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AFONSA JANAÍNA DA SILVA

ANÁLISE CINEMÁTICA E DINÂMICA DE CHUTES DO TAEKWONDO

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AFONSA JANAÍNA DA SILVA

ANÁLISE CINEMÁTICA E DINÂMICA DE CHUTES DO TAEKWONDO

Tese apresentada à Faculdade de Educação Física da Universidade Estadual de Campinas como parte dos requisitos exigidos para obtenção do título de Doutora em Educação Física, área de concentração Biodinâmica do Movimento e Esporte.

Orientador: Prof. Dr. RICARDO MACHADO LEITE DE BARROS

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A ATA DA DEFESA COM AS RESPECTIVAS ASSINATURAS DOS MEMBROS ENCONTRA-SE NO PROCESSO DE VIDA ACADÊMICA DO ALUNO.

DEDICATÓRIA

Dedico este texto aos momentos de impacto vividos até aqui.

Momentos estes que viram e definem nossas vidas.

Cada um de nós é a soma destes momentos vividos e de todas as pessoas que já conhecemos.

E são esses momentos que se tornam nossa história.

Como este que estou prestes a viver.

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Sentirei saudades...

Até breve.

RESUMO

O objetivo geral da presente tese foi analisar a cinemática e cinética de chutes do Taekwondo considerando os fatores: confiabilidade das variáveis a serem analisadas; efeito da vinculação a diferentes federações e correlação entre o sistema de graduação por faixas e as variáveis biomecânicas do chute; análise comparativa de momentos e potência nos chutes; e análise individualizada de técnicas de chute do Taekwondo executados por uma atleta olímpica. Os sujeitos desta pesquisa foram selecionados a partir de uma triagem nas academias localizadas nas proximidades do centro de pesquisa e filiadas às instituições internacionais organizadoras da modalidade. No total foram avaliados 37 praticantes de Taekwondo, sendo 28 homens (idade 23,6 anos ± 6,7, estatura 1,76m ± 0,09, massa corporal 75.1 kg ±13.6, 19 faixas pretas e 9 coloridas, 8 afiliados a ITF e 20 a WTF) e 9 mulheres (idade 23,2 anos ± 7,0, estatura 1,70m ± 0,32, massa corporal 71,9 kg ±19,0, 4 faixas pretas e 5 coloridas, todas afiliadas WTF). O sistema de análise cinemática DVideo foi utilizado para aquisição das coordenadas tridimensionais de marcadores retroreflexivos posicionados nos membros inferiores dos sujeitos. Os movimentos foram gravados por cinco câmeras (Basler, 100Hz) dispostas ao redor do sujeito. Duas plataformas de força (Kistler, 500Hz - Bioware) fixadas no solo foram utilizadas para aquisição das forças de reação do solo de ambos os membros inferiores. Foi utilizado um protocolo de marcadores para representação dos membros inferiores compatível com a representação das articulações com três graus de liberdade. Para obtenção das variáveis foi utilizado o software Visual 3D. As seguintes variáveis foram analisadas: a) velocidade linear do maléolo da perna de chute, b) tempo de execução, c) altura do alvo, d) distância ao alvo, e) ângulo e velocidades angulares da pelve, quadril e joelho, f) forças de reação do solo, g) momento articular do quadril e joelho e h) potência articular do quadril e joelho. Os dados foram analisados em relação aos seguintes fatores: 1) estilo competitivo, 2) nível técnico (graduação), 3) posição inicial para execução (controlada ou movimentação de luta) e 4) técnica de chute. Foram utilizados testes estatísticos não paramétricos para a comparação dos dados de acordo com os fatores estudados. Os principais resultados foram: o estilo competitivo influencia a cinemática da pelve e do quadril da perna de chute, o sistema de graduação por faixa do Taekwondo tem moderada correlação com as variáveis do chute - força de reação do solo, velocidade linear e tempo de execução, a posição inicial advinda da movimentação de luta afeta a forças de reação do solo de ambas as pernas e o mecanismo de potência gerada nas articulações é afetado pela técnica executada. De forma geral, os resultados apresentados nesta tese levantam informações relevantes a novas investigações na área de biomecânica dos esportes de combate, bem como, ao ensino e treinamento de força no Taekwondo.

Palavras-chave: artes marciais, biomecânica, nível técnico, estilo competitivo, mecanismo articular.

ABSTRACT

The general aim of this thesis was to analyze the kinematics and kinetics of Taekwondo kicks considering the factors: reliability of variables to be analyzed, effect of affiliation to different federations and correlation between the belt system and kick biomechanical variables, analysis comparative of selected kick moments and power, and individualized analysis of Taekwondo kick techniques performed by an olympic athlete. The subjects were selected from a screening at academies located near of research center and affiliated to the sport international institutions. In total 37 Taekwondo practitioners were evaluated: 28 men (age 23.6 years ± 6.7, 0.09 ± 1.76m height, mass 75.1 ± 13.6 kg, 19 black belts and 9color belts, 8 affiliated to ITF and 20 to WTF) and 9 women (age 23.2 years ± 7.0, ± 0.32 1.70 m height, mass 19.0 ± 71.9 kg, 4 black belts and 5 color belts, all WTF affiliated) . The DVideo kinematic analysis system was used to acquire three-dimensional coordinate of retro-reflective markers placed on subject lower limbs. The movements were recorded by five cameras (Basler, 100Hz) arranged around the subject. Two force platforms (Kistler, 500Hz - Bioware) fixed in the floor were used for the acquisition of both lower limbs ground reaction forces. A body representation model compatible that represents joints angles with three degrees of freedom was used for lower limbs representation. The Visual 3D software was used to obtain variables. The following variables of both lower limbs were analyzed: a) linear velocity of the kicking leg malleolus, b) execution time, c) target height, d) distance to the target, e) pelvis, hip and knee angles and angular velocities, f) ground reaction forces, g) hip and knee joint moment and h) hip and knee joint power. Data were analyzed in relation to the following factors: 1) competitive style, 2) skill level (graduate), 3) kick initial position (static or hopping) and 4) kick techniques. Non-parametric statistical tests were used to compare the data according to the studied factors. The main results were: competitive style influences the kinematics of the pelvis and the hip kicking leg, the Taekwondo belt system showed moderate correlation with kick variables - ground reaction force, kick linear velocity and execution time, the hopping initial position affects the ground reaction forces of both legs, and the power generated joint mechanism is affected by the kick techniques. In general the results presented in this thesis provide specific information relevant to new research in combat sports biomechanics, as well as, teaching and strength training in Taekwondo.

Key-words: martial arts, biomechanics, skill level, competitive style, joint mechanism.

SUMÁRIO

Introdução

A essência de qualquer esporte é superar limites, para o desempenho competitivo ou melhora de aptidão física. Aliada a outras disciplinas, a Biomecânica pode auxiliar na determinação dos fundamentos capazes de embasar o planejamento e a aplicação de um programa do treinamento esportivo (Gerry, 1998; Amadio e Serrão, 2011).

O conhecimento da mecânica dos movimentos esportivos tem reconhecida importância na seleção da melhor técnica, na decisão de modificar uma técnica em favor das características individuais dos atletas e na identificação das causas e correção de falhas técnicas (Gerry, 1998; Zatsiorsky, 2004).

As modalidades de esporte de combate mais praticadas de forma competitiva, tanto profissional quanto amadora são: karate, taekwondo, judô, jiu-jitsu e kung-fu (Fernandes *et al.*, 2011). Os principais esportes de combate foram objeto de estudo da Biomecânica, tendo sido analisados por diferentes métodos: a cinemetria, a dinamometria, a eletromiografia e a antropometria (Sforza *et al.*, 2002; Santos *et al.*, 2005; Oliveira *et al.*, 2006; Gulledge e Dapena, 2008; Neto e Magini, 2008).

Os esportes de combate no Brasil têm alcançado repercussão e visibilidade social por meio de seu engajamento em competições internacionais, tendo os jogos Olímpicos à expressão maior de sua apresentação e, desta forma, criando a demanda por profissionais qualificados que compreendam os princípios operacionais para adequação de aspectos associados à preparação física e orientação técnico-tática de atletas (Correia e Franchini, 2010). Dentre as modalidades de esporte de combate o judô é a modalidade com maior número de medalhas conquistadas (9) em jogos Olímpicos até Londres 2012, sendo seguido pelo boxe (3) e não menos importante pelo Taekwondo (1).

O Taekwondo é atualmente popular no mundo como uma forma de condicionamento físico e autodefesa. Sua abrangência como esporte de competição aumentou mundialmente após sua oficialização como esporte olímpico nos Jogos Olímpicos de Sydney, 2000.

O Taekwondo utiliza as mãos e os pés como instrumentos de ataque e defesa, diferenciando-se de outras lutas pela utilização de várias técnicas de chute. As técnicas de chute destacam-se como os principais instrumentos de ataque no Taekwondo, sendo comum a execução sucessiva destas durante a luta. Estas técnicas originam-se a partir da movimentação complexa dos membros inferiores, sendo o domínio de tais técnicas essencial ao desempenho competitivo.

Existem no mundo duas principais federações que se propõe a organizar e difundir a prática do Taekwondo: ITF - Federação Internacional de Taekwondo e WTF - Federação Mundial de Taekwondo. Ambas as instituições promovem luta entre dois oponentes com duração e tempo de intervalo semelhantes. Os atletas são divididos em categorias de peso corporal, com diferenças entre as federações, e os pontos são marcados de acordo com critérios semelhantes para as técnicas de pés e divergentes para técnicas de mão.

A análise biomecânica do Taekwondo evoluiu progressivamente de estudos de variáveis chaves ligadas a elementos dos chutes dos mais simples aos mais complexos: velocidade de execução e tempo de execução (Pearson, 1997; Falco *et al.*, 2009), correlação entre flexão e extensão do joelho da perna de chute e a velocidade máxima do chute (Kim, 2002), força de impacto e tempo de impacto (Pearson, 1997), forças de reação do solo (O'sullivan *et al.*, 2009; Estevan *et al.*, 2013; Chenga *et al.*, 2015). Alguns estudiosos focaram nas características dos participantes e fatores mecânicos que podem potencialmente afetar a execução do chute: efeito da distância ao alvo na velocidade do chute e no tempo de execução (Falco *et al.*, 2009; Estevan *et al.*, 2011), efeito da distância ao alvo nos movimentos da pelve e quadris da perna de apoio e de chute (Kim *et al.*, 2010), efeito da posição inicial para aplicação no tempo de execução, tempo de reação e velocidades dos segmentos (Estevan *et al.*, 2013), posição da perna de chute em relação à perna de apoio (Kong *et al.*, 2000; Lara *et al.*, 2011), diferentes técnicas de chute (Falco *et al.*, 2011), praticantes de diferentes modalidades de esporte de combate (O'sullivan *et al.*, 2009). Após os jogos Olímpicos de Pequim o novo critério de pontuação, atribuindo maior pontuação a chutes direcionados a face do oponente, criou uma nova demanda por estudos que analisassem a biomecânica de técnicas de chutes altos (O'sullivan *et al.*, 2009; Estevan *et al.*, 2012), sendo o chute semicircular o mais utilizado em combate (Kim *et al.*, 2011). Torna-se fundamental compreender suas diferenças ao ser aplicado ao tronco (Bandal chagui) ou face (Dolyo chagui).

Embora diferentes estudos tenham sido conduzidos em busca de compreender a biomecânica dos chutes do Taekwondo, poucos consideraram aspectos característicos do combate competitivo como: a movimentação característica da luta (Kim *et al.*, 2015), a análise conjunta da perna de chute e apoio (Kong *et al.*, 2000; Kinoshita e Fujii, 2014), ou a influencia dos estilos propostos pelas principais federações (Pedzich *et al.*, 2012).

As diferenças culturais entre as federações (ITF e WTF) resultam em diversidade entre regras competitivas, bem como, nos métodos de ensino e treinamento. Pedzich *et al.*

(2012) demonstrou estas diferenças ao comparar torques musculares estáticos entre atletas de ambas federações.

Considerando o âmbito competitivo, outro aspecto a ser considerado é o grau de habilidade exigido para se competir. As grandes competições em Taekwondo (Olimpíadas e Mundiais) de ambas as federações exigem aos seus participantes um requisito mínimo, o grau de faixa preta. Compreender as relações entre o sistema de graduação por faixas no Taekwondo e as variáveis biomecânicas das técnicas de chute pode auxiliar no aperfeiçoamento das estratégias de ensino e treinamento.

Um importante fator que pode potencialmente afetar a execução dos chutes e os resultados no Taekwondo é a variabilidade advinda das particularidades na execução de cada atleta (Estevan *et al.*, 2013). Segundo Hopkins *et al.* (1999) é importante conhecer a variabilidade no desempenho de um grupo de atletas, pois esta variabilidade pode ser determinante na conquista de resultados, bem como, pode representar as diferenças entre as habilidades dos atletas. Desta forma, estabelecer a confiabilidade das variáveis biomecânicas permite que o pesquisador determine quão fortemente as medidas de cada atleta assemelham-se entre si e para com seus oponentes.

Outro fator pouco abordado na literatura específica é a demanda dos esportes de combate em gerar potência no final da cadeia de movimento, no caso do Taekwondo nos pés preferencialmente. Como posto, grande parte dos estudos focaram em aspectos cinemáticos dos chutes do Taekwondo, poucos até hoje objetivaram o entendimento dos mecanismos de produção e absorção de potência nos membros inferiores durante a execução dos chutes (Cabral *et al.*, 2011; Jandačka *et al.*, 2013). Este tipo de análise demanda um desenvolvimento instrumental e metodológico complexo, bem como fornece informações fundamentais ao aperfeiçoamento do treinamento de força de atletas (Kinoshita e Fujii, 2014; Selbie *et al.*, 2014).

Isto posto, o objetivo central da tese foi analisar a biomecânica de chutes selecionados do Taekwondo, considerando os seguintes fatores intervenientes: 1) confiabilidade das variáveis a serem analisadas; 2) efeito da vinculação do atleta à ITF ou WTF sobre a biomecânica de chutes selecionados; 3) análise da correlação entre o sistema de graduação por faixas e as variáveis biomecânicas do chute e 4) análise comparativa de momentos e potência articulares no Bandal e no Dolyo; e 5) análise individualizada de técnicas de chute do Taekwondo executados por uma atleta olímpica.

Desta forma, os objetivos específicos da presente tese foram:

- analisar a confiabilidade das variáveis cinemáticas do chute Dolyo chagui,
- comparar variáveis cinemáticas do chute Dolyo chagui entre praticantes de Tekwondo das principais federações internacionais da modalidade, World Taekwondo Federation (WTF) e International (ITF),
- investigar a existência de correlação entre o sistema de graduação por faixa no Taekwondo e variáveis cinemáticas e dinâmicas das técnicas de chute.
- comparar o momento e a potência articular gerados nos membros inferiores durante a execução do chute semicircular do Taekwondo direcionado ao tronco (Bandal chagui) e face (Dollyo chagi) e executados por atletas com diferentes níveis de habilidade.
- avaliar a cinemática de diferentes técnicas de chute executados por uma atleta de alto nível,

Diferente do modelo tradicional de redação de tese foi proposto neste estudo aproximar o tópico de análise e discussões dos resultados a cada um dos assuntos abordados nos capítulos. Desta forma, a tese apresenta-se através da junção de artigos produzidos no decorrer do processo de doutorado.

O plano de redação foi assim composto:

- Uma *introdução*, para detalhar o contexto de estudo em biomecânica do Taekwondo (essa que se segue),
- Cinco *capítulos/artigos*, cada um referente a um objetivo específico da tese,
- *Considerações finais*, fechamento e desdobramento das idéias discutidas nos capítulos/artigos.

Capítulo I

RELIABILITY OF BIOMECHANICAL VARIABLES DURING DOLYO CHAGUI IN TAEKWONDO

Introduction

It is conventional for sport researches to deliver reports after evaluating athletes. In order to generate a report, it is common to compare the various measurements with reference to values or previous evaluations in order to classify the athlete performance. However, the execution particularities of each athlete could affect the measurements when comparing groups (Hopkins *et al.*, 1999).

In order to surprise the opponent, it is common for the combat sports athlete to execute the same technique in different ways (e.g. amplitudes, motion phase range). This intra-subject variability could affect the data. Furthermore, it is important to analyze the role of the individual variability in the group.

Dolyo chagui, also known as roundhouse kick to the head, is the most used and studied technique in Taekwondo (TKD). Nevertheless, the reliability of the main variables used to describe this movement biomechanically is not well known.

The most accurate design of a biomechanical study will not overcome the damage caused by unreliable or imprecise measurements. A fundamental component of a study that has randomization as its objective is the requirement of high quality measurement (Fleiss, 1999). Some of the unfortunate consequences of unreliable measurement are sample sizes larger than necessary and biased estimates.

Reliability is the overall consistency of a measurement. It ensures the measurement quality through the knowledge of the variance proportion assigned to objects of measurement (Mcgraw e Wong, 1996). Establishing the measurement reliability enables the researcher to know how similar the same group measurements are.

Nevertheless, biomechanical variables reliability in Taekwondo is still relatively limited. Only a few studies stated to have tested their variables this way. Estevan *et al.* (2013) in a study on the stance position effect on kick performance in Taekwondo through video analysis determined the reliability of the following biomechanical variables in round house kick: reaction time, execution time, ground reaction force, and thigh, shank, and foot velocity peaks. Nevertheless the reliability of both lower limbs angular variables during TKD kick execution was rarely detailed in specific literature. Thus the aim of this study was to evaluate the reliability of execution time, and linear and angular variables of the kicking and supporting legs during the Dolyo chagui execution in Taekwondo.

Methods

Seventeen male TKD athletes with average age of 26 (7.5) years, height of 1.77 (0.08) m, mass of 76.3 (10.3) kg and 12 (5.6) years of experience, participated in the study voluntarily. All of them were 1 to 5 DAN graduation black belt holders. Ethics approval was secured from the Research Ethics Committee of Scholl of Medical Sciences - Unicamp (CEP Nº237/2011) and informed consents were obtained from the participants prior to data collection.

After warm up and stretch in accordance with their routines, the anatomical markers were placed on the athlete's body. A static trial was collected first, with the participant in the anatomical reference position. The athletes performed three Dolyo chagui repetitions with the preferred limb. A sparring doll positioned in front of the athlete was used as a target. It was elevated until it reached the participant's head height. An extra marker was placed on the top of the sparring doll head (fig. 1). The initial position of the kicking leg was behind the supporting leg (fig. 1). In order to reproduce the combat situation, the athlete was allowed to choose the preferred distance to hit the target and to bounce on the floor until the kick was executed

A total of sixteen reflexive markers were placed on the athlete's body, in particular anatomical places: anterior and posterior superior iliac spines, great trochanters (right, left), epicondyles of the femur (lateral, medial), malleolus (lateral, medial) and one distal third of the gastrocnemius (right, left). The athlete's body was modeled with five segments: pelvis, thighs and shanks (right and left). The medial markers were removed after this trial to prevent any interference in the kicking motion.

The DVideo kinematic analysis system was used to obtain the markers three dimensional coordinates (Figueroa *et al.*, 2003; Barros *et al.*, 2006). The system consisted of five Basler cameras (A602fc) working at 100 Hz. A calibration frame with 162 control points was used for camera calibration based on a nonlinear calibration method (Silvatti *et al.*, 2009). The data was filtered with a Butterworth 4th order low pass filter with a cut-off frequency of 10 Hz, set based on spectral analysis.

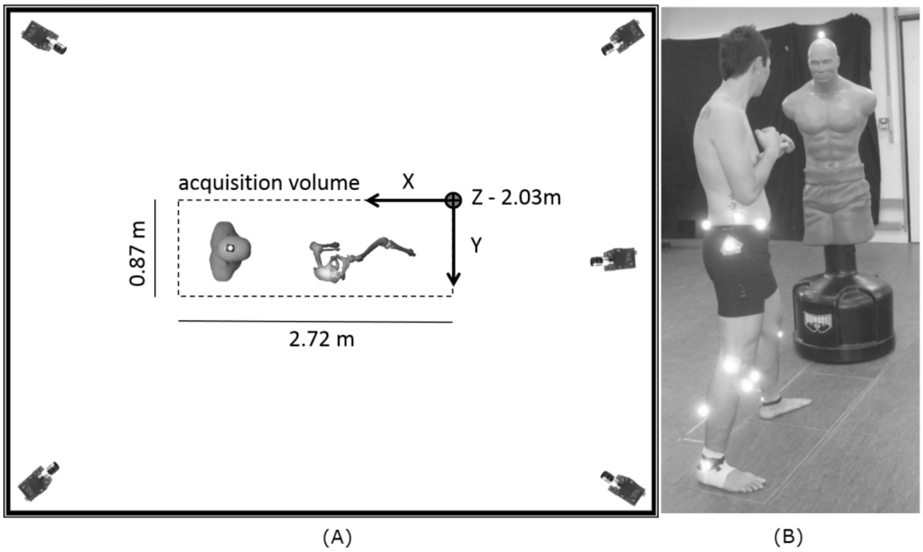


Figure 1(A) Cameras set up. (B) Initial position.

The local coordinate system of the pelvis, right and left thighs and shanks were defined in the Visual 3D Professional software (v5.01.11). Pelvis orientation angles were computed in relation to the global reference system, thighs orientation angles were computed in relation to the pelvis reference system, and shanks orientation angles were computed against the thighs reference system, with a XYZ Cardan sequence.

Data analysis was performed on three pre-determined kick movement events. The events were defined with basis on literature (Kim, 2002; Kim *et al.*, 2010): A) Start, B) Execution Phase and C) Impact. These conditions were determined objectively by an algorithm, which was designed with basis on the analysis of the kicking leg lateral malleolus anterior-posterior velocity and the sparring doll marker scalar velocity. The Start condition was defined as the instant prior to the detectable 0.1 m/s threshold of the kicking leg malleolus velocity in the anterior-posterior direction. The Impact was defined as the moment of the doll head marker first detectable movement, the previous moment before reaching the sparring doll marker velocity 0.1m/s threshold. The Execution Phase was considered as the period between the Start and the Impact. The maximum values of each variable during the execution phase were analyzed. The linear variables and time were defined trough the scalar position and kicking leg lateral malleolus velocity (execution time - period of time between A and C, target distance - perpendicular distance from the supporting leg to the target at A, impact distance - straight distance between the malleolus position in A and C, trajectory length - the malleolus trajectory between A and C, impact velocity- kicking leg malleolus velocity in C, and kicking leg malleolus maximal velocity - malleolus maximal velocity in B).

The pelvis, hips and knee (left and right) angles and angular velocities, at the selected conditions (start, execution phase and impact), were extracted and used as variables.

Preliminary analysis (Anderson-Darling) showed a non normal distribution of all the considered variables. In order to describe the biomechanical variables reliability, the intraclass correlation coefficient (ICC) was calculated. The variables between subjects and observations absolute agreement was tested, considering the different athletes (*n* - rows) and their kick repetitions (*k* - columns) as variance systematic sources. A two-way model for single measurement was used to represent the data (Eq.(1)). Preliminary analyses of variance on a randomized block data provided the three mean squares used in the ICC calculation: a mean square for rows (MS_R), a mean square for columns (MS_C), and a residual mean square referred to as mean square error (MS_E) (Mcgraw e Wong, 1996). The adopted ICC classification was: poor agreement (ICC≤0.4), satisfactory agreement (0.4<ICC<0.75), excellent agreement (ICC≥0.75) (Fleiss, 1999).

$$ICC = \frac{MS_R - MS_E}{MS_R + (k-1)MS_E + \frac{k}{n}(MS_C - MS_E)} \qquad (1)$$

Results

The typical curves of kicking leg knee flexion angle and malleolus scalar velocity, as well as the sparring doll head marker scalar velocity are presented in figure 2. The figure shows the intra-subject variability when executing the Roundhouse kick to the head. The three curves were synchronized by the kicking leg malleolus scalar velocity pick

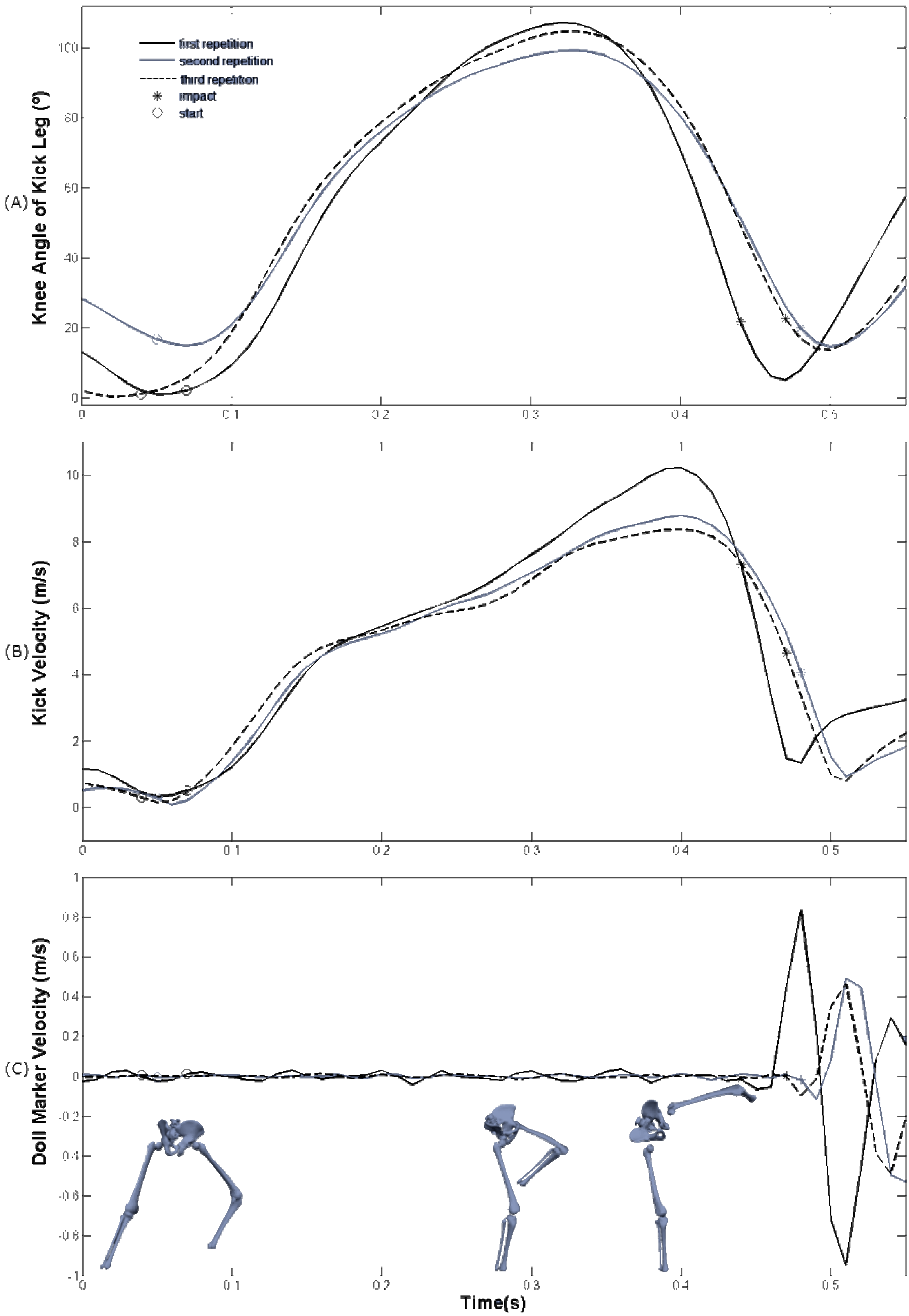


Figure 2 Example of the roundhouse kick motion three repetitions executed by a Taekwondo experienced athlete. Typical curves of kicking leg knee flexion angle (A), kicking leg malleolus scalar velocity (B) and of scalar velocity of sparring doll head marker are shown (C). Body postures at different conditions are presented (C): start, maximal knee flexion and impact.

Table1 details the execution time and linear biomechanical variables (malleolus impact velocity, malleolus maximal velocity, target distance, impact distance and trajectory length) statistics. The variables showed ICC ranging from 0.59 to 0.96 with the majority set in the excellent agreement. Only the execution time and the malleolus impact velocity demonstrated satisfactory agreement.

Table 1 Descriptive data of execution time and linear variables for each motion event and intra-class correlation coefficient (ICC) and confident interval**.**

	Mean	SD	ICC (95% CI, inf-sup limits)
Execution Time (s)	0.40	0.04	0.59 (0.31-0.81)
Malleolus Impact Velocity (m/s)	8.18	1.60	0.65 (0.38-0.84)
Malleolus Maximal Velocity (m/s)	10.66	1.50	0.86 (0.72-0.94)
Target Distance (m)	1.02	0.09	0.82 (0.65-0.92)
Impact Distance (m)	2.18	0.12	0.96 (0.91-0.98)
Trajectory Length (m)	2.49	0.12	0.77 (0.57-0.90)

Table 2 presents the angular biomechanical variables in the three movement events (the angles and velocities of pelvis segment, hip and knee joint of supporting and kicking legs) statistics. The pelvis, hip and knee angles of both legs ICC ranged between 0.75 - 0.99 in the three analyzed events, demonstrating excellent agreement. The only exception was the kicking leg knee flexion/extension angle at the impact event (0.20). The results for the angular velocities showed an ICC range between 0.27 - 0.80, with most velocities presenting satisfactory agreement.

Table 2 Descriptive data of angular variables for each motion event, intra-class correlation coefficient (ICC) and confident interval.

	Start			Execution Phase			Impact		
	Mean	SD	ICC (95% CI, inf-sup limits)	Mean	SD	ICC (95% CI, inf-sup limits)	Mean	SD	ICC (95% CI, inf-sup limits)
Pelvis Tilt (º)	4.7	6.9	0.90 (0.80-0.96)	12.7	9.43	0.82 (0.66-0.93)	23.8	16.2	0.94 (0.87-0.98)
Pelvis Obliquity (º)	8.3	8.4	0.92 (0.84-0.97)	11.0	5.8	0.91 (0.81-0.96)	-6.5	9.1	0.99 (0.97-0.99)
Pelvis Rotation (º)	-47.1	11.8	0.95 (0.88-0.98)	77.9	32.7	0.91 (0.81-0.96)	-7.3	11.9	0.97 (0.94-0.99)
V Pelvis Tilt (º .s^{-1})	-11.7	42.4	0.34 (0.03-0.65)	53.4	88.6	0.88 (0.75-0.95)	-72.8	88.4	0.52 (0.23-0.77)
V Pelvis Obliquity (º .s-1)	0.20	40.9	0.11 (-0.14-0.46)	27.3	49.9	0.55 (0.26-0.78)	-91.8	69.5	0.90 (0.80-0.96)
V Pelvis Rotation (º .s-1)	110.1	72.2	0.70 (0.46-0.87)	525.8	157.1	0.96 (0.91-0.98)	-19.6	153.7	0.72 (0.49-0.88)
S Hip Flex/Ext (º)	36.8	9.6	0.90 (0.79-0.96)	41.8	8.9	0.94 (0.86-0.97)	20.9	20.1	0.91 (0.82-0.97)
S Hip Add/Abd (º)	-20.8	13.1	0.91 (0.82-0.97)	-7.1	5.3	0.91 (0.81-0.96)	-49.9	4.9	0.82 (0.64-0.92)
S Hip Int/Ex Rot (º)	31.4	25.4	0.99 (0.98-0.99)	-2.7	9.1	0.97 (0.93-0.99)	11.1	18.1	0.95 (0.89-0.98)
S *V*Hip Flex/Ext (º . s-1)	-57.6	79.9	0.33 (0.04-0.65)	252.4	95.0	0.57 (0.28-0.80)	42.6	125.2	0.74 (0.53-0.89)
S *V*Hip Add/Abd (º . s-1)	-7.7	104.6	0.43 (0.14-0.70)	136.9	46.8	0.70 (0.46-0.86)	33.9	45.2	0.55 (0.27-0.78)
S *V*Hip Int/Ex Rot (º . s-1)	-16.0	200.0	0.57 (0.29-0.79)	111.9	41.4	0.54 (0.25-0.78)	22.4	32.7	0.55 (0.27-0.78)
K Hip Flex/Ext (º)	-3.4	9.6	0.87 (0.74-0.95)	24.9	15.6	0.95 (0.90-0.98)	10.2	20.7	0.95 (0.89-0.98)
K Hip Add/Abd (º)	-10.9	6.7	0.86 (0.72-0.94)	-7.3	5.8	0.93 (0.82-0.97)	-42.5	4.8	0.85 (0.70-0.94)
K Hip Int/Ex Rot (º)	-8.9	10.9	0.99 (0.97-0.99)	-4.7	9.6	0.97 (0.94-0.99)	-11.2	15.0	0.98 (0.96-0.99)
K*V*Hip Flex/Ext (º . s-1)	-14.6	96.4	0.36 (0.06-0.66)	286.5	75.8	0.49 (0.19-0.75)	-1.9	205.2	0.75 (0.54-0.89)
K *V*Hip Add/Abd (º . s-1)	-24.9	66.4	0.51 (0.22-0.76)	88.7	55.8	0.45 (0.15-0.73)	-0.4	62.7	0.58 (0.30-0.80)
K *V*HipInt/Ex Rot (º . s-1)	-42.3	107.1	0.57 (0.28-0.80)	90.3	36.6	0.40 (0.11-0.69)	4.2	49.5	0.40 (0.10-0.69)
S Knee Flex/Ext (º)	36.8	9.6	0.78 (0.58-0.91)	3.0	9.9	0.86 (0.73-0.94)	5.7	10.3	0.79 (0.60-0.91)
S *V*Knee Flex/Ext (º . s-1)	-57.6	79.9	0.27 (-0.03-0.60)	-276.1	70.9	0.46 (0.15-0.73)	201.1	81.6	0.60 (0.33-0.82)
K Knee Flex/Ext (º)	20.8	12.9	0.75 (0.54-0.89)	8.9	9.4	0.86 (0.72-0.94)	23.8	16.2	0.20 (-0.09-0.54)
K *V*Knee Flex/Ext (º . s-1)	-14.6	96.4	0.36 (0.06-0.66)	941.4	226.4	0.66 (0.41-0.85)	923.9	259.7	0.35 (0.04-0.66)

Note: *V*-Velocity, S- supporting leg, K-kicking leg, Flex/Ext - Flexion/Extension, Add/Abd- Adduction/ Abduction, Int/Ex Rot - Internal/External Rotation.

The angular velocities best results were observed for pelvis segment velocities, which ranged from satisfactory to excellent reliability at the execution phase and impact. Poor reliability was observed only at the start event for pelvis tilt and obliquity. The rotation velocity presented a satisfactory reliability in this event.

Regarding the supporting leg hip velocities, satisfactory reliability was observed for all planes and events. The only exception was the flexion/extension velocity at the start event (poor reliability). The kicking leg hip presented the same results, with the exception of the flexion/extension velocity at the start event and internal/ external rotation velocity at the execution phase and impact.

Concerning the knee flexion/extension velocity of both legs, the supporting leg knee presented satisfactory reliability at the execution phase and impact. The reliability was poor only at the start event. On the other hand, the kicking leg knee showed satisfactory reliability only at the execution phase, being poor at the other ones.

Discussion

To the best of our knowledge, a study describing the biomechanical variables reliability of the Taekwondo kick analyzed in this study has not yet been published.

The aim of this study was to analyze the reliability of select biomechanical parameters in the Dolyo chagui in Taekwondo, considering three movement events (start, execution phase and impact).

The results provide evidence to support the reliability of the measurements between TKD athletes.

The linear variables (malleolus maximal velocity, target and impact distance, trajectory length) ICC was above 0.75, which means it can be considered as having good reliability (Fleiss, 1999), with agreement among subjects measurements and kick repetitions. The only exception was the malleolus impact velocity, which presented satisfactory reliability. It suggests that the athlete's techniques change more when they hit the target. It could be due to each athlete’s strategy to hit the target with preferred force and velocity.

Pelvis, hip and knee angles of both legs presented ICC above 0.75 at all events that were analyzed. This suggests that the attitude of angles during Dolyo kick could provide reliable results. The angles ICC single exception was the kicking leg knee flexion/extension angle at the impact event, which could be an effect of a greater variability between subjects and repetitions.

In terms of angular velocities, a great variability of ICC results for the different variables through the three events was observed. Regarding segment and joints, an excellent reliability was observed only for pelvis velocities. Concerning these events, the best ICC for velocities were observed at the execution phase. The reasons for that could be due to increased inter/intra subject variability or to the possible error propagation related to the numerical procedures to obtain the derivate.

Fleiss (1999) concluded that unreliable measurements of response variables increase the sample size. On the other hand, measurement with excellent reliability could be used in studies with smaller samples (15 - 20). This way, the pelvis, hip and knee angles measurement and the linear variables of this group could be used without concern, while angular velocities should be used carefully.

In the present study, the subjects were expert black belt athletes. This could explain the execution low variability detected by the ICC analysis. Future studies are necessary to establish the kinematic variables reliability among different age or level groups.

Conclusion

The variables reliability was tested through a two-way model for a single measurement, which proves the absolute agreement of variables among the different athletes and their kick repetitions.

Therefore, the Dolyo chagui biomechanical variables reliability for experienced athletes showed excellent agreement between the variance assigned to athletes and kick repetitions for pelvis, hip and knee angles, and linear variables (malleolus maximal velocity, target and impact distance, trajectory length). The pelvis, hip and knee angular velocities reliability was more affected by the proportion of variance assigned to the athletes and repetitions, presenting worst reliability.

These results might not be the same for other Taekwondo kicks and for athletes with different training levels, which suggests that biomechanical variables reliability should be examined prior to any biomechanical investigation.

Capítulo II

BIOMECHANICAL COMPARISON OF DOLYO CHAGUI KICK PERFORMED BY ATHLETES OF INTERNATIONAL AND WORLD TAEKWONDO FEDERATIONS: ITF vs. WTF

Introduction

Taekwondo (TKD) is a Korean martial art which combines kick and punch techniques to combat or self defense. TKD was developed in the 1940's, through a combination of Okinawan Karate, Korean Kongsudo and Tansugo. It was called Taesudo in 1950's, when it was improved by a variety of masters from the Korean army. Renamed as TKD in 1960's, it received the official support of the South Korean Government (Burdick, 1997; Gillis, 2008).

TKD has two main competition systems, organized by two distinct federations: ITF- International Taekwondo Federation and WTF-World Taekwondo Federation. Both institutions promote combat between two opponents on an identical mat, with similar round duration and resting time. The athletes are divided into weight categories and points are scored according to similar criteria. Some points however are validated through an electronic waistcoat in WTF whereas ITF does not use such equipment. There are also differences in some rules: WTF allows knockouts and forbids head punches whereas ITF allows head punches and forbids knockouts.

Many aspects of TKD have been scientifically investigated, such as speed and movement time of the kicking foot (Falco *et al.*, 2009; Estevan *et al.*, 2011), and impact force (O'sullivan *et al.*, 2009), among others. Recently, some authors have focused on the legs and pelvis joint angles kinematics (Lara *et al.*, 2011). This computation requires segmental reference frames defined by landmarks at the respective segment, which results in a more complex analysis that could highlight movement pattern details in kicking techniques. Kim and co-authors (2010) used this strategy to analyse the target distance effect in pivot hip, trunk, pelvis and kicking hip movement.

One reason to improve the knowledge about the possible differences among practitioners of both federations is the possible unification of the sport which has been globally discussed in recent years. Some reasons supporting the unification are the common historical origin, the similarity of both styles and the advantages of having TKD as a sport with a stronger global presence than presently. However, after a long period of separate development, the same basic strokes may present technical differences.

The study of possible performance biomechanical differences could provide insights to help future adaptations towards a unified sport. Beyond this reason, the performance biomechanical comparison of practitioners of both modalities can provide a better understanding of the characteristics of each one, helping the training and the overall improvement of the sport.

Only few aspects of both federations were analyzed: the importance of anthropological characteristics and technical and tactical competence to success in TKD (Cular, Munivrana, *et al.*, 2013), the fitness status effect on success in TKD (Cular, Krstulovic, *et al.*, 2013), and the muscle torque differences under static condition (Pedzich *et al.*, 2012). Therefore the aim of this study was a biomechanical comparison of Dolyo chagui performed by ITF and WTF expert athletes.

Methods

Subjects

Seventeen black belt male TKD athletes were divided in two groups, one with eight ITF practitioners and the other with nine WTF practitioners. All participants were recruited in local gyms affiliated to the international federations. Only the volunteers with previous local competition experience were included. Ethics approval was secured from the Research Ethics Committee of Scholl of Medical Sciences - Unicamp (CEP Nº237/2011) and informed consents were obtained from the participants prior to data collection. The groups' characteristics are presented in Table 1.

Table 1 Means (SD) of time of practice and anthropometrical characteristics of the athletes and technical graduation (DAN).

	ITF	**WTF**
Time of practice (years)	12 (7)	11 (4)
DAN	1 - 5	1 - 4
Weight (kg)	70.8 (11,63)	74.00 (8.94)
Height (m)	1.74 (0.09)	1.77 (0.08)
Age (years)	25 (10)	26 (4)

Experimental procedures

Prior to data collection, each athlete was required to warm up and stretch in accordance with their routines. A sparring doll, with a retro-reflexive marker on the top of its head was used as a target. The doll was positioned in front of the athlete, in their preferred target distance and leveled to the participant's head height at the initial position to kick. After the warm up, the retro reflexive makers were placed on the athlete's body according to the biomechanical model.

Each participant performed three Dolyo chagui repetitions with the preferred limb. The kicking leg started behind the supporting leg. Verbal instructions were given on each trial, so the athletes would perform the kick with the objective of reproducing a successful kick in competition. In order to simulate the combat condition, the athletes were allowed to move as in combat, hopping until the command 'go'. Sufficient resting (1 to 2 minutes) were allowed between the trials to prevent exhaustion.

Biomechanical model

The biomechanical model used to represent each athlete’s body was developed in the Visual 3D Professional software (v5.01.11). It consisted of five linked rigid body segments: pelvis, thighs and shanks (right and left), and four joints: right and left hip and knee joints. Figure 1 illustrates the marker set, constituted by 16 anatomical retro-reflective markers and the location and attitude of the segment local coordinates system. The Pelvis was oriented in relation to the global reference system. Thighs and shanks were oriented in relation to their proximal segments according to a XYZ Cardan rotation sequence.

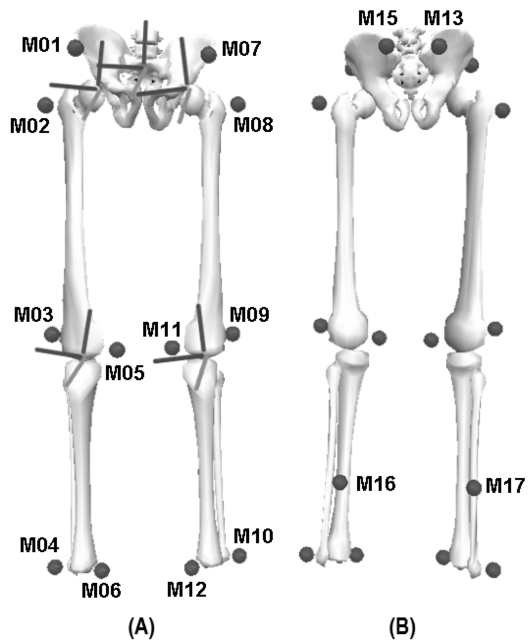


Figure 1 Marker set and local coordinates systems used to represent the athlete's body. (A) Front view, (B) Posterior view. M01, M07 - right and left anterior superior iliac spines, M13, M15 - right and left posterior superior iliac spines, M02, M08 - right and left great trochanters, M03, M05, M09, M11 - lateral and medial epicondyles of femur of right and left legs, M04, M06, M10, M12 - lateral and medial malleolus and M16, M17 - 2/3th distal of shank. Axis X was considered as the latero-larteral axis, Y axis as anterior-posterior and Z the vertical axis.

Kinematics analyses system

The DVideo kinematics analyses system (Figueroa *et al.*, 2003; Barros *et al.*, 2006) was used to obtain the markers 3D coordinates. The movements were recorded by five Basler cameras (model A602fc), working at 100 Hz. The camera calibration was done by using a nonlinear procedure, as described by Silvatti et al (2009, 2012). The coordinates were filtered with a low pass 4^{th} order digital Butterworth filter with a 10 Hz cut-off frequency, defined by spectral analysis.

Statistical analyses

To facilitate data analysis, a group of meaningful conditions was defined: 1) the Start, 2) the Execution phase, and 3) the Impact (fig. 2). Among the conditions, Start (the beginning of the motion) was automatically identified by a threshold in the kicking leg lateral malleolus anterior posterior velocity. Impact (the end of the motion) was automatically identified by a threshold in the sparring doll head marker latero-lateral velocity. The

Execution Phase was defined between the start and the impact conditions. The maximum values of each variable during the execution phase were used to compare the groups.

The execution time, linear and angular variables were defined according the movement condition. The execution time was defined as the time interval from Start to Impact and was normalized by target distance. Malleolus impact and maximal velocities were considered as the kicking leg lateral malleolus velocity in the instant before the Impact condition and the peak during the execution phase, respectively. The target distance was defined as the perpendicular distance between the supporting leg (lateral malleolus) and the target (sparring doll's head marker), at the Start condition. The impact distance was calculated as the vector norm between the kicking leg position at Start and Impact conditions, it was normalized by the athlete's trochanter height. Trajectory length was considered as the kicking leg trajectory length between Start and Impact conditions. The pelvis segment, hips and knees joints angles and angular velocities were extracted and used as variables for comparisons.

According to the Anderson-Darling test, data was not normally distributed. Therefore, nonparametric statistical tests were applied. In a previous study (Silva *et al.*, 2015), the TKD kinematical variables reliability was determined. Only variables with satisfactory ICC, over 0.43 for angular velocities, and excellent ICC, over 0.82 for joint angles, linear variables and execution time, were used in this study. The Mann-Whitney test was performed to compare the groups' characteristics, times of practice and graduation (DAN) variables. A one-way repeated measures Friedman test was performed to compare groups' linear variables and execution time. The statistical significance for all tests was adjusted at $p< 0.05$. After this procedure, in order to avoid the family-wise error rate at significant level, possibly caused by a multiple hypotheses tested in a small sample, a simple sequentially rejective multiple test was applied, the Holm correction (Holm, 1979). The objective was to tightly control type I errors. The corrected p-values ($p\_cor<0.05$) were used to test statistical differences. The mean values, standard deviations and box plot representations of three replicates of Dolyo chagui were used to describe data distribution. The data was analyzed by Matlab® (R2012a).

Results

No statistical difference between ITF and WTF was observed in groups's characteristics, times of practice and graduation (DAN) variables (Table 1), and on the execution time and linear variables (Table 2).

Table 2 Means and (SD) of the execution time and linear variables of Dolyo chagui executed by athletes of International and World Taekwondo Federations. Friedman test**,** *p_cor<0.05.

VARIABLES	**ITF**	**WTF**
Execution Time (s)	0.40 (0.05)	0.39 (0.05)
Malleolus Impact Velocity (m/s)	8.52 (1.34)	8.07 (1.72)
Malleolus Maximal Velocity (m/s)	10.81 (1.65)	10.59 (1.35)
Target Distance (m)	0.99 (0.09)	1.06 (0.09)
Impact Distance (m)	2.35 (0.09)	2.39 (0.16)
TrajectoryLength (m)	2.49 (0.09)	2.49 (0.14)

In order to better describe the differences between groups's execution, figure 2 presents examples of Dolyo chagui performed by two typical athletes, the first an ITF practitioner and the other, a WTF practitioner. The ITF athlete shows a pelvis anteversion attitude at start and reaches a retroversion attitude during the motion and ends in a smaller anteversion attitude. WTF, on the other hand, begins the motion in retroversion and ends it in a higher anterversion (fig.2A). The supporting leg hip joint remained on flexion and abduction for ITF, whereas WTF reaches a hip extension during motion (fig. 2B). The kicking leg knee joint remained on flexion throughout the whole kick in both groups (fig. 2C).

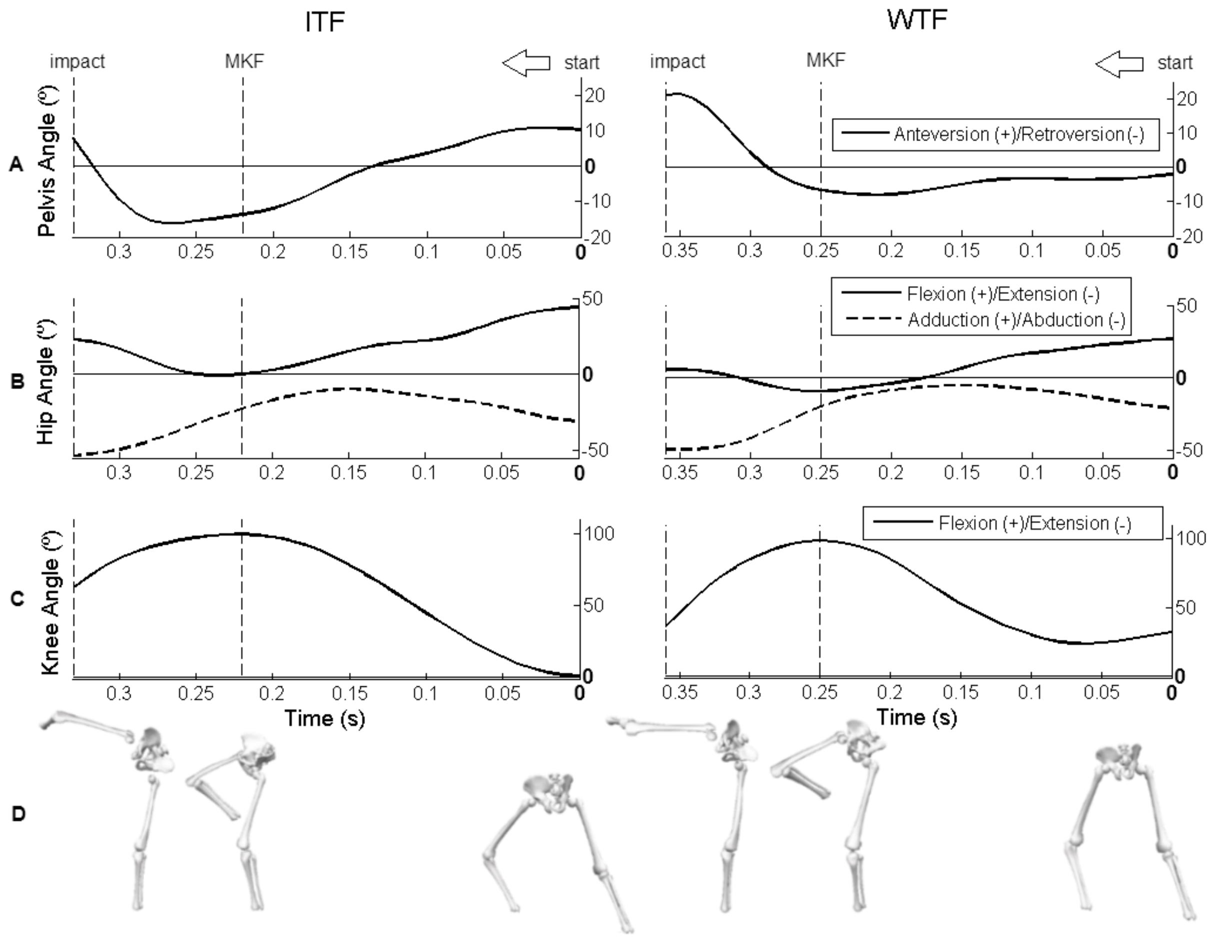


Figure 2 Typical motions of International (ITF) and World (WTF) Taekwondo Federations subjects performing Dolyo chagui. Typical curves of pelvis (A), supporting leg hip (B) and kicking leg knee (C) are shown. Body postures at different conditions are presented (D): Start, Maximal knee flexion (MKF) and Impact. In order to better visualize the pelvis motion in D, according with the coordination system, the time scale in graphics were reverse.

In terms of pelvis motion (fig. 3), significant differences were found in the left obliquity angles (ITF > WTF) compared at start condition. During the Execution phase, the ITF group pelvis presented higher left obliquity angles than the ones of WTF subjects. No significant difference was observed at Impact condition. The ITF group was characterized by a significantly left obliquity compared to WTF.

Concerning the supporting leg hip joint motion (fig. 3), significant differences were observed in the flexion angles (ITF > WTF) at the three conditions of motion (Start, Execution phase and Impact) and abduction angle at impact. The ITF group consistently showed an increased supporting leg hip flexion throughout the motion and increased hip abduction when hitting the target.

In terms of the kicking leg hip and both legs knee joints, no significant difference was observed at the three conditions of Dolyo chagui.

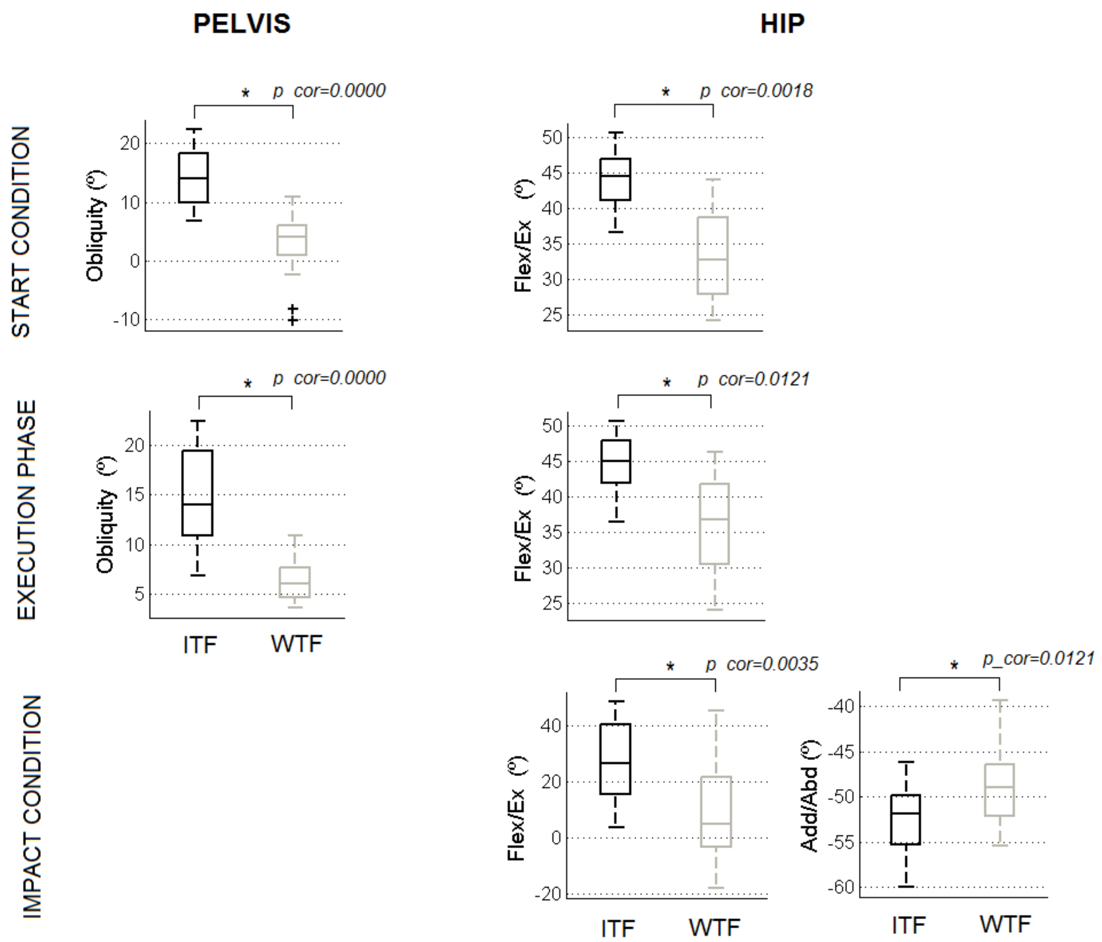


Figure 3 Box plot representation of pelvis and supporting leg hip angles at the start, execution phase and impact conditions in Dolyo chagui executed by International and World Taekwondo Federations athletes (ITF, WTF). Flex/Ex - Flexion/Extension, Add/Abd - Adduction/Abduction. Left obliquity, flexion and adduction were considered as positive sides. Only the joint variables that presented statistical difference between groups were presented. **p_corr*<0.05.

Discussion

Few studies were found in literature comparing athletes of different TKD federations. However, none of them investigated the kinematical differences in kick execution. In terms of biomechanical analysis, only one single study was found reporting the difference between ITF and WTF groups on muscle torque under isokinetic condition for lower extremity. According to Pedzich, Mastalerz and Sadowski (2012), the sum of muscle torque for lower right and left extremities was significant higher for WTF than ITF, 10% and

8% respectively. The author attributed the difference to the contact touch in combat, light-contact for ITF and full-contact for WTF. Regarding kinematic of pelvis, hips and knee during the kick techniques execution, no previous study comparing ITF and WTF athletes was found.

The results of the present study clearly show that athletes of both federations (ITF, WTF) execute the Dolyo chagui kick differently. The ITF group adopted a crouched overall attitude during the execution of Dolyo kick, revealed by the supporting leg hip flexion higher values. This strategy, adopted by ITF, could be the result tactics to escape from possible head punch attacks with the appropriated body balance, noting that ITF allows head punches while WTF does not. In the same way the abduction position of the supporting leg hip at the impact position could be the result of the hip flexed position in order to hit the target while avoiding the opponent's head punch attack.

The most obvious difference between TKD combat styles is that the competition rules of ITF allow hit in the face with fist and forbids knockout while WTF rules allow only hit with fist in the trunk and knockout. These rules affect directly the athletes choices on combat, because of that WTF mainly uses foot techniques (Pedzich *et al.*, 2012). Therefore, Dolyo chagui kinematics of ITF and WTF athletes significantly differ, mostly for pelvis and supporting leg hip angles.

One important factor which can potentially affect the execution and outcome of a kick is the target distance (Falco *et al.*, 2009; Kim *et al.*, 2010). Despite no statistical difference was found, after Holm correction, when the target distance was compared to the literature, two target distances were adopted by the groups. ITF group adopted the normal target distance and WTF a longer target distance according to Kim *et al.* (2010) being 0.96m ±0.12 and 1.21m±0.13 the reference values respectively. The ITF target distance could be related to the possibility of using head punch attacks in combat, which requires a shorter distance than kick techniques. In the other hand, a longer target distance could provide more space to reach higher velocity to hit the target, which could be necessary to provide the knockout in WTF combat.

Another important factor discussed in literature is the kick maximal velocity (Kong *et al.*, 2000; O'sullivan *et al.*, 2009). Similarly as target distance, kicking leg malleolus maximal velocity was lower than the values (16.45m/s) found in literature (O'sullivan *et al.*, 2009). Although the groups had the same performance in this study, both presented lower performances when compared to literature, which could indicate a different training level, despite their experience level (1 to 5 DAN).

Investigating the kicking leg malleolus maximal and impact velocity, was observed that both groups presented lower malleolus impact velocity than the maximal velocities reached during the kick execution phase (Friedman test, p=0.00). This finding suggests that both groups hit the target with less velocity than they could reach during the kick execution, which is expected for ITF group since this aims a light contact, but not for WTF group since this aims knockout. Future studies should investigate if this suggests a safe strategy to hit the target or if it is the consequence of this kick technique complexity.

The results provided in this study should be considered in the scope of the following limitations: First, a small number of subjects were recruited for this study. It is to note that all the selected athletes were actually affiliated to the mentioned federations that, especially for ITF, it represented by a very low number of athletes on Brazil, about 400 black belts between one to nine Dan, in the state of the current study there are 50 athletes actually training and competing. Thus the current study participants are 16% of the sample. On the other hand, in spite of the small number of subjects, a high reliably of the variables, over than 0.82, was used as criteria to choose the variables of comparison. Evidently achieving a greater statistical power could have positively influenced the results of the statistical analysis possibly highlighting further significant differences.

A very conservative statistical method has been applied to detect the above mentioned differences in order to avoid the possible type I error inflation due to the number of tested variables. However, it is well known in literature that this kind of procedure could inflate type II error by concealing differences on the sample (Cabin e Mitchell, 2000; Nakagawa, 2004). Even with this conservative approach, many variables presented statistical difference between groups, reinforcing the results and conclusion of the present study (ITF and WTF athletes perform the same kick differently). Despite this, it is clear that future studies are necessary to further knowledge in this matter.

Secondly, the current study considered only expert TKD practitioners, not elite athletes or world champions. However, it is evident that the different skill level influences the kick execution. This kind of analysis with elite athletes has been done by Pedzich, Mastalerz and Sadowski (2012). Additionally, the investigating of different skill and training levels could help to understand the motor control adaptation required for kicking tasks.

These study findings provide important implication for the unification of TKD federations. For a successful unification, the two federations should observe the differences in the kick techniques between both styles, considering the effects of training routine and combat rules. However, the majority of papers reviewed did not explicitly inform the athletes' affiliation.

Conclusion

The present paper revealed that athletes affiliate to different TKD Federations present a diverse kinematic motion pattern of performing the same type of kick (Dolyo chagui). The ITF group adopted a crouched overall attitude during the execution of Dolyo chagui compared to WTF athletes. This original finding might be related to the need of defence of punches to the head allowed by ITF and forbidden by WTF rules. The mentioned motion pattern differences, among others shown in the present paper, should be considered for training and competition improvement as well as when a possible sport unification is under discussion.

Capítulo III

IS THE BELT SYSTEM IN TAEKWONDO CORRELATED TO KICK BIOMECHANICAL VARIABLES?

Introduction

Taekwondo (TKD) is a Korean martial art characterized by the use of a set of kick techniques. To win the combat, it is necessary to hit the opponent in a specific way at predefined targets in order to score points. Successful kicks or punches depend on a combination of the athlete's mental, physical, technical and tactical abilities.

As in many martial arts, the athlete's skill level in Taekwondo is commonly associated to the sport basic techniques use and control. Thus, from beginner to expert levels, the athletes are graded according to a belt system based on the sport fundamentals individual domain. The color belts are usually granted by a highly graduated instructor and certified by the TKD federations. Therefore, the evolution in the learning process is rewarded with a step further in the belt system. There are ten grades within color belts and more nine degrees (DAN) among black belts in TKD. The black belts are recognized as athletes with the highest expertise level. For instance, to be eligible to participate in the most important championships, such as the Olympic Games and World championships, the athlete needs to be, at least, a first degree of black belt. Among the sport activities that require very high skill levels of performance, martial arts represent a good challenging model to be investigated in depth. According to Williams (Williams *et al.*, 2015) skill is the ability to assign optimal parameters to the controlled variables in order to achieve an efficient or consistently performance. Know how the ability improves according to the TKD belt system could be important to improve the training techniques. Moreover, could be use in scientific study of group comparison. Previous studies have compared groups of athletes with different competitive levels in their general physical and physiological features (Bridge *et al.*, 2011; Bridge *et al.*, 2014; Callan e Naito, 2014). However few studies investigated the differences between the athletes according to the belts system: Kazemi et al (2009) demonstrated that color belts had more injuries than black belts during competition, Skelton, Glynn and Berta (1991) indicated a significant inverse relationship between the children's taekwondo rank and their aggression behaviors (Skelton *et al.*, 1991; Kazemi *et al.*, 2009).

To the best of our knowledge, no previous study investigated possible correlations among the athlete's Taekwondo belt system and biomechanical variables during basic TKD kick techniques execution. The better understanding of this matter is relevant because of two main reasons. The first one is that only a few studies in the literature address the biomechanical comparison of TKD athletes from beginners to experts (Callan and Nataio, 2014; Covarrubias et al, 2015). Therefore, there are few references for comparisons or analyzes with academic or applied purposes. The second reason to conduct this study is to answer the question about how strongly biomechanical variables, expected to be related to performance, correlate to the TKD widely used belt system. Therefore, the objective of the present study was to analyze the possible correlations among the TKD belt system and selected biomechanical variables in the Bandal chagui and Dolyo chagui kicks, with two different initial positions.

Methods

Subjects

After signing a written informed consent and a local ethical committee approval, 23 Taekwondo athletes (age 22.3 ±4.5 years, stature 1.70 ±0.11 m, body mass 65.5 ±15.2 kg, fourteen male and nine female), all affiliated to the World Taekwondo Federation, volunteered to participate in the study. Ethics approval was secured from the School of Medical Sciences Research Ethics Committee - Unicamp (CEP Nº237/2011). The TKD athletes participating in the study were TKD graduated between first color belt to third black belt degree, with a minimum training practice of five hours per week and one month of TKD practice for the first belts (white to blue) and seven years of practice for last belts (red and black belts).

Experimental Procedures

A sparring doll was positioned in front of the athlete, adjusting its relative position according to the athlete's preferred distance of execution (Kim *et al.*, 2010) and target height (Gulledge e Dapena, 2008). Athletes were allowed a specific warm-up that consisted of familiarizing themselves with the target kicking process. The rest interval among trials was 1 to 2 minutes. The athletes were asked to kick the doll at the trunk (Bandal chagui) and at the face (Dolyo chagui), starting from two different initial positions: a) static and b) hopping. The last one simulates the combat condition. Each participant performed 12 kick trials: three for each of the two target heights and three for each of the two initial positions. The participants started the trials with one foot on each force plate.

Two retro-reflective markers (ϕ=25 mm) were attached to the lateral aspect of the volunteer's shanks right and left malleolus in order to make the analyses of the kick execution time and further kinematical variables possible. An extra retro-reflective marker was located on the top of the sparring doll head. It was used to identify the moment of contact between the athlete and the doll.

Kinematic and Dynamic Analyses Systems

Ground Reaction Force (GRF) signals were recorded during the Roundhouse kicks executions using two force plates (Kistler, 9286AA, 600 x 400 mm), at 500 Hz. Data was normalized and presented as body weight percentage (%BW). The three components of GRF (lateral - x, sagittal - y, vertical - z) were measured and analyzed separately as horizontal (module) and vertical forces.

The DVideo kinematical analyzes system (Figueroa *et al.*, 2003) was used to obtain the markers 3D coordinates . The movements were recorded by five Basler cameras (model A602fc), at 100 Hz. The cameras were calibrated by a nonlinear procedure, described by Silvatti et al (2009). Data was filtered with a low-pass 4th order digital Butterworth filter with a 10 Hz cut-off frequency, defined by spectral analysis. Data was analyzed with Visual 3D software (C-motion, USA).

Experimental Variables

During the movement, three main phases were identified: (1) the start phase, (2) the propulsion phase until the instant the kicking leg ground reaction force lifted 1% of the athlete's body weight, and (3) the instant when the first target movement was detected (i.e., the impact moment, when the sparring doll's marker moved).

The kinematical variables used in this study were the maximal velocity of kicking leg malleolus and the execution time, defined as the time period between phase 2 and phase 3. The kinetic variables were: the horizontal plane GRF (F_H), the vertical plane GRF (F_Z) and the corresponding force development rate (dF_H/dt ,dF_Z/dt). A scale from 1 to 11 points was used to represent the belt system, where one is the first color belt grade and 11 the corresponding rank for all black belt degrees.

Statistical analyses

The correlation coefficient was used to measure the linear relation degree among the TKD belt system and selected biomechanical variables. Considering that the color belt system consists of a non-continuous variable, the Spearman coefficient was used to test the correlation with biomechanical variables. The correlation coefficient significance was tested to verify if it was significantly greater than zero ($p < 0.05$). The adopted correlation coefficient classification was: $|\rho| = 0$ null correlation, $|\rho| = 1.0$ perfect correlation, $0 < |\rho| < 0.5$ weak correlation, $0.5 \leq |\rho| < 0.8$ moderate positive and $0.8 \leq |\rho| < 1.0$ strong correlation. Statistical analyses were carried out using Matlab® (R2012a). Biomechanical data was graphically presented in function of the belt system with the indication of correlation, p-values and least square lines.

Results

The execution time and kick maximal velocity did not correlate significantly to the TKD belt system, presenting weak correlations for Bandal chagui ($\rho=0.02$, $p=0.94$) and Dolyo chagui ($\rho=0.24$, $p=0.27$). The maximal velocity of kicking leg during the Dolyo chagui kick presented moderate correlation ($\rho=0.43$, $p=0.04$) with the belts system. No significant statistical correlation was found between the kicking leg maximal velocity and the belt system during the Bandal chagui execution.

The horizontal (F_H) and vertical (F_z) ground reaction forces and the horizontal (dF_H/dt) and vertical (dF_z/dt) force development rates during the Bandal chagui are shown in Figure 1. Least-squares reference lines of selected kinetic variables against TKD belt system are represented in the two initial positions, static and hopping. Scales were fixed for each variable in order to facilitate comparisons.

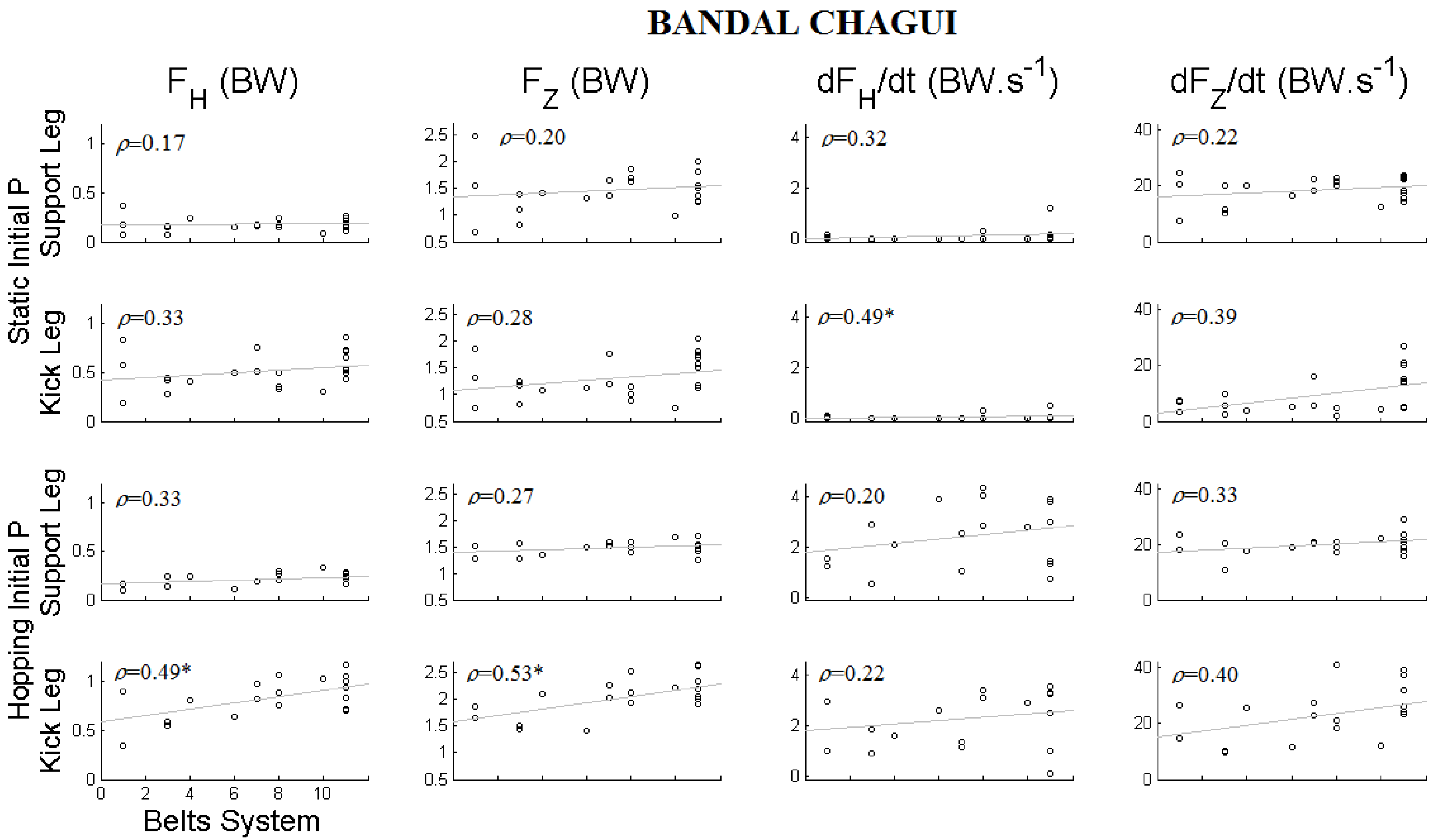


Figure 1 Horizontal (FH) and vertical (Fz) ground reaction forces and the horizontal (dFH/dt) and vertical (dFz/dt) force development rates during the Bandal chagui starting in static or hopping conditions. Spearman Correlation values (ρ) are indicated as well as the corresponding least-squares reference lines. The forces are expressed in terms of Body Weight (%BW). Belt system was represented from white belt (1) to black belt (11).* indicates statistical differences for correlation (*p<0.05*).

The Bandal chagui dynamic variables presented significant positive correlation to the TKD belt system only in the kicking leg ground reaction forces in hopping initial position, weak correlation for F_H and moderate correlation for F_z, and weak correlation for kicking leg dF_H/dt in static position.

Figure 2 presents the scatter graphs and least-squares reference lines of selected kinetic variables against the TKD belt system for Dolyo chagui in accordance with initial position.

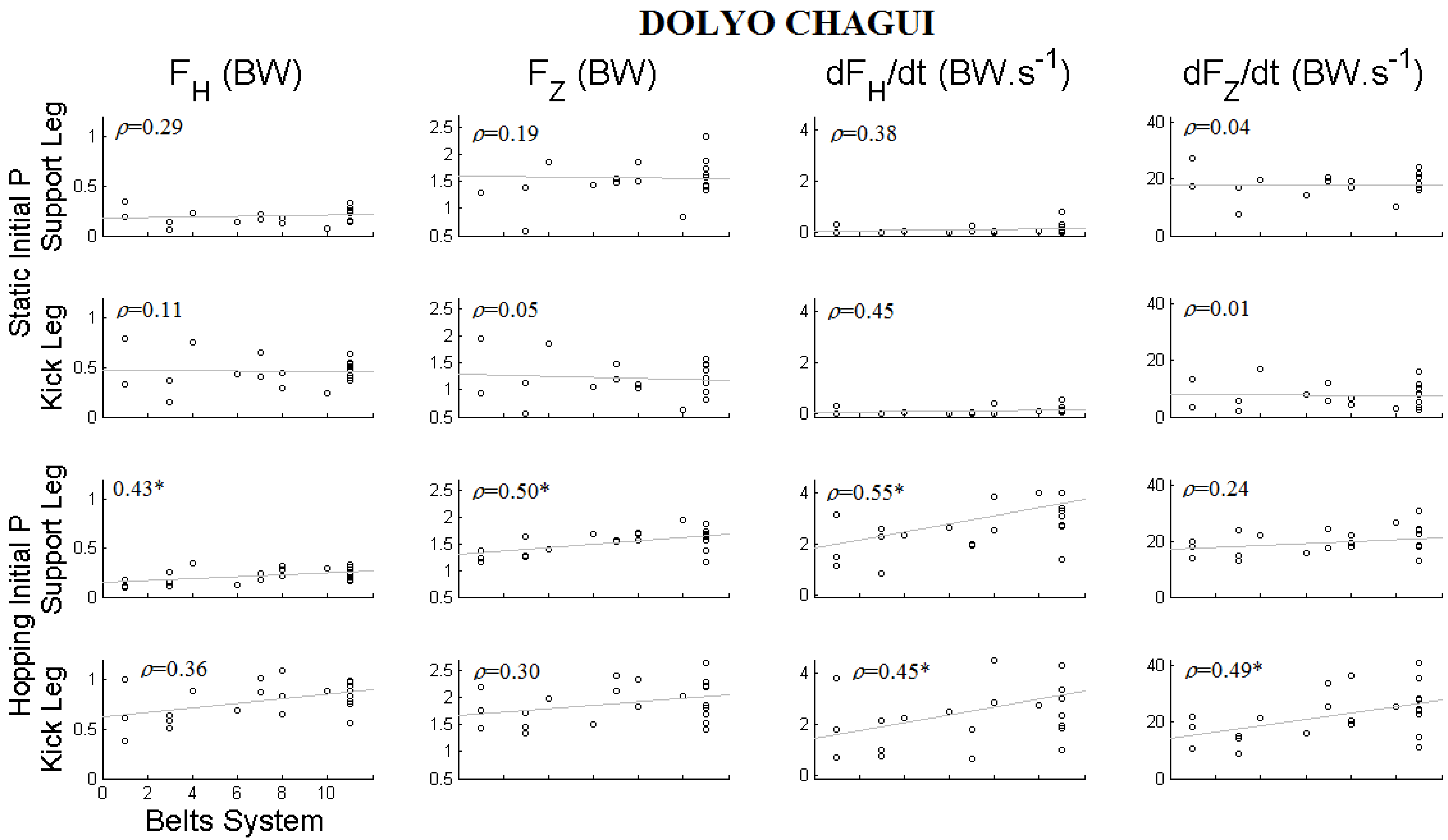


Figure 2 Horizontal (F_H) and vertical (F_z) ground reaction forces and the horizontal (dF_H/dt) and vertical (dF_z/dt) force development rate during the Dolyo chagui, starting in static or hopping conditions. Spearman Correlation values (ρ) are indicated as well as the corresponding least-squares reference lines. The forces are expressed in terms of Body Weight (%BW). The Belt system was represented from white belt (1) to black belt (11).* indicates statistical differences for correlation (*p<0.05*)

The dynamic variables of Dolyo chagui presented significant positive correlation with the TKD belt system only in the hopping initial position. The supporting leg showed significant positive correlation in all dynamic variables, except vertical plane strength development. The kicking leg showed significant positive correlation in strength development in both planes.

Comparing the kick styles (Bandal chagui vs. Dolyo chagui), the majority of significant positive correlations was found in the same initial position, the hopping one, although in different legs depending on kick styles: kicking leg for Bandal chagui and supporting leg for Dolyo chagui.

Discussion

The purpose of this study was to investigate the correlation between the TKD belt system and selected biomechanical variables. The hypothesis was that there were significant relationships between biomechanical variables and the TKD belt system, which could help to between practitioners with different skill levels. To our knowledge, this is the first study that attempts to understand the relations between the martial arts belt system and biomechanical variables, presenting results from different skill levels practitioners.

Many schools introduced the belt system as a way of establishing public recognition for the practitioner's ability. Thus the practitioners are divided in groups of different proficiency levels according to belt colors. The last belt should present the highest proficiency or performance. However, the current study showed that the TKD belt system is poorly related to the analyzed performance biomechanical variables.

According to Bridge *et al.* (2011, 2014) the physical activity and physiological requirements of Taekwondo competition require athletes to be competent in several fitness aspects, including aerobic and anaerobic power, muscular strength, muscular power, flexibility, speed and agility. However there is a scarcity of research available on the physical characteristics of Taekwondo athletes in relation to age, sex, competition levels and weight categories.

According to Burke *et al.* (2011) the time and procedures to come into proficiency and found different periods according to the stroke technique (Burke *et al.*, 2007; Burke *et al.*, 2011).

According to the British United Taekwon-Do Federation, 9th degree black belts (the highest) are the elite who fully understand all the particulars of Taekwon-Do, signifying the mental and physical pinnacle of what is usually a life time of dedication to the art. Although the TKD ranking system *rationale* is not related only to the athlete's performance, which could explain the weak correlation with the biomechanical variables frequently used to evaluate performance.

The roundhouse kick is a circular kick, whose execution is carried out in different planes (Kim *et al.*, 2011), the kick generally starts in the sagittal plane and finishes in the transversal plane (Pieter e Pieter, 1995; Falco *et al.*, 2009). Pieter and Pieter (1995) found that kicks with circular trajectories generate a greater foot velocity at impact than linear kicks on one plane because rotation of segments in different planes is involved.

The result of the current study shows that the roundhouse kick dynamic affects the ground reaction forces in the horizontal and vertical planes according to the kick style (Bandal chagui or Dolyo chagui) for both legs (supporting and kicking leg). The kicking leg GRF in both planes increased according to the belt system for Bandal chagui. The GRF also increased in the supporting leg for Dolyo chagui. However, the same behavior was not observed for Bandal chagui kick velocity, which suggests that the athletes do not use the GRF to improve kick velocity in this technique. On the other hand, there is a weak correlation with belt system for Dolyo chagui, which suggests that the athletes increase the GRF and the kick velocity to execute this technique.

A study of stance position in TKD found that a kick ground reaction force of kicking leg on vertical axis was not affected by the stance in the roundhouse kick, although the ground reaction force in lartero-lateral axis was affected (Estevan *et al.*, 2013). Ours results partially support Estevan et al. (2013) findings since we observed horizontal plane diverse behaviors as the authors, and also in the vertical plane. On the other hand, a combat sports study found that the kick ground reaction force in the three axes is not affected by the target height (O'sullivan *et al.*, 2009). The studies mentioned worked with experienced athletes only, all of them black belt holders, which could explain why no difference was found.

It should be taken into account that Bandal chagui is one of the first techniques trained in a TKD program, which could explain why there are no linear correlation between the GRF and kick velocity to the belt system.

The majority of the athletes practically use rhythmic hop as a preparatory motion during sparring in TKD, while they are waiting for attacks and dodging in response to the opponent's action (Kim *et al.*, 2015). A hooping frequency study in TKD kick found that a faster hopping frequency would be beneficial to kicking performance (Kim *et al.*, 2015). In the same way, the results for hopping initial position, in the present study, showed better correlations to the TKD belt system, which suggests that the hopping initial position results is a better indicator of skill proficiency in TKD.

The results provided in this study should be considered in the scope of the following limitations: First, the variation within biomechanical variables. This could be the result of the difference in training routine, since the athletes belong to different schools. Second, the variables analyzed are more used in performance analysis in TKD biomechanics and may not be the best indicator in proficiency. Future longitudinal studies should be conducted with non prior experience in martial arts practitioners and athletes under same training routine that might explore other biomechanical variables.

The present paper showed that the TKD belt system is weak to moderate positively related to ground reaction force, which suggests that mastery in TKD skill level is needed for an increased use of ground reaction force during the roundhouse kick propulsion phase. Further, ours results indicate that during the acquisition of skills the athletes applied the ground reaction force in different legs according to the kick style.

Conclusion

The first contribution of the present paper is to provide biomechanical results, obtained with updated methods and a standardized protocol, from TKD practitioners with a wide range of technical levels. Data including beginners and expert athletes under the same protocol are rarely presented in the scientific literature and can lead to a better comprehension of the evolution process of learning and mastering the TKD fundamentals.

The main conclusion of the present paper was that the TKD ranking belt system is not strongly correlated to biomechanical variables in the studied group as we could expect. This finding suggests that the belt colors system should not be used to characterize TKD athletes' technical or performance level in academic or practical evaluations carefully. Further research should attempt to replicate these findings in other Martial Arts and also examine whether a long period of practice could yield further information about TKD practitioners performance. It is, therefore, important that coaches and sports scientists collect objective information from their athletes' execution pattern to substantiate the training objectives, to provide feedback and to motivate athletes during training and competition.

Capítulo IV

JOINT MOMENT AND POWER GENERATION COMPARISON OF BANDAL AND DOLYO KICKS IN TAEKWONDO

Introduction

Taekwondo (TKD), the Korean martial art, is characterized by a diverse array of fast, high and spinning kicks. It is studied in over 200 countries and practiced by million practitioners of all ages and it is part of the modern Olympic Games.

The roundhouse kick is the most common and fast type of kick in TKD. It is executed with high coordination of lower extremities individual joints movements (Kim *et al.*, 2011). The demand of maximum power production at the distal end of a kinetic chain, which is required in an explosive task such as a kick, is common in combat sports (Melhim, 2001). Over the years, researchers have been studying combat sport strikes by measuring impact forces, segment velocities and electromyographic data, and then comparing values obtained from different level athletes. For example Quinze *et al.* (2013) investigated the knee flexor and extensor muscles neuromuscular response in elite and amateur karatekas. Estevan (Estevan et al., 2013) compared the effect of three stance positions in the segments velocity, kick execution time and time reaction of roundhouse kick performed by male and female TKD athletes. Estevan *et al.* (2015) analyzed the lower limb segments peak velocity, and the time to reach it during the roundhouse kick execution. Nevertheless this kind of study did not describe possible differences in the mechanism required to generate a powerful movement. Recently, some researchers developed studies in order to understand how the mechanical power is generated and absorbed. For example Pozo *et al.* (2011) compared execution time, lower limb kinetics and kinematics in the mae-geri kick of national and international Karate athletes. Cabral *et al.* (2011) analyzed whether athletes of different skill levels present different relative joint moment contributions to the generated power in the Karate roundhouse kick. Jandacka *et al.* (2013) compared the generated net joint power during three types of stance phase in the TKD roundhouse kick. Kinoshita and Fujii (2014) described the lower limb mechanism during the phase before kicking foot toe off, focusing on producing a faster kick speed in TKD roundhouse kick. However, the motion analysis and the establishment of cause-effect relationships in roll kick execution, from the stance phase until impact with the opponent, is extremely complex and rarely present in scientific literature (Cabral *et al.*, 2011; Kim *et al.*, 2011; Pozo *et al.*, 2011).

Maximum kick velocity great magnitude, in a short period of execution time, can be reached when the joint generates sufficient net power (Kinoshita e Fujii, 2014). Accordingly, with the dynamic coupling phenomenon in a multijoint rigid body system, any net joint moment contributes to all joints' intersegmental forces and, consequently, to all segments net power (Selbie *et al.*, 2014).

The calculation of net joint, power during motion, derived from inverse dynamics calculations, has been successfully used to indirectly determine the muscle groups concentric or eccentric action and mechanical energy flow (Jandačka *et al.*, 2013; Kinoshita e Fujii, 2014). Therefore, inverse dynamics could provide information on kick movement in TKD particular phases or requirements.

The knowledge about net joint moment and power generation during TKD kicks execution could help to understand the main difference among kick techniques (Cabral et al., 2011). To the best of our knowledge, no studies where TKD kick techniques were compared during the entire execution have been conducted. Moreover, it could provide information that would help TKD athletes and coaches to guide muscle power peak training (Kinoshita e Fujii, 2014). Thus, the aim of this study was to compare the generated joint moment and power (hip and knee) during the kick movement in Taekwondo roundhouse kick according to two factors: kick techniques, Bandal chagui (roundhouse kick to trunk) and Dolyo chagui (roundhouse kick to face), and lower limbs, supporting and kicking legs.

Methods

Subjects

After signing a written informed consent and local ethical committee approval, 9 Taekwondo athletes (age 22.2 ±2.4 years, stature 1.68 ±0.8 m, body mass 65.2 ±15.7 kg, four male and five female), all affiliated to the World Taekwondo Federation, volunteered to participate in the study. Ethics approval was secured from the Research Ethics Committee of School of Medical Sciences - Unicamp (CEP Nº237/2011). The TKD athletes participating in the study were graduated in TKD from white belt to black belt degrees, with a minimum training practice of three hours per week and at least three months of TKD regular practice. All participants had previous knowledge of the studied kick techniques.

Experimental Procedures

A sparring doll was positioned in front of the athlete. Its relative position was adjusted according to the athlete′s preferred execution distance (Kim *et al.*, 2010) and target height (Gulledge e Dapena, 2008). Athletes were allowed to conduct the common warm-up of their training routine and to familiarize themselves with the process of kicking the target. After warming up, the anatomical markers were placed on the athlete's body. A static trial was collected first, with the participant in the anatomical reference position. The athletes were asked to kick the doll at the doll′s trunk (Bandal chagui) and face (Dolyo chagui), starting from the hopping initial position, which simulates the combat condition. Each participant performed two kick trials, one for each of the two target heights. The participants started the trials with one foot (barefoot) on each force plate with kicking leg at the rear (fig.1). All participants used the right leg as the preferred leg. The rest interval between trials was 1 to 2 minutes. A retro-reflective marker was located on the top of the sparring doll head and used to identify the moment of contact between the athlete and the doll.

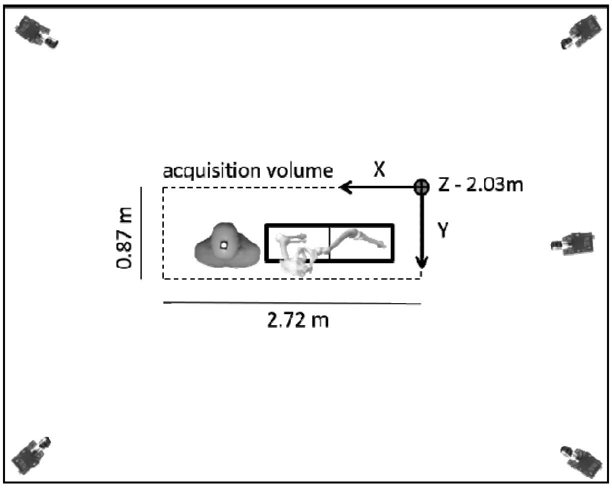


Figure 1 Experimental SET UP

The biomechanical model used to represent the athlete's body was developed in the Visual 3D Professional software (v5.01.11, C-motion, USA). It consisted of five linked rigid body segments: pelvis, thighs and shanks (right and left), and four joints: right and left hip and knee joints. To track the motion during the kicks, a total of twenty one reflexive markers were placed on the athlete's body, in the following anatomical places: anterior and posterior superior iliac spines, top of iliac crest (right and left), great trochanters (right and left), femur epicondyles (lateral and medial), malleolus (lateral and medial) and tibial tuberosity (right and left). The medial markers were removed during the kick execution to prevent any interference in the kicking motion.

The lower segments extremities were modeled as frustum cones, while the pelvis was modeled as a cylinder (Hanavan, 1964). The pelvis orientation was conducted according to CODA recommendation (Bell *et al.*, 1989). The thighs and shanks (right and left) orientation was done according to the International Society of Biomechanics recommendation. The local coordination system was defined with Z axis as the unit vector directed from the distal segment end to the proximal segment end. Y axis was determined by the unit vector that is perpendicular to both the frontal plane and the Z axis. Finally, X axis is determined by the cross product (ZxY). The Pelvis was oriented in relation to the global reference system. Thighs and shanks were oriented in relation to their proximal segments according to a XYZ Cardan rotation sequence.

In order to provide a more realistic and anatomically based model, an inverse kinematic procedure was applied to calculate the joint angles, with Levenberg-Marquardt optimization (Lu e O'connor, 1999). The kinematic chain was calculated with 3 degrees of freedom for hip rotation (Flexion/Extension, Adduction/Abduction and Internal/External Rotation), and 1 degree of freedom for knee rotation (Flexion/Extension).

The foot was not portrayed in the body representation model in order to avoid injuries during the impact with the target, caused by the use of passive markers, and to provide a comfortable set up for the athletes. The lateral malleolus was used to represent the position and velocity of lower limbs extremities.

Kinematic and Dynamic Analyses Systems

The DVideo kinematical analyzes system (Figueroa *et al.*, 2003) was used to obtain the markers 3D coordinates . The movements were recorded by five Basler cameras (model A602fc), working at 100 Hz (fig.1). The cameras were calibrated by a nonlinear procedure, described by Silvatti *et al.* (2009). The datas were filtered with a low-pass 4^{th} order digital Butterworth filter with a 10 Hz cut-off frequency, defined by spectral analysis.

Ground Reaction Force (GRF) signals were recorded during the execution of the Roundhouse kicks using two force plates (Kistler, 9286AA, 600 x 400 mm), working at 500 Hz. The data were normalized and presented as a body mass percentage. The three components of GRF (lateral - x, sagittal - y, vertical - z) were measured and analyzed as horizontal forces (module) and vertical forces separately. The analog data was filtered with a low-pass 4^{th} order digital Butterworth filter with a 10 Hz cut-off frequency, like the kinematic data.

The data from kinematic and dynamic systems were treated with Visual 3D software (v5.01.11, C-motion, USA).

Experimental Variables

The kick movement was divided in three main phases with four events as illustrated in Figure 2. The following time points were marked: the time point at which the kicking foot touched the ground after hopping (START) and the reaction force surpassed 1% of the participant's body weight. The time point at which the kicking foot left the ground (TOE OFF) and the reaction force dropped below 1% of the participant's body weight. Finally, the time point moments of kicking leg maximum knee flexion (MKF) and impact with the target (IMP).

The first phase was designated as Impulse. It was determined as the time between START and TOE OFF. The second phase was termed Knee Flexion, and started at TOE OFF and ended at MKF. The third phase, named Swing, consisted of the period between MKF and IMP. No further analysis was conducted after the impact due to the limited frequency of acquisition.

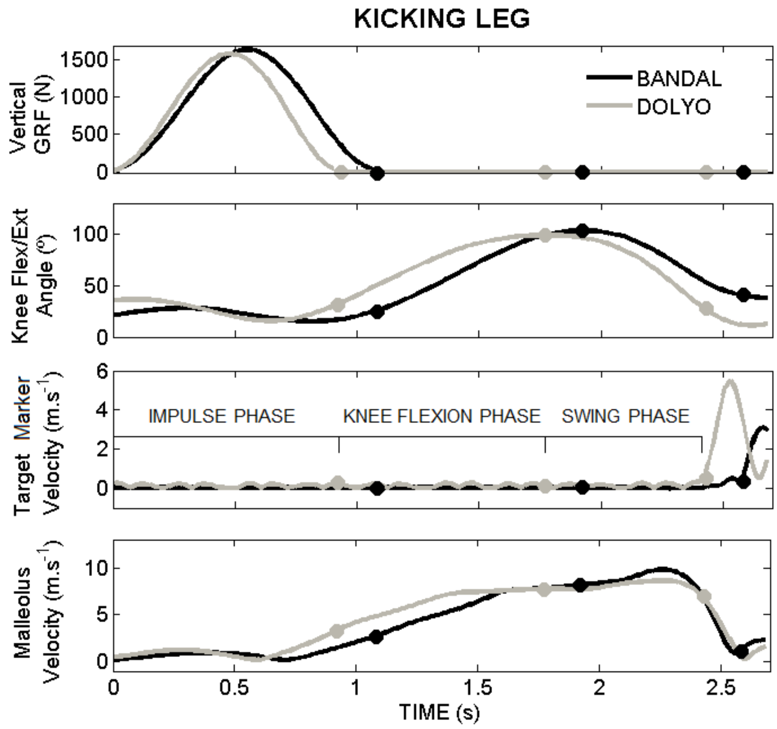


Figure 2 Roundhouse kick motion phases. The graphs begin at the Start event. The first mark on the black and grey lines represents the Toe Off, the second mark, the Maximum Knee Flexion and the third, the Impact event. Graphs were synchronized by malleolus maximum velocity at strike phase.GRF - ground reaction force, Flex/Ext - Flexion/Extension.

The hip and knee joint moment and joint power of both legs (supporting and kicking) were calculated using the inverse dynamic method available in the Visual 3D software and in accordance with the description of (Selbie *et al.*, 2014). The joint moment was calculated as the net internal joint moment and the joint power was calculated as a product of the joint angular velocity and joint moment. Both were resolved in the proximal segment to the joint local coordination system. All joint moments and powers values were normalized using the subjects' body mass. The joint moment and power peaks at three movement phases were used to compare kick techniques and legs (supporting and kicking).

Statistical Analyses

All variables were not normally distributed (Anderson Darling test). Therefore, a paired samples Wilcoxon Signed Ranks test was performed to compare kick techniques (Bandal chagui and Dolyo chagui) and legs (supporting and kicking) according to the movement phase. The maximum net hip and knee joints moments and power on the three kick movements were compared. The "*W*" Wilcoxon test statistic was run. Unlike most test statistics, smaller values of *W* are less likely under the null hypothesis (Berger e Casella, 2001). The probability that the test correctly rejects the null hypothesis was tested with statistical power (SP) expressed according to Cohen (1988). The statistical significance for all tests was adjusted at $p < 0.05$. The statistical analysis was performed using Matlab® (R2012a).

Results

In order to describe the lower limbs movement mechanism during Bandal chagui and Dolyo chagui executions, the subject with higher kicking leg malleolus scalar velocity and shorter kick execution time movement curves were presented. The curves were synchronized by the kicking leg maximum malleolus scalar velocity. The movement mechanism was described according to the kick movement phases, which are presented on the hip power in the frontal plane graph.

Figure 3 shows the supporting leg mechanism during Bandal chagui and Dolyo kick executions. On the Impulse phase it was observed that an extension angular velocity in hip joint occurs in the sagittal plane at the same time as an extensor moment and the peak power generation, which means extensor muscles concentric contraction. Moreover, there is an abduction angular velocity at the same time as a hip adductor moment and a reduced power generation in the frontal plane, which means muscles eccentric contraction. In the transversal plane, there is a peak power generation in the hip joint at the same time as an internal rotation angular velocity and moment, which means internal rotators muscles concentric contraction. The knee joint, in this phase, presented an extension angular velocity accompanied by an extensor moment and a peak power generation, which means extensor muscles concentric contraction.

On the Knee Flexion phase, the supporting leg power generation, in the sagittal plane, decreased accompanied by a hip extensor moment and an extension angular velocity, which means extensor muscles concentric contraction. In the frontal plane, the peak power generation in the hip joint occurred at the same time as an abductor moment and an abduction angular velocity, which means muscles concentric contraction. At the same time, there was a slight power absorption in the transversal plane. There was an extension angular velocity in the knee joint at this phase accompanied by an extensor moment and a peak power generation, which means extensor muscles concentric contraction.

The supporting leg hip joint at Swing phase presented a flexion angular velocity, accompanied by a peak power generation and a flexor moment in the sagittal plane. This means flexor muscles concentric contraction. On the frontal plane, there was an abduction angular velocity accompanied by an adductor moment and a power absorption peak, which means abductors muscles eccentric contraction. Hip joint in the transversal plane and knee joint in the sagittal plane present a slight contribution to the power generation in this phase.

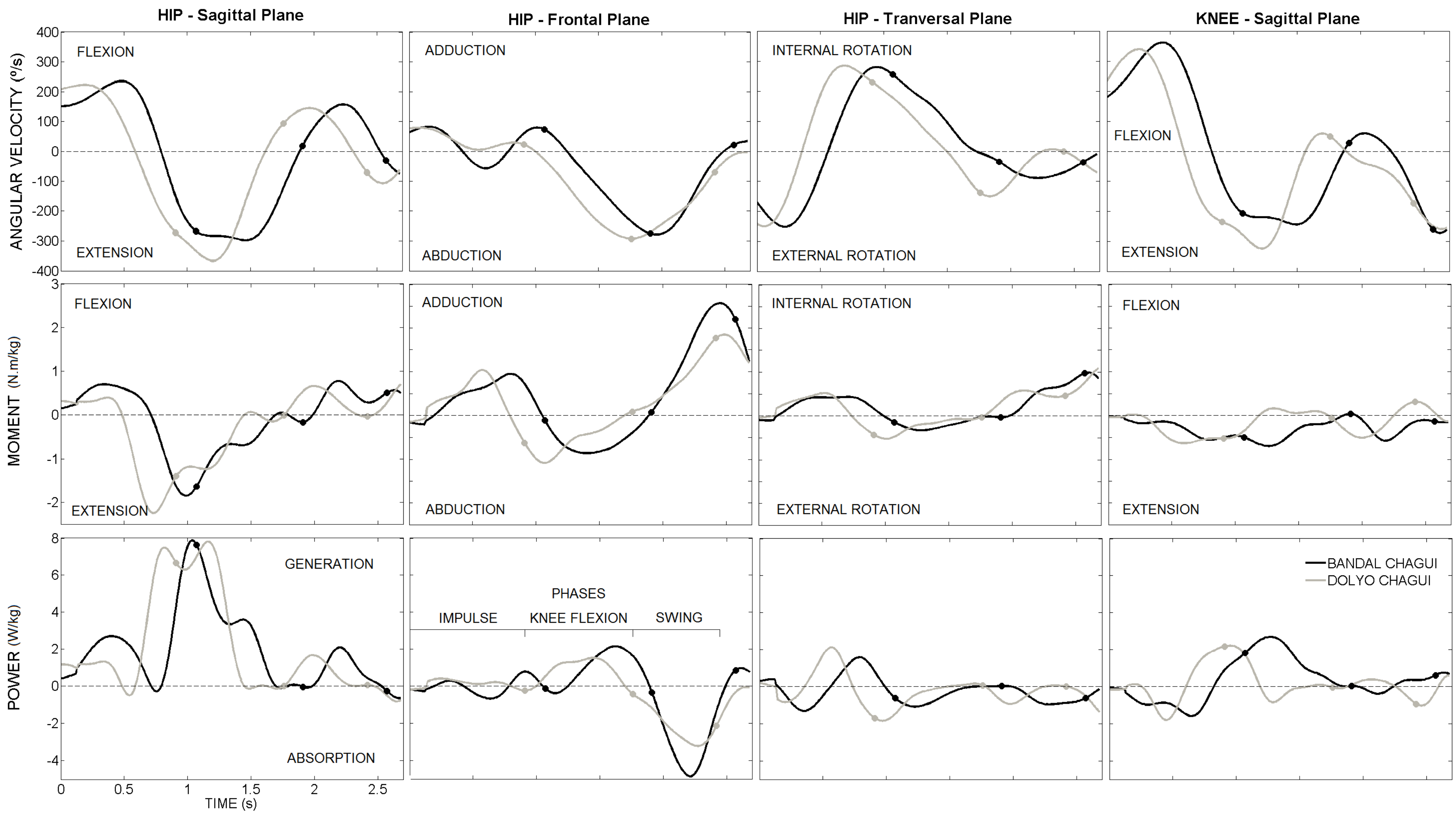


Figure 3 Example motion of supporting leg during Bandal chagui and Dolyo chagui execution performed by a taekwondo athlete. The graphs begin at the Start event. The first mark on the black and grey lines represents the Toe Off, the second mark, the Maximum Knee Flexion and the third, the Impact event. The curves were synchronized by the maximum malleolus scalar velocity of kicking leg.

Figure 4 shows the mechanism of kicking leg during Bandal chagui and Dolyo kick execution. On the Impulse phase there was an extension velocity on hip joint at the same time as a peak power generation and extensor moment, which means extensor muscles concentric contraction. In the frontal plane there was an adduction angular velocity accompanied by an abduction moment and a power absorption peak, which means abductor muscles eccentric contraction. In the transversal plane, there were external rotation angular velocity and moment accompanied by a peak power generation. This means internal rotators muscles concentric contraction. The knee joint presented an extension angular velocity at the same time as a flexor moment and a power absorption peak, which means extensor muscles eccentric contraction.

Kicking leg on Knee Flexion phase presented a reduced power generation in the sagittal plane accompanied by a hip flexor moment and flexion angular velocity, which means flexor muscles concentric contraction. In the frontal and transversal planes, there was slight power generation. Knee joint presented a flexion angular velocity accompanied by a flexor moment and a slight power generation.

At Swing phase in the sagittal plane, there was an extension angular velocity on hip joint, at the same time as an extensor moment and a peak power generation, which means extensor muscles concentric contraction. In the frontal plane, there was an abduction angular velocity accompanied by an adductor moment and a power absorption peak. This means abductors muscles eccentric contraction. Hip joint in the transversal plane presented a slight contribution to power generation at this phase. The kicking leg knee joint at Swing phase presented a extension angular velocity accompanied by a flexor moment and a power absorption peak, which means extensor muscles eccentric contraction.

Observing the curves, the kick techniques (Bandal chagui, Dolyo chagui) have presented the same behaviour. In order to verify the difference between kicks, the Wilcoxon test was performed to compare the maximum values of joint moment and power in the kick movement phases. Additionally, the differences between legs (supporting and kicking) during the kicks execution were also tested.

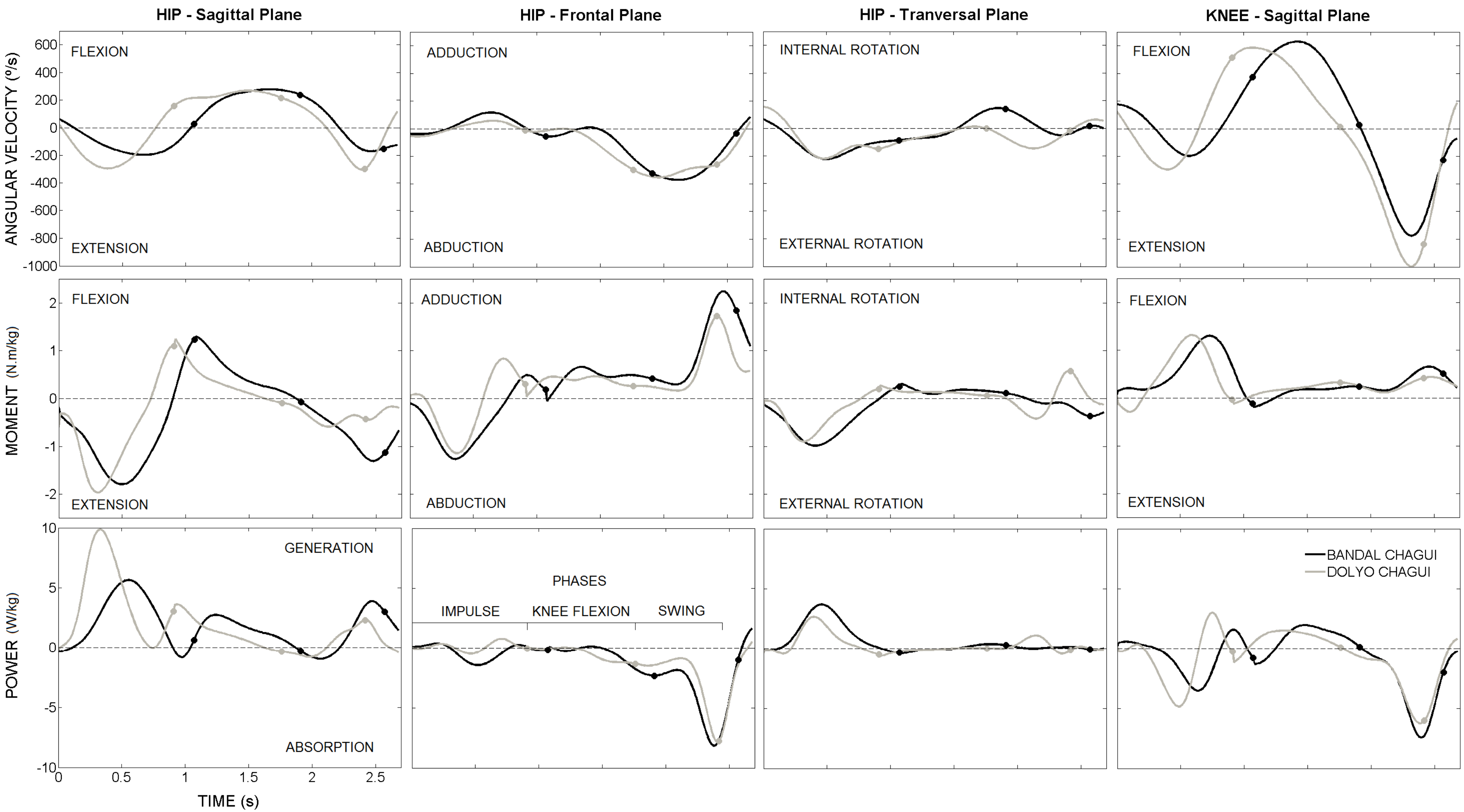


Figure 4 Example motion of kicking leg during Bandal chagui and Dolyo chagui executions performed by a taekwondo athlete. The graphs begin at the Start event. The first mark on the black and grey lines represents the Toe Off, the second mark, the Maximum Knee Flexion and the third, the Impact event. The curves were synchronized by the maximum malleolus scalar velocity of kicking leg.

The Wilcoxon test showed that there was no statistical difference between Bandal chagui and Dolyo chagui joint moments and power on the Impulse phase (Table 1). However, when the supporting and kicking legs of each kick were compared separately, a statistical difference was found in Bandal chagui hip moment in frontal (*W*=3, *p*=0.04, SP=0.87) and transversal planes (*W*=1, *p*=0.02, SP=0.99), with opposite behaviours between legs in both planes. Differences were also found in Dolyo chagui hip moment in sagittal (*W*=0, *p*=0.01, SP=1.0) and transversal planes (*W*=0, *p*=0.01, SP=1.0) and Dolyo chagui hip power in the transversal plane (*W*=1, *p*=0.02, SP=0.84), with power absorption in the supporting leg and generation in the kicking leg.

Table 1 The mean and standard deviation of peak generated net hip and knee joints moments and power during Impulse phase of Bandal chagui and Dolyo chagui.

	Supporting Leg		Kicking Leg	
	BANDAL	DOLYO	BANDAL	DOLYO
Hip Moment (N.m/kg)				
Sagittal	-0.01 ±0.78	0.09 ±0.22[a]	-1.07 ±0.73	-1.32 ±0.70[a]
Frontal	0.19 ±0.46[a]	0.29 ±0.48	-0.47 ±0.54[a]	-0.18 ±0.43
Transversal	0.27 ±0.37[a]	0.19 ±0.24[a]	-0.41 ±0.28[a]	-0.53 ±0.34[a]
Hip Power (W/kg)				
Sagittal	0.62 ±1.92	0.24 ±0.78	0.86 ±2.27	1.84 ±3.45
Frontal	-0.02 ±0.33	-0.04 ±0.14	-0.27 ±0.61	-0.22 ±0.60
Transversal	-0.16 ±0.62	-0.07 ±0.79[a]	0.61 ±1.06	1.05 ±0.99[a]
Knee Moment (N.m/kg)				
Sagittal	-0.05 ±0.09	-0.06 ±0.24	0.63 ±0.87	0.53 ±0.56
Knee Power (W/kg)				
Sagittal	-0.21 ±0.45	-0.13 ±0.71	-0.62 ±1.92	-1.12 ±2.04

Legend: ([a]) statistical difference between kick legs (supporting and kicking), $p<0.05$.

At the Knee Flexion phase, a statistical difference between Bandal chagui and Dolyo chagui in the kicking leg hip moment in the frontal plane was found (*W*=2, *p*=0.02, SP=0.88), with higher values of maximum adductor moment for Bandal chagui. The same occurred in the kicking leg knee flexor moment (*W*=0, *p*=0.01, SP=0.92), with higher values of knee flexor moment for Dolyo chagui (Table 2).

Concerning the difference between legs, statistical differences were found in the Bandal chagui hip flexor moment (*W*=1, *p*=0.02, SP=0.96), with higher values for kicking leg, and in the Bandal chagui knee flexor moment (*W*=3, *p*=0.04, SP=0.81), with opposite behaviours between legs. In terms of power, statistical differences were found in the Bandal chagui hip power in sagittal (*W*=1, *p*=0.01, SP=0.99) and frontal planes (*W*=1, *p*=0.01, SP=0.98), with higher values of power generation in the supporting leg. Statistical differences were found in the Dolyo chagui hip flexor moment (*W*=0, *p*=0.01, SP=1), with higher values for kicking leg, and also in the knee flexor moment (*W*=0, *p*=0.01, SP=0.96), with opposite behaviour between legs. In terms of power, differences were found in the Dolyo chagui hip power in sagittal (*W*=0, *p*=0.01, SP=0.99) and transversal planes (*W*=0, *p*=0.01, SP=0.99), with higher values of power generation for supporting leg.

Table 2 The mean and standard deviation of peak generated net hip and knee joints moments and power during Knee Flexion phase of Bandal chagui and Dolyo chagui.

	Supporting Leg		Kicking Leg	
	BANDAL	DOLYO	BANDAL	DOLYO
Hip Moment (N.m/kg)				
Sagittal	0.45 ±0.47[a]	0.34 ±0.24[a]	1.07 ±0.27[a]	1.03 ±0.24[a]
Frontal	0.41 ±0.47	0.34 ±0.36	0.55 ±0.17[b]	0.36 ±0.11[b]
Transversal	0.18 ±0.18	0.14 ±0.21	0.30 ±0.11	0.27 ±0.11
Hip Power (W/kg)				
Sagittal	8.08 ±3.39[a]	7.46 ±3.53[a]	2.46 ±1.25[a]	2.26 ±0.70[a]
Frontal	3.19 ±1.98[a]	3.80 ±2.56[a]	0.24 ±1.25[a]	0.26 ±0.43[a]
Transversal	0.52 ±0.61	0.52 ±0.38	0.56 ±0.24	0.35 ±0.27
Knee Moment (N.m/kg)				
Sagittal	-0.02 ±0.28[a]	-0.15 ±0.40[a]	0.22 ±0.05[ab]	0.30 ±0.06[ab]
Knee Power (W/kg)				
Sagittal	1.77 ±1.19	2.15 ±0.70	1.68 ±0.48	1.65 ±0.47

Legend: ([a]) statistical difference between kick legs (supporting and kicking), ([b]) statistical difference between kick techniques (Bandal and Dolyo), *p<0.05*.

Table 3 shows the statistical difference between Bandal chagui and Dolyo chagui at Swing phase. Hip joint presents statistical difference between kicks in the kicking leg hip moment in the frontal plane (*W*=3, *p*=0.04, SP=0.30), with higher values of maximum adductor moment for Bandal chagui, and kicking leg knee flexor moment (*W*=1, *p*=0.02, SP=0.84), with higher values for Bandal chagui. In terms of joint power, the kicks present difference in the supporting (*W*=0, *p*=0.01, SP=0.96) and kicking leg (*W*=0, *p*=0.01, SP=0.96) knee power in the sagittal plane, with higher power generation for Bandal chagui.

Regarding the statistical difference between legs, they were found in the hip moment in the three planes in Bandal chagui (*W*=1, *p*=0.01, SP=1, *W*=1, *p*=0.02, SP=0.41, *W*=0, *p*=0.01, SP=1) and Dolyo chagui (*W*=2, *p*=0.02, SP=0.98, *W*=0, *p*=0.01, SP=0.56, *W*=0,

p=0.01, SP=0.98), with higher values of flexor, adductor and internal rotator moments for supporting leg. The difference for knee flexor moment was found only in the Bandal chagui (W=1, p=0.01, SP=1), with opposite behaviour between legs. In terms of power, the difference was found between legs in the Bandal chagui hip power in the transversal plane (W=0, p=0.01, SP=0.97), with higher power generation in the kicking leg.

Table 3 The mean and standard deviation of peak generated net hip and knee joints moments and power during the Swing phase of Bandal chagui and Dolyo chagui.

	Supporting Leg		Kicking Leg	
	BANDAL	DOLYO	BANDAL	DOLYO
Hip Moment (N.m/kg)				
Sagittal	1.04 ±0.24[a]	0.68 ±0.49[a]	0.11 ±0.19[a]	0.05 ±0.11 [a]
Frontal	1.79 ±0.72[a]	1.47 ±0.47 [a]	1.35 ±0.60[ab]	1.08 ±0.45[ab]
Transversal	0.69 ±0.30[a]	0.74 ±0.31 [a]	0.13 ±0.11[a]	0.30 ±0.17 [a]
Hip Power (W/kg)				
Sagittal	1.15 ±0.73	0.42 ±0.85	1.40 ±1.46	0.48 ±0.74
Frontal	0.58 ±1.57	-0.45 ±1.24	0.40 ±0.69	0.36 ±1.06
Transversal	0.26 ±0.33[a]	0.51 ±0.48	1.20 ±0.72[a]	0.38 ±0.32
Knee Moment (N.m/kg)				
Sagittal	-0.27 ±0.34[a]	0.04 ±0.57	0.76 ±0.19[ab]	0.54 ±0.16[b]
Knee Power (W/kg)				
Sagittal	0.86 ±0.47[b]	0.14 ±0.42[b]	2.09 ±1.57[b]	0.21 ±0.62[b]

Legend: ([a]) statistical difference between kick legs (supporting and kicking), ([b]) statistical difference between kick techniques (Bandal and Dolyo), *$p<0.05$.*

Discussion

The present paper first contribution is to provide biomechanical results, obtained with updated methods and a standardized protocol, throughout the whole kick execution. Data including kick execution kinematics from the phase before toe off until impact are rarely present in scientific literature and can lead to a better understanding of the kick mechanism. Moreover, the present study provides results on the mechanism to perform kicks techniques to hit trunk and face from both legs simultaneously.

Coordinated movements are results from the tension in muscles acting across joints in harmony with the body-environment interaction. This can be described by forces and joint moments (Selbie *et al.*, 2014).

Bandal chagui and Dolyo chagui presented the same mechanism at Impulse phase, which could be explained by the fact that both are derived from the roundhouse kick. However, when the lower limbs were compared during the execution of each kick technique, Dolyo chagui showed higher hip power generation in the transversal plane. Our study supports the findings of Jandacka *et al.* (2013), which suggests that coaches and taekwondo trainers should focus their power peak training in the muscle groups that cause the hip joint extension and external rotation at impulse phase for kicking leg. However, our results highlight a peak power absorption by an abductor muscles eccentric contraction in the frontal plane.

The kick techniques were different on kicking leg mechanism at Knee Flexion phase, suggesting that, to hit the face, less hip adductor moment and more knee flexor moment are required. Our study provides specific and complementary information supporting the findings for kicking leg mechanism in Cabral *et al.* (2011), suggesting that coaches and taekwondo trainers should focus their power peak training on kicking leg knee flexor muscle groups. Furthermore, when legs were compared, the supporting leg contributed more to power generation in sagittal and frontal planes, suggesting that training practice should be focused in power peak training in the hip joint extensor and abductor muscle for supporting leg.

Both legs' joints at Swing phase acted absorbing power with hip abductor and knee extensor muscles eccentric contraction. This mechanism could be explained by different factors, such as the passive resistance offered by adductor muscles when close to hip abduction maximum amplitude, although joint amplitude tests would be necessary to confirm this assumption, as well as the variability caused by signal processes near the Impact phase (Cabral *et al.*, 2011).

The hypothesis that target height has an effect on the peak of the generated net hip joint power has been confirmed. Bandal chagui and Dolyo chagui kicks presented the same execution mechanism in terms of kinematic, with higher power generation for Bandal chagui at Swing phase. These results offer additional information supporting the results in (Lara *et al.*, 2011), indicating that a more complex kick movement generates less power at the phase before impact. Moreover, since full contact is allowed in WTF competitions, a more powerful kick is required to hit the trunk (Bandal chagui) than the face (Dolyo chagui).

The hip joint mechanism contributed more for power generation during the kick execution of both techniques. The supporting leg hip generated the largest power at Knee Flexion phase. The kicking leg generated the highest power peaks at first and last phases. The highest joint power generation was reached at Impulse phase. This result offers additional information supporting the findings in Pozo *et al*. (2011), suggesting that the phase before the kicking foot toe off is fundamental to kick performance.

The results provided in this study should be considered in the scope of the following limitations: First, given the small sample size and repetitions, some non significant results may be related to a lack of reliability. However, in our study, the SP threshold of 0.8 was achieved for the majority of tests, which means good power test (Cohen, 1988). It failed only in the same tests at Impulse phase. Second, the ankle joint moment and power were not considered in order to provide a similar to training and competition situations comfortable kick execution and, although the ankle variables are slightly related to kick velocity (Cabral *et al.*, 2011; Kinoshita e Fujii, 2014).

Conclusion

The outcome from this study provided a new insight into the lower limbs mechanism in the roundhouse kick execution. Bandal chagui and Dolyo chagui kicks presented the same execution mechanism in terms of kinematic, with higher hip adductor moment and knee power generation for Bandal chagui at the phase before impact. This must be taken into account when rationalizing strength training or selecting the TKD roundhouse kick technique. Additionally, the supporting leg is fundamental for power generation during kick execution. Coaches should pay attention at the supporting leg mechanism during the roll kick execution, focusing their power peak training mainly on hip flexion/extension and adduction abduction muscles.

Capítulo V

KINEMATICS OF HEAD TAEKWONDO KICKS PERFORMED BY OLYMPIC ATHLETE: A CASE STUDY

Introduction

Taekwondo is currently practiced in most countries of the western world as a form of physical fitness and self defence. After its recognition as an official Olympic sport in the Sydney 2000 Olympic Games, an increase in the number of practitioners has been observed, with over 200 nations represented as members of the World Taekwondo Federation actually.

TKD has become the object of academic research, where the technique most discussed is the roundhouse kick (Kinoshita e Fujii, 2014). This is the most frequently used kick in this sport modality (Kim, 1998; Lee, 1998; Kim *et al.*, 2011). Kinematic analyses of movement were used to investigate different aspects of this kick, such as execution velocity, impact force, time of impact (Pearson, 1997), the association between flexion and extension of the kicking leg and peak velocity (Kim, 2002), and the effect of distance from the target on velocity and execution time, as well as its movement pattern (Falco *et al.*, 2009; Kim *et al.*, 2010).

For the Olympic cycle 2009-2012, TKD has undergone an adaptation of its rules, with kicks to the head being authorised. These alterations could cause changes in the dynamics of fights and training. Although the investigation of the kinematics of kicks directed to the head is essential to improve the performance of athletes, especially considering the higher scores achieved with kicks in this area, few studies have investigated this aspect (O'sullivan *et al.*, 2009; Estevan *et al.*, 2011; Falco *et al.*, 2011).

One important approach in the study of the biomechanics of a sport is the understanding of the specific movements of top athletes. According to Hopkins, Hawley, & Burke (1999), the analysis of high-level athletes should be based on an individual-level investigation, so that the particularities of the characteristic movements performed by each athlete can be determined. In many instances this may be the only means to provide useful information that can be used to improve performance.

Currently, the literature on this area is more focused on the biomechanics of kicks performed only by male athletes. Indeed, there has been only few study to date with high-level female athletes involving kicks in the high section (Estevan *et al.*, 2013; Estevan *et al.*, 2015). This is particularly important considering that female athletes now represent 50% of the Taekwondo Olympic competitors (Kazemi *et al.*, 2006; Kazemi *et al.*, 2010). The purpose of this study was therefore to describe the kinematic characteristics of four Taekwondo kicks aimed at the head, performed by a high-level female Olympic athlete. Kinematic differences between kick styles were analysed. Additionally, differences between the left and right foot in their execution were also studied.

Methods

Subjects

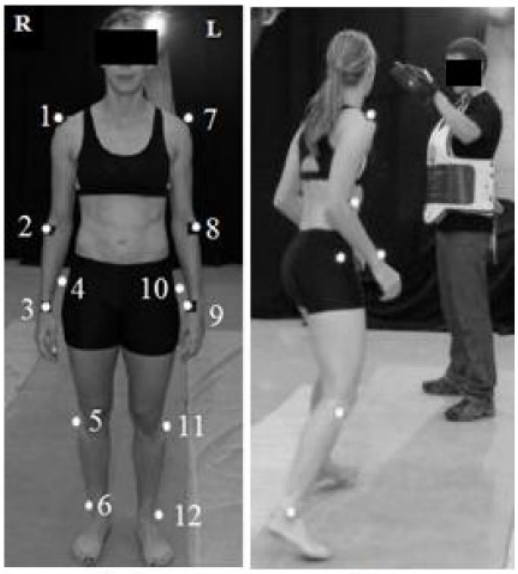
A high-level Brazilian female athlete, ranked among the top ten in women's TKD according to the World Taekwondo Federation (WTF) holder of one bronze medal in Olympic Games, four gold medals in World Games and one gold medal in Pan-american games, participated voluntarily in this study. The evaluation occurred at the end of the season training during the athletes' transition to start the rest phase. Body weight, height, age, and skill level of the athlete were respectively: 69.4 kg, 1.78 m, 28 years, and first Dan. Ethics approval was secured from the Research Ethics Committee of Scholl of Medical Sciences - Unicamp (CEP Nº237/2011) and informed consent was obtained from the participant prior to data collection.

Instrumentation

A three-dimensional kinematic analysis protocol was developed to analyse the movements of TKD kicks techniques. The movements were recorded by six Basler cameras (model A602FC) positioned around the athlete, connected by a genlocked system, with 120 Hz acquisition frequency. Calibration of cameras was performed using a nonlinear procedure, as described by (Silvatti *et al.*, 2009; Silvatti *et al.*, 2012). The kinematic model consisted of nine body segments (trunk, arms, forearms, thighs, shanks) and eight joint angles (glenoumeral, elbows, hips, and knee joints) obtained by 12 anatomical retro-reflective markers placed on the athlete's body (Figure 1(a)).All joint angles were represented with one degree of freedom.

Trial conditions

After the athlete had spent 20 minutes warming up and stretching, the retro-reflective markers were fixed on her body according to the kinematic model (Figure 1(a)). The initial position for carrying out the kicks was not static, but rather from the fight movements, leaving the athlete free to hopping. The initial position of the kicking leg was behind the supporting leg (Kong *et al.*, 2000; Lara *et al.*, 2011). All the data collection was done in one day without stopping. The athlete was asked to perform 5 repetitions of each kick for each limb consecutively, with one minute of rest between leg change and two between kick styles. For a target a second volunteer was used, wearing protective clothing and positioned in static position in front of the athlete (Figure 1(b)). As the execution distance the preferred target distance of the athlete was used (Kim *et al.*, 2010). Four kick techniques were analyzed: The Round House Kick (RHK), in which the athlete swings her leg around in a semicircular motion, striking target with the front of the leg or foot, Outside Crescent Kick (OCK), in which the kicking leg is lifted into the air in an arcing motion that starts from the center of the body and moves outward hitting the target outside edge of the foot, Axe Kick (AK), in which the athlete hit the target in a straightened leg descending and Spinning Hook Kick (SHK), in which the athlete strike target with the hell and with straightened leg after spin the roll body. All techniques chosen were performed aiming the opponent face.



(a) **(b)**

Figure 1 a) Body representation model where: acromiuns (1,7), lateral epicondilus (2,8), radius styloid process (3,9), trochanters (4,10), lateral condyles of femur (5,11), and lateral malleolus (6,12). b) Representation of the Target.

Data reduction and processing

Among the five replicates the ones used were the second, third, and fourth kicks, for a better standardisation of the movement. The tracking and 3D reconstruction of each marker were conducted using the Dvideo system (Figueroa *et al.*, 2003; Barros *et al.*, 2006). The three-dimensional coordinates of the 12 markers were filtered using a Butterworth digital filter, fourth order and 6 Hz cut off frequency. The kick movement cycle was defined by the follow criteria (Figure 2): beginning and end of cycle were defined from the velocity of the vertical coordinate of the malleolus. The beginning of cycle corresponds to the minimum local point (b) on the velocity curve previously to the instant of greatest velocity (a). The end of cycle corresponds to the maximum local point (c) on the velocity curve after the instant of lowest velocity.

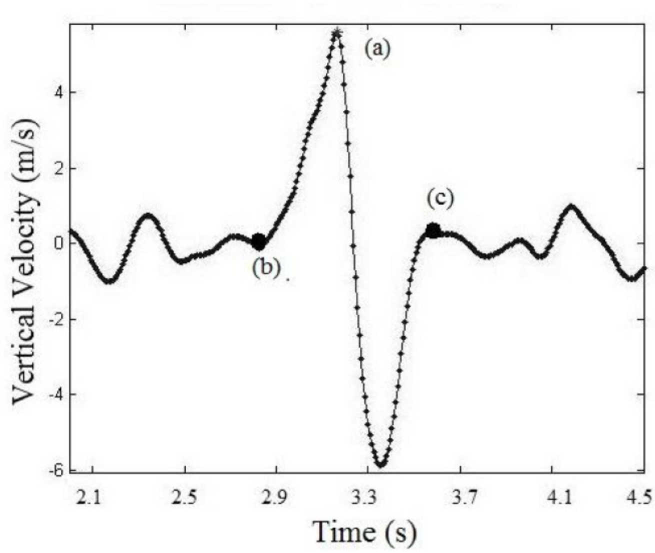


Figure 2 Representation of the kick cycle through the vertical velocity curve of the malleolus. Cycle points: greatest velocity (a), kick cycle beginning (b) and kick cycle end (c).

The frame corresponding to the instant when the athlete's foot hits the target (contact) was determined visually on the images. The contact was considered as the first frame in which the foot hit the target. The execution time was considered as the period of time from the kick cycle beginning until the instant corresponding to contact.

Data analyses

Ten dependent variables were analysed in the study: 1) execution time of kick, 2) foot maximal height, 3) foot maximal velocity, 4) foot maximal acceleration, as well as angular variables related to the knee 5) maximum extension angle, 6) maximal extension velocity, and 7) maximal extension acceleration, and related to the hip 8) maximum flexion angle, 9) maximal flexion velocity, and 10) maximal flexion acceleration.

The mean values and standard deviation of three replicates of each type of kick: Round House Kick (RHK), Outside Crescent Kick (OCK), Axe Kick (AK), and Spinning Hook Kick (SHK) for each limb, right and left, were described and used in comparisons. All variables were normally distributed (Lilliefors test).Two-way analysis of variance (ANOVA) was used to compare the means of different variables according to two factors: type of kick and right or left foot. Initially a full model was used to test all interactions. Non-significant interactions were removed from this model and the ANOVA was recalculated. Where a significant effect was detected, Tukey's honestly significant difference criterion ($p<0.05$) was performed. The data were analysed using Matlab® (R2012a).

Results

Considering the recent approval of high kicks in Olympic Taekwondo, we used kinematic analyses to identify the factors affecting the performance of a female Olympic athlete when using the four most common types of kicks aimed at the adversary's head. Additionally, we investigated putative differences in performance in the foot predominantly used by this athlete. To this end, we examined three linear variables as well as the execution time of the kicks (Table 1). An additional analysis was also conducted, in which the angle, velocity, and acceleration of the knee and hip of the leg executing the kick were measured (Table 1).

Table 1 Linear and angular performance variables and execution time of four kicks to the head executed by a female Olympic Taekwondo athlete using both feet. The malleolus was used as a reference point for the linear variables.

Kick	Foot	Execution Time (s)	Foot Maximal Height(m)	Maximal Velocity (m/s)	Maximal Acceleration (m/s^2)	Knee Maximal Extension Angle (°)	Knee Maximal Extension Velocity (°/s)	Maximal Acceleration of Knee Extension ($°/s^2$)	Hip Maximal Flexion Angle (°)	Hip Maximal Flexion Velocity (°/s)	Maximal Acceleration of Hip Flexion ($°/s^2$)
Round House Kick	R	0.40 (0.00)	1.67 (0.02)	12.15 (0.56)	142.83 (8.51)	6.34 (2.90)	-515.13 (47.11)	4235.05 (6015.36)	94.71 (7.54)	747.93 (66.99)	16140.34 (2300.36)
	L	0.43 (0.03)	1.65 (0.02)	11.31 (0.50)	143.92 (7.62)	6.65 (1.72)	-558.33 (81.54)	9089.06 (4568.88)	92.95 (6.44)	578.23 (33.06)	12319.92 (2929.56)
Outside Crescent Kick	R	0.46 (0.07)	1.75 (0.01)	10.93 (0.26)	69.78 (13.49)	2.83 (2.19)	-847.28 (125.43)	-11256.16 (746.01)	129.89 (6.70)	566.15 (10.73)	25708.63 (22192.58)
	L	0.47 (0.01)	1.75 (0.03)	10.07 (0.21)	62.58 (0.26)	3.01 (1.69)	-805.03 (78.00)	-5461.09 (1571.71)	136.23 (3.92)	599.49 (29.56)	8445.92 (1761.93)
Axe Kick	R	0.37 (0.25)	1.61 (0.06)	10.05 (0.26)	146.07 (2.36)	2.41 (0.75)	-1129.63 (67.80)	-16021.25 (391.45)	118.08 (6.44)	810.85 (19.42)	62682.72 (3619.25)
	L	0.51 (0.01)	1.59 (0.02)	10.01 (0.14)	133.90 (4.63)	6.74 (1.78)	-1348.91 (16.12)	-12537.08 (2243.60)	131.57 (4.09)	1000.22 (41.35)	66145.34 (23572.40)
Spinning Hook Kick	R	0.41 (0.02)	1.70 (0.02)	11.10 (0.47)	60.90 (9.00)	53.80 (17.50)	-170.53 (56.4)	667.19 (4842.46)	87.69 (0.47)	313.08 (24.00)	21802.33 (6422.82)
	L	0.42 (0.01)	1.63 (0.03)	10.88 (0.14)	48.44 (4.13)	25.14 (4.48)	-591.45 (113.15)	-17025.76 (2334.25)	88.07 (4.96)	391.38 (49.55)	9857.22 (4206.25)

Note: R - Right, L - Left. Data are presented in Mean and(SD) format.

The results of both analyses show a trend towards a higher performance with the right leg in the four kick styles, as indicated by a shorter execution time and higher maximal height, velocity, and acceleration in the linear analyses. Furthermore, the performance ranged from the feet to the angular variables and varied among the four types of kicks analysed. The data showed high values of standard deviation for the angular variables. To determine if the observed differences between foot performance and kick styles were statistically significant, a two-way ANOVA was conducted in which kick style (OCK, RHK, AK, SHK) and kicking foot (RF and LF) were included as terms in the model. Statistically significant differences in performance among kick styles are depicted in Table 2.

Table 2 Statistically significant differences in performance of four kick styles (OCK, RHK, AK, and SHK) executed by a female Olympic Taekwondo athlete, and direction of difference, as measured by linear and angular kinematic analyses.

	Variables	**Significant differences among kick styles ($p<0.05$)**
LINEAR and TIME	Execution Time	No Significant Difference
	Maximal Height	OCK>RHK, AK>SHK
	Maximal Velocity	RHK>OCK, SHK, AK, SHK>AK
	Maximal Acceleration	RHK, AK>OCK,SHK
ANGULAR	Knee Maximal Extension Angle	SHK>RHK,OCK,AK
	Knee Maximal Extension Velocity	SHK,RHK>OCK>AK
	Knee Maximal Extension Acceleration	RHK>OCK,AK,SHK
	Hip Maximal Flexion Angle	OCK,AK>RHK,SHK
	Hip Maximal Flexion Velocity	AK>OCK,RHK>SHK
	Hip Maximal Flexion Acceleration	AK>OCK,RHK,SHK

Note: OCK - Outside Crescent Kick, RHK - Round House Kick, AK - Axe Kick, SHK - Spinning Hook Kick.

Table 2 showed significant differences among kick styles for all performance variables examined in both kinematic analyses. Notice, however, that these differences were highly variable in terms of the parameters analyses, with different kicks achieving the highest performance for the distinct parameters measured. The only exception was execution time, for which no significant differences were observed despite the different movements involved in each case. In contrast, there were significant and consistent differences in the maximum velocity (Right=11.06m/s, Left=10.57m/s) and acceleration (Right=104.57m/s^2, Left=97.21m/s^2) of the malleolus, as well as in the maximum knee extension velocity (Right=-665.64º/s, Left=-825.93º/s) between the right and left feet, with significantly higher values associated with the former (p<0.05). The analyses of the interaction between kick style and foot used were not significant for any of the variables examined.

Discussion

In this study we characterised kinematic parameters associated with differences among the frequently used head kicks performed by a high-level female athlete. The four head kicks presented significant difference in all dependent variables, except for execution time. Additionally, the results provide information about athlete's leg performance suggesting unbalance between right and left leg execution.

Independently of the kick style, we found significantly higher values associated with the right foot as measured by maximum linear velocity and acceleration, and higher values of knee extension velocity for the left foot. With the exception of a previous study that showed differences between the right and left foot in terms of knee maximum angular velocity and acceleration (Lara *et al.*, 2011) during the execution of Bandal chagui and Dolyo chagui Taekwondo kicks. These findings demonstrate that there is a difference in the mechanics of movement among legs for this athlete. This information should be considered in training to improve performance.

Although there were differences between the uses of feet by this athlete, execution times were similar for both feet and all kick styles, suggesting that this lack of difference can be used to surprise the opponent through unpredictable combinations of foot and kick styles. We believe that the assessment of bilateralism in the use of feet could be used as a means to enrich training and improve performance.

One interesting finding that emerged from our characterisation of this athlete is that, even though the execution time for the Round House Kick was higher than that of Spanish medallists (Estevan *et al.*, 2011), it was lower than that reported for a male athlete of the Spanish national team (Falco *et al.*, 2011). By indicating a similar, or even superior, performance by female TKD athletes, this finding emphasises the importance of studying this group.

The kicks analysed belong to two categories (Falco *et al.*, 2011): swing kicks RHK and SHK (executed with a lower leg and foot rotation about the knee) and thrust kicks OCK and AK (executed with a foot translational motion from hip). Thrust kicks to the head (OCK, AK) reached higher height than swing kicks (RHK, SHK), a result which we expected since the thrust techniques chosen for this study are executed in a downward movement

(Serina e Lieu, 1991; Sorensen *et al.*, 1996). In addition to being associated with the highest values of linear velocity and acceleration (RHK), swing kicks also showed the highest knee extension velocities (SHK). This could be explained by differences in the distance between the kicking foot and the target in every kick style. Here, this variable was not controlled to enable the kicking movements to be executed as they would be in a fighting situation, thus increasing the likelihood of measuring parameters representative of the athlete's performance in a fight.

In addition to conducting linear kinematic analysis, we also measured angular variables associated with the kick. Our results also showed that the angular kinematics of the knee and hip were different between thrust and swing kicks. Hip flexion angle, velocity, and acceleration were higher for thrust than swing kicks. Conversely, knee extension angle, velocity, and acceleration were higher for swing kicks. It was expected that the angular kinematics were different between the kicks style since they happened in different direction of string foot (downwards for OCK and AK, latero-medial for the RHK and SHK).

The identification of patterns associated with these kick styles, and their corresponding differences in performance, indicate that the integrated use of linear and angular kinematic analyses is effective to describe the movement pattern of kicks in Taekwondo, and therefore can be used as a means to improve training at different levels, showing which are the techniques to be used for reach the higher height. In this study we used an integrated approach to describe TKD kicks to the head performed by a high-level female athlete. The results should provide a better understanding of the use of these techniques during competition. Further research is needed to determine if our findings can be generalised to other athletes.

Conclusion

In conclusion, the paper explicit the kinematic difference of the four head Taekwondo kicks performed by a female Olympic athlete. This information should be used by coaches in order to improving the technical training of these four techniques. Furthermore the analysis highlighted the unbalance performance between kicking foot, that information could be used by the coaches to change the training strategies depending of the athlete aims, as well as an alert to the injury possibility.

Considerações Finais

O objetivo desta tese foi analisar a cinemática e cinética dos chutes do Taekwondo em condições experimentais que simulam a luta competitiva. Levando em conta os resultados e discussões apresentadas, alguns pontos devem ser ressaltados tendo em vista as contribuições deste estudo à área de biomecânica do Taekwondo.

Um ponto a ser ressaltado é a aproximação do procedimento experimental empregado a situação de combate. Nota-se pela observação dos resultados de todos os capítulos que a perna de apoio tem fundamental importância na execução das técnicas de chute do Taekwondo em situação experimental de luta. Sendo a perna de apoio responsável por grande parte da aquisição de potência dos membros inferiores durante a execução do chute.

Adicionalmente no capítulo III evidencia-se que a movimentação de luta (hopping) influencia significativamente a execução das técnicas de chute em termos da dinâmica das forças de reação do solo. Estudos futuros devem considerar estes resultados, e mesmo em ambientes controlados de laboratório buscar reproduzir a situação de combate, para que as pesquisas possam contribuir para o desenvolvimento de treinamentos compatíveis a demanda encontrada na competição.

Outro fator a ser considerado é a análise de diferentes grupos de praticantes, como observados nos resultados apresentados nos capítulos II, III e V o estilo de combate proposto pelas federações e o nível técnico dos atletas afetam diretamente as execuções da mesma técnica. Como visto no capítulo II as regras impostas pelas associações dirigentes da modalidade competitiva influencia diretamente as estratégias dos atletas durante a luta. Afetando a movimentação dos membros inferiores, com destaque para pelve.

Atualmente as pesquisas em biomecânica dos chutes de Taekwondo são focadas apenas em atletas de nível competitivo (faixas pretas), de alto nível ou amador. O presente investigou as relações entre o sistema de graduação do Taekwondo e as variáveis biomecânicas, apesar de comprovar que estas relações são moderadas, a observação dos resultados sugere que a investigação dos padrões de movimentos de praticantes com níveis técnicos diferenciados do competitivo pode contribuir a compreensão da mecânica das técnicas de chutes no Taekwondo. Estudos futuros devem ser conduzidos em busca da descrição e análise de outros grupos com diferentes faixas etárias e com níveis de treinamento e aprendizagem diferenciados.

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Apêndices

CARTA DE CIÊNCIA E AUTORIZAÇÃO PARA RECRUTAMENTO NA ACADEMIA

Eu Afonsa Janaína da silva, RG 25.547.594-9, pesquisadora colaboradora do Laboratório de Instrumentação para Biomecânica da Faculdade de Educação Física da Universidade Estadual de Campinas, sob a orientação do professor doutor Ricardo Machado Leite de Barros, venho por meio desta pedir autorização para recrutamento de atletas de Taekwondo na presente academia.

Desenvolvo o trabalho intitulado "Proposição de um Protocolo de Avaliação Cinemática para chutes do Taekwondo", que tem como objetivo geral desenvolver um protocolo de avaliação cinemática tridimensional para os chutes de TKD, capaz de gerar informações que caracterizem as técnicas de chute em condições próximas as condições de combate.

Para o desenvolvimento deste projeto será necessária a participação de atletas de Taekwondo praticantes regulares da modalidade. Os atletas serão informados dos procedimentos e do caráter voluntário de sua participação na pesquisa através do Termo de consentimento livre e esclarecido em anexo.

Depois de conhecer e entender os objetivos, procedimentos metodológicos, riscos e benefícios da pesquisa, através do presente termo, a academia________________________ ____, autoriza a pesquisadora Afonsa Janaína da Silva a realizar o recrutamento de atletas em suas dependências.

Campinas, _____ de ____________________ de 20____

_________________________ _______________________________

Representante da Academia Afonsa Janaína da Silva

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TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

(MAIOR DE 18 ANOS)

Eu, ____, idade _______ portador do RG nº____________________, residente à _________________________ ___________________________________nº________, bairro_______________________ ______________________ na cidade de ______________________________, Estado _____, Telefone nº__________________ declaro que aceitei participar da pesquisa intitulada “Efeitos da faixa etária, gênero, prática e treinamento na cinemática e dinâmica das técnicas de chute do Taekwondo”, que tem como objetivo geral desenvolver um protocolo de avaliação cinemática tridimensional para os chutes de TKD, capaz de gerar informações que caracterizem as técnicas de chute em condições próximas as condições de combate, desenvolvida pela Profissional de Educação Física CREF 082002-G/SP, no Laboratório de Instrumentação para Biomecânica da Faculdade de Educação Física da Universidade Estadual de Campinas, sob a orientação do professor doutor Ricardo Machado Leite de Barros.

Nesta unidade fui devidamente informado sobre os procedimentos a serem realizados:

1. serão colocados 19 marcadores afixados externamente na pele de maneira não invasiva, sem efeitos colaterais, não trazendo qualquer risco para a minha integridade física,
2. que contribuirei para a coleta adequada dos meus dados, estando ciente dos trajes a serem utilizados durante a pesquisa, mesmo que segmentos corporais apresentem-se expostos,
3. que contribuirei executando chutes de Taekwondo em um segundo voluntario devidamente trajado com roupas de segurança e implementos de treino, sendo este experiente no manejo destes artigo. Que todos os golpes serão executados com as ambas as pernas, de forma consecutiva para cada golpe e condição inicial proposta.
4. que as imagens obtidas durante da coleta serão exclusivamente utilizadas para análise e tratamento dos dados, pela pesquisadora e membros do Laboratório de Instrumentação em Biomecânica, com finalidade científica, sendo posteriormente eliminadas,
5. antes da realização da filmagem será feita uma avaliação antropométrica de comprimentos e circunferência dos segmentos corporais, bem como, uma avaliação de goniometria para avaliação da flexibilidade articular.
6. que a pesquisa é de caráter voluntário e poderei, a qualquer momento, retirar-me do pesquisa, sem que com isso venha ser prejudicado nos demais serviços realizados UNICAMP.
7. que receberei uma cópia deste termo de consentimento.

Campinas, SP, _____, de _____________________de ________

_____________________________ _____________________________

Afonsa Janaína da Silva *Voluntário*
Pesquisadora Responsável

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TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

(MENORES DE 18 ANOS)

Eu, ____, idade _______ portador do RG nº____________________, residente à ______________________________ ____________________________________nº________,bairro_________________________ ______________________ na cidade de ______________________________, Estado _____, Telefone nº__________________ declaro ter conhecimento sobre pesquisa intitulada "Efeitos da faixa etária, gênero, prática e treinamento na cinemática e dinâmica das técnicas de chute do Taekwondo", que tem como objetivo geral desenvolver um protocolo de avaliação cinemática tridimensional para os chutes de TKD, capaz de gerar informações que caracterizem as técnicas de chute em condições próximas as condições de combate, desenvolvida pela Profissional de Educação Física CREF 082002-G/SP, no Laboratório de Instrumentação para Biomecânica da Faculdade de Educação Física da Universidade Estadual de Campinas, sob a orientação do professor doutor Ricardo Machado Leite de Barros.

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2. que contribuirei para a coleta adequada dos meus dados, estando ciente dos trajes a serem utilizados durante a pesquisa, mesmo que segmentos corporais apresentem-se expostos,
3. que contribuirei executando chutes de Taekwondo em um segundo voluntario devidamente trajado com roupas de segurança e implementos de treino, sendo este experiente no manejo destes artigo. Que todos os golpes serão executados com as ambas as pernas, de forma consecutiva para cada golpe e condição inicial proposta.
4. que as imagens obtidas durante da coleta serão exclusivamente utilizadas para análise e tratamento dos dados, pelos pesquisadores, com finalidade científica, sendo posteriormente eliminadas,
5. antes da realização da filmagem será feita uma avaliação antropométrica de comprimentos e circunferência dos segmentos corporais, bem como, uma avaliação de goniometria para avaliação da flexibilidade articular.
6. que a pesquisa é de caráter voluntário e poderei, a qualquer momento, retirar-me do pesquisa, sem que com isso venha ser prejudicado nos demais serviços realizados UNICAMP.

7. que receberei uma cópia deste termo de consentimento.

Autorizo voluntariamente a participação do menor ________________________________ ____________________________________, idade ___________, sabendo que as imagens obtidas pela filmagem e os dados coletados estarão sob o resguardo científico e do sigilo profissional, e contribuirão para o alcance dos objetivos deste trabalho.

Para qualquer esclarecimento ou reclamação, sei que posso ligar para o Comitê de Ética da UNICAMP (telefone 3788-8936) ou para o Laboratório de Instrumentação para Biomecânica (telefone 3788-6626).

Campinas, SP, _____, de ____________________de ________

____________________________ ____________________________

Afonsa Janaína da Silva *Assinatura do responsável*
Pesquisadora responsável

Afonsa Janaína da Silva : (19)21213022
Prof. Dr Ricardo Machado Leite de Barros : (19) 3521 6626
Comitê de Ética em Pesquisa/FCM/UNICAMP
Tel: (19)3521 8936, Fax (019) 3521-7187, email:www.fcm.unicamp.br/fcm/pesquisa
Rua: Tessália Vieira de Camargo, 126 – CEP 13083-887 – Campinas, SP.

QUESTIONÁRIO DE CARACTERIZAÇÃO DO SUJEITO

Nome:______________________________________ Profissão:____________________

Email: _____________________________________ Data de nascimento:___/___/___

Peso:_______________________________________ Altura:______________________

1)Há quanto tempo você pratica Taekwondo?

____

2)Qual sua graduação?

____

3) Pratica regularmente o Taekwondo? Se sim, quantas vezes por semana? Quantas horas por dia?

Não :_____

Sim:____

4)Realiza outro tipo de treinamento físico? Se sim, qual, há quanto tempo e quantas vezes por semana?

Não :_____

Sim:____

____

5)Qualeu membro inferior dominante?

____

Anexos

UNICAMP

FACULDADE DE CIÊNCIAS MÉDICAS
COMITÊ DE ÉTICA EM PESQUISA

www.fcm.unicamp.br/fcm/pesquisa

CEP, 07/07/11
(Grupo III)

PARECER CEP: N° 237/2011 (Este n° deve ser citado nas correspondências referente a este projeto).
CAAE: 0180.0.146.000-11

I - IDENTIFICAÇÃO:

PROJETO: **"PROPOSIÇÃO DE UM PROTOCOLO DE AVALIAÇÃO CINEMÁTICA PARA CHUTES DO TAEKWONDO".**
PESQUISADOR RESPONSÁVEL: Afonsa Janaína da Silva
INSTITUIÇÃO: Faculdade de Educação Física/UNICAMP
APRESENTAÇÃO AO CEP: 07/04/2011
APRESENTAR RELATÓRIO EM: 07/07/12 (O formulário encontra-se no *site* acima).

II – OBJETIVOS

Desenvolver um protocolo de avaliação cinemática tridimensional para os chutes de Taekwondo (TKD), capaz de gerar informações que caracterizem as técnicas de chutes em condições próximas as de combate, aperfeiçoando o treinamento das diferentes técnicas.

III – SUMÁRIO

Participarão do estudo 20 atletas de TKD, de ambos os sexos, com idade mínima de 17 anos, praticantes há mais de quatro anos, com freqüência semanal, que serão submetidos a uma avaliação antropométrica e goniométrica. Cumprida esta etapa, os participantes farão 20 minutos de aquecimento e na seqüência serão afixados 19 marcadores retro-reflexivos. Os sujeitos serão posicionados sobre um tatame frente a outro voluntário estaticamente posicionado, denominado "alvo" e, por isso mesmo, devidamente protegido e com familiaridade com os equipamentos de proteção. Serão feitas cinco repetições de cada tipo de chute (são cinco tipos), a partir de uma posição não estática, com o intuito de simular um movimento de combate. Após o protocolo de chute o os voluntários realizarão 18 segundos de luta livre (trajando equipamentos de proteção). Os movimentos serão registrados por seis câmeras dispostas de tal forma a permitir a reconstrução tridimensional dos movimentos em um espaço previamente calibrado em relação a um sistema de coordenadas. A análise dos chutes será feita 1) pelo cálculo das variáveis lineares e angulares das articulações do tornozelo, joelho e quadril e 2) pela análise da trajetória dos marcadores, que serão comparados com os dados da literatura. Esses resultados serão analisados a partir de rotinas desenvolvidas pelo software Matlab.

IV - COMENTÁRIOS DOS RELATORES

Após respostas às pendências, o projeto encontra-se adequadamente redigido e de acordo com a Resolução CNS/MS 196/96 e suas complementares, bem como o Termo de Consentimento Livre e Esclarecido.

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V - PARECER DO CEP

O Comitê de Ética em Pesquisa da Faculdade de Ciências Médicas da UNICAMP, após acatar os pareceres dos membros-relatores previamente designados para o presente caso e atendendo todos os dispositivos das Resoluções 196/96 e complementares, resolve aprovar sem restrições o Protocolo de Pesquisa, bem como ter aprovado o Termo do Consentimento Livre e Esclarecido, assim como todos os anexos incluídos na Pesquisa supracitada.

O conteúdo e as conclusões aqui apresentados são de responsabilidade exclusiva do CEP/FCM/UNICAMP e não representam a opinião da Universidade Estadual de Campinas nem a comprometem.

VI - INFORMAÇÕES COMPLEMENTARES

O sujeito da pesquisa tem a liberdade de recusar-se a participar ou de retirar seu consentimento em qualquer fase da pesquisa, sem penalização alguma e sem prejuízo ao seu cuidado (Res. CNS 196/96 – Item IV.1.f) e deve receber uma cópia do Termo de Consentimento Livre e Esclarecido, na íntegra, por ele assinado (Item IV.2.d).

Pesquisador deve desenvolver a pesquisa conforme delineada no protocolo aprovado e descontinuar o estudo somente após análise das razões da descontinuidade pelo CEP que o aprovou (Res. CNS Item III.1.z), exceto quando perceber risco ou dano não previsto ao sujeito participante ou quando constatar a superioridade do regime oferecido a um dos grupos de pesquisa (Item V.3.).

O CEP deve ser informado de todos os efeitos adversos ou fatos relevantes que alterem o curso normal do estudo (Res. CNS Item V.4.). É papel do pesquisador assegurar medidas imediatas adequadas frente a evento adverso grave ocorrido (mesmo que tenha sido em outro centro) e enviar notificação ao CEP e à Agência Nacional de Vigilância Sanitária – ANVISA – junto com seu posicionamento.

Eventuais modificações ou emendas ao protocolo devem ser apresentadas ao CEP de forma clara e sucinta, identificando a parte do protocolo a ser modificada e suas justificativas. Em caso de projeto do Grupo I ou II apresentados anteriormente à ANVISA, o pesquisador ou patrocinador deve enviá-las também à mesma junto com o parecer aprovatório do CEP, para serem juntadas ao protocolo inicial (Res. 251/97, Item III.2.e)

Relatórios parciais e final devem ser apresentados ao CEP, de acordo com os prazos estabelecidos na Resolução CNS-MS 196/96.

VII- DATA DA REUNIÃO

Homologado na IV Reunião Ordinária do CEP/FCM, em 26 de abril de 2011.

Steiner

Prof. Dr. Carlos Eduardo Steiner
PRESIDENTE do COMITÊ DE ÉTICA EM PESQUISA
FCM / UNICAMP

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