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The Influence of Wearable Resistance Loading on Taekwondo Axe Kick Kinematics among Elite Taekwondo Athletes

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Abstract Wearable resistance (WR) is an alternative proposed to be used in training with the aim to increase sport performance by allowing specific movements to be performed with additional loading. Although the benefits of allowing more sport-specific movement are undeniable, studies conducted on the effects of this WR in Taekwondo sport are scarce. This study aims to determine the acute effects of WR loading on Taekwondo axe kick kinematics. Twenty-four (n=24) state-level taekwondo athletes were recruited and were required to perform axe kick in four conditions by wearing a WR suit on their thigh and shank. Four different loadings were attached at the suit; i) 3% of body mass (3WR), ii) 5% of body mass (5WR), iii) 8% of body mass (8WR) and iv) without load (0WR). During the movement, movement kinematics (maximum kick height, angle between thighs, range of motion (ROM) of hip, ROM of knee, duration of power load, maximum speed of ankle, duration of drive and total time were analyzed for both dominant and non-dominant leg. Cameras attached to motion analysis systems were used to record participant's kicking kinematics. The kinematics data obtained were compared between each loading condition. Results showed that only wearing WR of 3% body mass did not change the kinematics of kicking (except for maximum kick height) as without WR. Wearing WR of 5% and 8% body mass caused significant changes to the movement kinematics when compared to without WR. To conclude, this study has added the knowledge on the alternatives for resistance training that can be performed among Taekwondo athletes. Through the findings of this study, it was found that wearing WR of 3% body mass is suitable for athletes during training session as they can maintain their technical effectiveness while also increase stimulus for body to adapt in long term while a minimum of 5 % body mass might affect the kicking technical efficiency. It is suggested for chronic studies to be conducted to determine the long term effects of WR loadings on the kicking techniques efficiency.

Keywords Wearable Resistance, Specificity, Resistance Training, Training Loads, Martial Art

1. Introduction

Taekwondo is one of an unarmed combat/martial art designed for self-defense. Kicking, blocking and striking are the fundamental techniques of this sport. Believed to be originated from Korea in 1940s, the technical and tactical features of Taekwondo have improved by various masters from Korean army during 1950s. According to Kazemi et al. [1], kicking contributed to almost 98% of scoring in Taekwondo. Therefore, it is important for an athlete to improve their kicking effectiveness. Kicking effectiveness could be measured by the kinematic and kinetic characteristics. In terms of kinematic, the ability of athlete to kick with high velocity will enhance more chances to hit the opponent while ability to kick higher will create more chances to get more points by hitting the opponent's head. Among popular kicks in Taekwondo include front, roundhouse and axe kick.

Several aspects of Taekwondo have been scientifically investigated such as impact force among participants of distinct level of expertise [2], movement time and speed of kicking foot [3, 4]. Several authors have studied the kinematics of the lower extremity and pelvis [5].

Throughout previous researches, front kick and roundhouse kick had being the primary focus kicks to be studied. Wasik [6] in his study stated that center of gravity (COG) at take-off, the flight height of the COG, the leg length and the angle formed between the plane perpendicular to the board and the leg are the main factors influencing the kick height performed an athlete. One of the kick that is believed to be powerful to collect points while at the same time increase chances to knockout the opponent is axe kick. Mailapalli et al. [7] in their review found that axe kick in Taekwondo is a highly effective offensive and defensive technique with the purpose is to attack the opponent's head, collarbone or chest with a powerful downward force. Axe kick is performed by bringing up the kicking leg in a circular motion, and at the peak height, brings the heel straight down (like a downward movement of an axe) upon the opponent's shoulder or head [7, 8]. Figure 1 showed four stages of axe kick in Taekwondo.

Throughout those researches that had been conducted, it is without a doubt that kicking effectiveness will affect the match outcomes. Therefore, ability to produce good kick (i.e. axe kick) should be among the main aim of Taekwondo training, and training with resistance is recommended to fulfil the need.

Resistance training is a kind of training that involves any kinds of equipment/tools to become the resistance. Traditionally, resistance training involved individuals to go to the gym and lift weights. Unfortunately, until now, the issue of transferability of strength gains achieved from traditional resistance training methods to sport-specific performance is still debated among strength and conditioning coaches, practitioners and athletes [9-11]. Several strength and conditioning researchers have argued that a better training transfer can be achieved from exercises that display mechanical specificity to the movement performed in competition [12, 13] and specificity of velocity of movement [14].

Currently, strength training protocols for majority of sports including combat sports utilize the normal available weight machines and free weight apart from the most widely used bodyweight strength training [15, 16]. It is proposed that training should utilize loading methods that are more functional in nature, and able to be loaded while performing the actual combat sports movement. Therefore, loadings that permit performer to move freely according to sports skill movement are suggested.

Wearable resistance training involves an external load being attached to certain segments of the body during various sporting movements [17, 18]. Wearable resistance is used in athletic training with the aim of increasing power output and performance by enabling specific movements to occur with additional loading without adversely affecting the technical execution of the action being performed [19]. The new wearable resistance technologies (e.g. the Lila TM Exogen TM exoskeleton suit) enable much greater customisation of load magnitudes, orientations and locations around the body. This kind of wearable resistance enables sport specific actions to be performed in an overloaded manner [19].

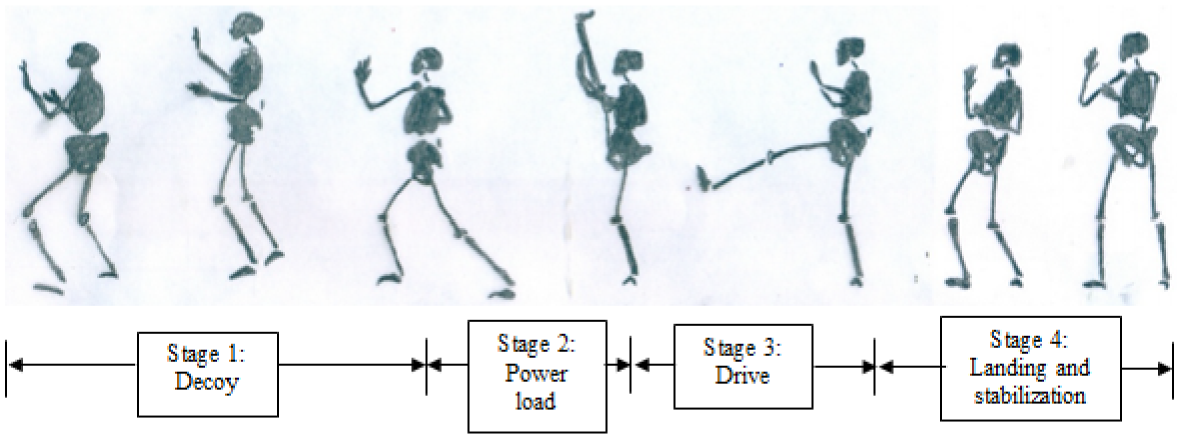

Figure 1. Stages of axe kick (figure adapted from Mailapalli et al. [7])

Applying wearable resistance to Taekwondo training is believed to enhanced athletes ability to perform better kick, as athletes can train their kicking by wearing loads. However, it is not known how much loads should be attached, as too heavy loadings could affect the movement patterns thus making the movement to be less specific. Currently, as to the authors' knowledge after articles searching through several databases, no studies had yet been conducted on determining the effects of wearable resistance on taekwondo kicking kinematics. Thus a study in this area will contribute new knowledge on the effectiveness of wearable resistance training, with also considering the loading effects.

This study aims to determine and compare the movement kinematics (maximum kick height, angle between thighs, range of motion (ROM) of hip, ROM of knee, duration of power load, maximum speed of ankle, duration of drive and total time) between WR with 3% of body mass (3WR), WR with 5% of body mass (5WR) WR with 8% of body mass (8WR) and without WR (0WR) for both dominant and non-dominant leg during axe kick in Taekwondo.

2. Methodology

2.1. Participants

Participants of this study involved twenty-four (N=24) elite Taekwondo athletes that have black belt in Taekwondo and are currently active participating in any Taekwondo tournament at state or university level during data collection. All the participants should be free of any injuries. Despite all these, it is found that participants had no previous experience with WR. Participants were needed to fill in the Physical Activity Readiness Questionnaire (PAR-Q) and inform consent. All participants were reminded that their participation in this study is based on volunteerism and they are free to withdraw from the study at any time. This study has been approved by researchers' University Human Research Ethics Committee [Code: UPSI/PPPI/PYK/ETIKA(M)/014(164)]

2.2. Procedures

Five sessions were required to be attended by participants. The first session was spent for briefing and familiarization. The second, third, fourth and fifth sessions were the testing sessions separated by 72 hours in between. Each session took approximately 30 minutes to an hour, considering the participants preparation and the actual testing of the protocols.

For the first session, participants were given the briefings which include details of the study, personal rights to withdraw, consent letter and pre-exercise questionnaire screening. Once agreed by participants and participant signing in the consent letter, the session continued with introduction to all testing apparatus that will be used, and trial of all the equipment for the purpose of the study. The equipment trial was important, as all the participants did not have any experience with the WR. During the other four testing occasions, the exercise protocol was completed with three different percentages of loads to body mass (3, 5 and 8% of body weight) and one more, without WR. The loadings were attached to the suit worn by participants at the dominant side of their thigh and shank. Figure 2 showed the research workflow.

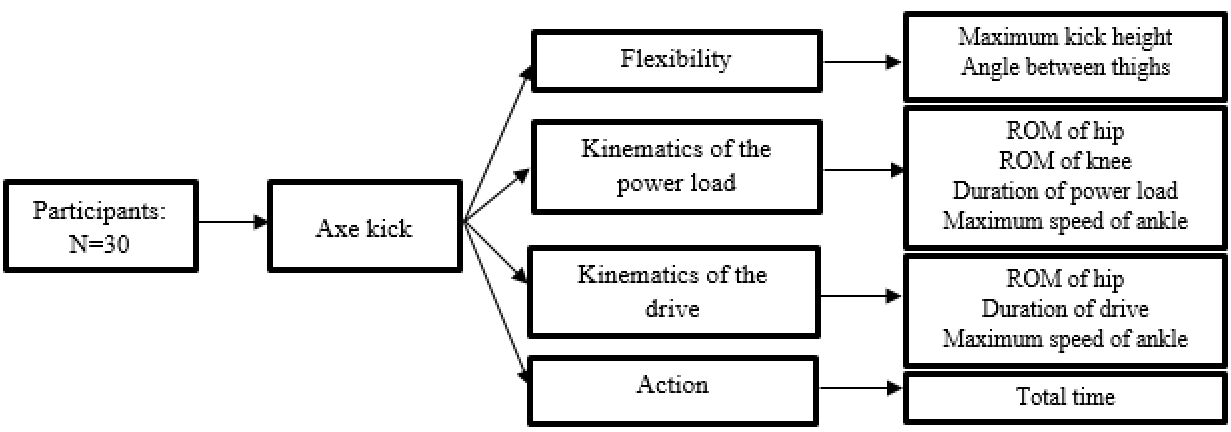

Figure 2. Research flow

2.3. Axe Kick

According to Yu et al. [8], there are four stages to perform axe kick; i) Decoy, ii) Power load, iii) Drive and iv) Landing and stabilization. This study put focus on the most important two stages that are the power load and drive. The movement of the axe kick was started with participant get ready in fighting stance position, one leg in front (supporting leg) and one leg behind (kicking leg). Then participant lift the rear leg and kick into the air as high as they can. In this movement, rear leg was straight up and when reaches at maximum height, participant then swing down the heel to strike the target and at the same time started the downward phase. During downward movement, participant quickly drives forward the heel downward and back to normal fighting stance position.

2.4. Data Analysis

Six infra-red cameras motion analysis systems (Vicon T10s, Oxford Metrics, UK) were used to collect kinematics data, sampled at 100 Hz. Based on the Plug-in-Gate Marker Set, reflective markers were attached to participant body at the second metatarsal, lateral malleolus, calcaneus, lateral shank, lateral femoral epicondyle, lateral thigh and anterior superior iliac spine at both sides of body. Analysis of data was conducted using Vicon Workstation software. The kinematic model of the lower body consisted of the shank, thigh and pelvis of the kicking leg. The joint displacement and movement time were obtained through tracking the reflective makers automatically, and then the joint velocity was derived from the time series.

2.5. Statistical Analysis

Means and standard deviations were used to represent centrality and spread of data for all performance measures. One way repeated measure analysis of variances (ANOVA) was used to determine if significant differences existed across different percentage of loads. An alpha level of 0.05 was set to assess statistical significance for all tests.

3. Results

Table 1 showed the demographic background of participants involved in this study.

Table 1. Participants' demographic background

Age (years old)	22.19 ± 1.34
Height (m)	1.73 ± 0.08
Body mass (kg)	69.84 ± 4.53

Table 2. Score mean and standard deviation

	Parameters	0 WR	3 WR	5 WR	8 WR
Flexibility	Maximum kick height (% of body height)	121.71 ± 15.33 [bcd]	119.65 ± 17.21 [acd]	116.29 ± 15.12 [abd]	111.37 ± 13.02 [abc]
	Angle between thighs (°)	144.21 ± 5.32 [cd]	143.10 ± 6.22 [cd]	141.32 ± 7.28 [abd]	140.03 ± 5.19 [abc]
Kinematics of the power load	ROM of hip (°)	178.43 ± 8.15 [cd]	177.02 ± 10.93 [cd]	175.02 ± 11.93 [abd]	173.02 ± 10.01 [abc]
	ROM of knee (°)	24.14 ± 6.82 [cd]	23.68 ± 7.92 [cd]	21.38 ± 6.02 [ab]	21.01 ± 4.02 [ab]
	Duration of power load (s)	0.39 ± 0.66 [cd]	0.40 ± 0.25 [cd]	0.41 ± 0.85 [ab]	0.42 ± 0.91 [ab]
	Maximum speed of ankle (m/s)	8.25 ± 0.40 [cd]	8.23 ± 0.72 [cd]	8.18 ± 0.82 [ab]	8.17 ± 0.04 [ab]
Kinematics of the drive	ROM of hip (°)	119.25 ± 6.25 [cd]	118.38 ± 7.98 [cd]	115.82 ± 8.02 [ab]	114.14 ± 6.99 [ab]
	Duration of drive (s)	0.36 ± 0.72 [cd]	0.37 ± 0.21 [cd]	0.38 ± 0.83 [ab]	0.39 ± 0.30 [ab]
	Maximum speed of ankle (m/s)	8.71 ± 0.91 [cd]	8.67 ± 0.82 [cd]	8.56 ± 0.75 [abd]	8.50 ± 0.71 [abc]
Action	Total time (s)	0.80 ± 0.00 [cd]	0.81 ± 0.12 [cd]	0.83 ± 0.03 [abd]	0.84 ± 0.06 [abc]

[a] = significantly different from 0 WR
[b] = significantly different from 3 WR
[c] = significantly different from 5 WR
[d] = significantly different from 8 WR

Table 2 showed mean and standard deviation of kinematics data. Analysis showed significant effects for all the kinematic variables investigated in all loadings: i) maximum kick height, $F(3,69) = 428.18$; $p < 0.001$, ii) angle between thighs, $F(3,69) = 200.23$; $p < 0.001$, iii) ROM of hip during power load, $F(3,69) = 572.34$; $p < 0.001$, iv) ROM of knee, $F(3,69) = 302.28$; $p < 0.001$, v) duration of power load, $F(3,69) = 998.18$; $p < 0.001$, vi) maximum speed of ankle during power load, $F(3,69) = 982.38$; $p < 0.001$, vii) ROM of hip during drive, $F(3,69) = 762.18$; $p < 0.001$, viii) duration of drive, $F(3,69) = 573.28$; $p < 0.001$, ix) maximum speed of ankle during drive, $F(3,69) = 783.13$; $p < 0.001$, x) total time, $F(3,69) = 873.37$; $p < 0.001$. Pairwise comparison then was conducted to compare specifically between all the variables between loads. Maximum kick height were different between each of the loadings ($p<0.05$). Other variables were found not to be significantly different between 3WR and 0WR. However, 5WR and 8WR were found to have the other variables were to be significantly different from 0WR and 3WR.

4. Discussions

As axe kick is believed to be one of the most important kicks that can be vital to decide a match outcome [7, 20], this research aims to compare the kinematic effects of wearable resistance loading applied on the lower body of participants. The flexibility, power load stages, drive stages and total action time of the axe kick were analyzed.

Maximum kick height and angle between thighs were analyzed as measurement of flexibility. Results showed none of the WR loadings able to maintain the maximum kick height achieved during without loads. This showed that loading worn by participants affected the ability to move their leg to achieve the maximum height. However, 3WR was found to be able to maintain angle between thighs. This demonstrated that wearing 3% load give potential for the athletes to maintain flexibility which is important in real game.

For power load kinematics, it was found that only 3WR were found to be able to maintain the ROM of hip, ROM of knee, duration of power load, and maximum speed of ankle. Duration of power load is important as it reflects fast or slow the movement is executed. Ability to maintain the duration and speed showed that wearing 3% body mass load allow athletes to perform the similar movement pattern in power load stage, while at the same time able to lift weight that will be good for the athletes to overload themselves.

Next, ROM of hip, duration of drive, and maximum speed of ankle were analyzed as measurement of kinematics of the drive stage. It was found in this study that all the variables were maintained when participants wore 3% loading. This showed that participants able to show similar pattern of movement with low loadings. However, the movement was not able to be maintained as participant wore 5% and 8% thus demonstrated that 5% of body mass could be regarded as high load for the participant to be able to maintain the movement pattern.

Lastly, action was analyzed by taking the total time taken to complete the kicking. Again, only wearing 3% loading enable participant to maintain their movement pattern. It seems that wearing 3% loading did not affect participants' ability to perform fast kicks. Like the other variables, a minimum of 5% body mass loadings has disabled participants to maintain their movement patterns.

5. Conclusions and Recommendations

Wearing WR of 3% body mass was found to be suitable for athletes during training session as they can maintain their technical effectiveness while also increase stimulus for body to adapt in long term. Loading their body with more than 5% of body mass has disrupt their movement pattern, thus was not suggested to be applied among athletes. Despite all these, the limitation in this study was that all participants were first time experienced with the WR. Thus, it is suggested for future studies to be conducted in long term effects that might see athletes will be able to maintain their movement while wearing more loadings at their body. Comparison of dominant and non-dominant leg should also be conducted to see is there differences of effects across limb sites [21]. Coaches and athletes could implement wearable resistance as one of their training options as it allows the athletes to lift weights while at the same time perform movement specific to the skills performed in tournament.

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