance (m)	0.864	0.82	0.81	0.884	0.88	0.858	**0.85**	**0.03**
kicking ankle - distance (m)	2.578	2.575	2.541	2.646	2.533	2.499	**2.562**	**0.05**
kicking ankle - max. velocity (m/s)	8.651	7.629	7.642	8.638	7.377	7.778	**7.956**	**0.5**
kicking knee (v ankle = max.) - angle (°)	90.6	88.6	102.8	103.1	99.3	103.1	**97.9**	**6.1**
kicking hip - distance (m)	0.079	0.088	0.078	0.065	0.064	0.085	**0.077**	**0.01**
hit: COG - height (m)	0.97	0.942	0.963	0.989	1	0.99	**0.976**	**0.02**
hit: standing knee - angle (°)	138.4	124.5	138.5	127.9	134.9	137	**133.5**	**5.4**
preparatory phase: time (s)	0.32	0.3	0.41	0.3	0.29	0.3	**0.32**	**0.04**
flight phase: time (s)	0.15	0.14	0.12	0.14	0.18	0.16	**0.15**	**0.02**
finish phase: time (s)	0.14	0.2	0.12	0.17	0.12	0.12	**0.15**	**0.03**
total kick: time (s)	0.61	0.64	0.66	0.61	0.59	0.58	**0.62**	**0.03**

when the knee of the kicking leg formed an angle of 97.9±6.1°. From this moment on, extensores started straightening the knee actively. Figure 3 illustrates the course of ankle velocity of the kicking foot at the second attempt of kicking with the right leg, whereas the vertical line signifies the moment at which the ankle reached its maximum speed. So the results show that the maximum speed was reached before the kick was finished.

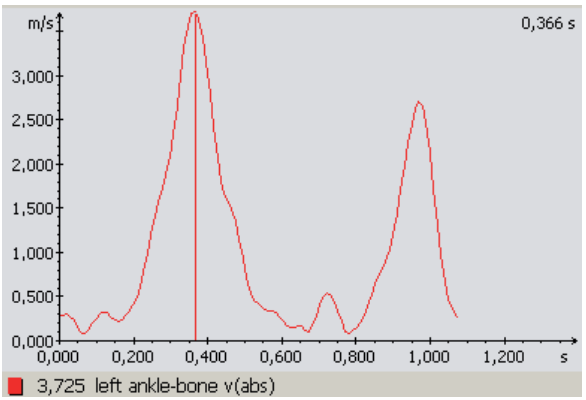

Figure 3. Course of velocity of the ankle of the left kicking leg at the second attempt of kicking

The trajectory by which the ankle approaches the target was also analyzed. The main interest was in the position changes in the vertical axis. Figure 4 shows the ankle of the kicking foot increasing steeply but fluently (red curve). The vertical (red) line in the graph illustrates the moment of finishing the kick. Thus, the vertical position of the ankle rises during the entire kick and reaches its highest point when hitting the imaginary target (Fig. 4). The second (green) curve presents the vertical movement of the centre of gravity. The total distance the ankle covered from the preparatory position to the moment of impact was 2.56±0.05 m.

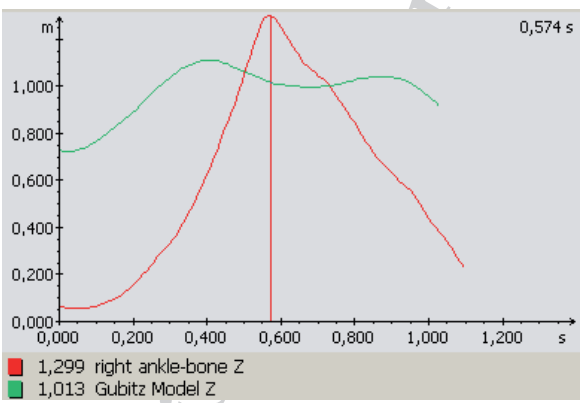

Fig. 4. Movement of the ankle of the kicking leg (red) and the centre of gravity (green) in the vertical axis

After there is maximum extension in the knee joint of the kicking leg, the ankle continues ahead towards the target, thanks to the movement of the hip, which the capoeiristas actively pushed forward for 0.077±0.01 m. In finishing the kick the standing lower limb is slightly flexed and the knee joint forms an angle of 133.5±5.4° (Fig. 1, microphase 8).

In conclusion, the timing of the kick was as follows: the preparatory phase until the moment of taking off from the standing leg lasted 0.32±0.04 s, the flight phase was 0.15±0.02 s and the phase from landing on the opposite lower limb to maximal flexion of the kicking leg, i.e., after finishing the kick, lasted 0.15±0.03 s. The total duration of the kick from the preparatory phase to finish was 0.62±0.03 s.

Discussion

Although a similar kick as the one described here exists in other combat sports, such as taekwondo (mirŏ ch'agi, pushing kick), scant scientific information is available on it. Hong *et al.* [2000] reported a performance time of 0.84±0.10 s for the standing pushing kick. Therefore, comparisons are limited to other forward kicks, such as the front and the roundhouse kicks in karate and taekwondo. Of necessity, the comparisons will have to be limited to common phases in the respective kicks.

The combat sport-specific characteristics of the kicks are evident when comparing the bencao kick to the standing front kick in taekwondo, for instance. Ankle speeds in experienced (not specified in terms of years of training) and beginning (years of training not indicated) *taekwondo-in* were 10.39±1.95 $m.s^{-1}$ and 8.18±1.76 $m.s^{-1}$, respectively [Landeo, McIntosh 2007].

Hip extension as well as knee extension just before (imaginary) target contact was also observed in the karate front kick and was suggested to be related to optimally contracting the muscles of the leg [Andrzejewski, Elbaum 2005].

In our study we found, that the ankle maximal velocity of kicking leg was reached significantly before hitting the imaginary target. This result is unsatisfactory, because the ankle velocity at the moment of impact is critical for kicks power. It would be suitable to provide measurement with hitting the target and compare results with this study.

Conclusions

On the basis of a theoretical analysis the key phases of the bencao kick were identified. With the use of 3D kinematical analysis we determined actual data of the most important spatio-temporal

characteristics. We are going to increase the sample of this study to define the pattern of the bencao kick. Next, we are going to extend the results of this work for analysis of other capoeira techniques, such as the martelo, armada, etc. and to compare their essential kinematic characteristics with analogous techniques from other martial arts (e.g., karate, aikibudo, etc.).

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Charakterystyka kinematyczna kopnięcia bencao z capoeiry

Słowa kluczowe: systemy walki, sztuki walki, capoeira, analiza kinematyczna, kopnięcie do przodu, bencao

Streszczenie

Artykuł stanowi charakterystykę kinematyczną kopnięcia *beneao* używanego w sztuce walki capoeira, która to zyskuje coraz większą popularność w Czechach. Autorzy pracy wykonali trójwymiarową kinematyczną analizę podstawowego kopnięcia *beneao.* Podmiotem badania był zaawansowany instruktor capoeiry, który wykonał kopnięcia prawą i lewą nogą do przodu. Przy użyciu dwóch aparatów cyfrowych z szybką migawką wykonano serię zdjęć, na podstawie których oceniono kinematyczną charakterystykę 13 punktów ciała. Kopnięcie zostało wykonane z podstawowego ruchu-*ginga*. W fazie przygotowawczej środek ciężkości znajdował się w odległości 0.74±0.03 m powyżej ziemi. Z tej pozycji środek ciężkości zmienił się w momencie uderzenia celu i wyniósł 0.98±0.02 m. Całkowity czas kopnięcia wyniósł 0.62±0.03 s. Maksymalna prędkość nogi wykonującej kopniecie wyniósła 7.96±0.5 m.s-1. Prędkość została zanotowana w momencie rozpoczęcia głównej fazy, kiedy kolano kopiącej nogi stworzyło kąt 97.92±6.1° i zaczęło się aktywnie napinać. Kinematyczna analiza 3D pozwoliła ustalić najważniejsze parametry przestrzenno-czasowe.

Autorzy wyrażają zamiar poszerzenia zakresu badań dotyczących innych technik capoeiry (*martelo, armada)* oraz porównać ich charakterystykę kinematyczną z analogicznymi technikami z innych sztuk walki. Badanie to stanowi część szerszych studiów na czeskim uniwersytecie w Masaryk, którego głównym celem jest biomechaniczna analiza różnych sportów między innymi sztuk walki i sportów walki.