# Biomechanical Analysis of Hakdariseogi of the "Kumgang" Poomsae; A comparison between Elite and Non-Elite Taekwondo Athletes

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## ABSTRACT

Biomechanical assessment of Taekwondo athletes' motion is essential to improve their performance. It is well known that balance tasks such as Hakdariseogi are determinant techniques which affect the result of a competition. So the aim of this study is to compare biomechanical variables of the support leg during Hakdariseogi task between elite and non-elite taekwondo athletes. Eighteen taekwondo athletes including ten elite and eight non-elite were participated. Six high-speed motion cameras and one force plate were used to acquire kinematics and kinetics data. MATLAB R2017b was used to plot support leg's joints curves. Statistical analysis was performed to compare variables between two mentioned groups.The average of joints' angles in the elite group was significantly more than non-elite group during the movement and balance phases ($p<0.05$).The amount of knee angular velocity in elite athletes was meaningfully higher than non-elite athletes during the movement phase ($p<0.05$). Also, the average amount

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of hip and ankle moments was greater in elite athletes during balance phase ($p<0.05$).There were no meaningful differences in other moment variables between elite and non-elite athletes ($p>0.05$).In some conditions, elites had more stability with greater angles and moments in the support leg’s joints. So they could perform Hakdariseogi task more quickly or in higher range of values than non-elite group and also generate more muscle activity due to the greater net joint moments, to create more joint moments for better control and stability, and neutralizing the external moments (such as ground reaction moments).

**Keywords:**Taekwondo,Hakdariseogi,Poomsae,Support leg,Kinematics,Kinetics, Elite Athletes,Non-elite Athletes

## Introduction

Biomechanical assessment of the athletes’ motion has drawn a great deal of attention over the years, because it influences performance enhancement in many fashions (Heydari, Nazari et al. 2020, Hoelbling, Baca et al. 2020). One of the most efficient motion in Taekwondo is Poomsae arisen in 2000 by World Taekwondo Federation (Kazemi, Ingar et al. 2016). There is not any physical contact in this form and some of the main goals of doing that, are improving defensive movements, stance balance and stability, muscle activity and strength, preparation for attacking motions in fighting and tighten the bond between the mind and body of the athletes to increase their skill (Yu, Wang et al. 2012, Kazemi, Ingar et al. 2016, Fachrezzy, Maslikah et al. 2021, Liu, Chu et al. 2021). It is well known that Hakdariseogi (Crane Stance) of the “Kumgang” Poomsae is a determinant technique which influences the result of a competition and it is comprised of two stages: standing on one foot and maintaining balance with the other foot (Yoo, Park et al. 2018). Although Hakdariseogi is an important phase for maintaining balance in Taekwondo, little literature is reported about the kinematics and kinetics variables of joints while elite and non-elite perform that (Kukkiwon 2006, Yoo, Park et al. 2018) .

Some previous studies investigated kinematics or kinetics of different kinds of kick such as Roundhouse kick, Yop Cha Jirugi, Bandae Chagui, Goquen Chagui, Diwicha Jirugui (Kinoshita and Fujii 2014, Estevan, Falco et al. 2015, Ruiz, Fernandez et al. 2015, Błaszczyszyn, Szczęsna et al. 2019, Hong and So 2019). Several researchers compared variables like linear velocity, angular velocity, acceleration, momentum of joints, ground reaction force and EMG activation of muscles between kicks in different combat sports like Taekwondo, Karate and Muay Thai or between elite and sub elite athletes (Burke, al-Adawi et al. 2017, Moreira, Franchini et al. 2018, Błaszczyszyn, Szczęsna et al. 2019, Diniz, Del Vecchio et al. 2021). In a study conducted on balance during Hakdariseogi of Kumgang Poomsae, it was found out that skilled players showed more stability while performing the motion (Ryu, Yoo et al. 2012). In an investigation, the effect of two kinds of training strategy on the athletes' balance progress while performing Hakdariseogi, was assessed. These trainings let them enhance their skill and brought them better performances (Yoo, Park et al. 2018).

The research discussed above suggests that biomechanical analysis of taekwondo kicks including kinematics and kinetics can offer coaches insightful theoretical views and brings athletes better capabilities (Estevan, Falco et al. 2015, Ruiz, Fernandez et al. 2015, Diniz, Del Vecchio et al. 2021). The present study is crucial in determining the biomechanical features of Hakdariseogi of the “Kumgang” Poomsae. Thus, the first purpose of this study was to achive the biomechanical data of support leg including hip, knee and ankle angles, angular velocities and angular accelerations and joints moments during the Hakdariseogi. The second aim was to compare achived variables differences between elite and non-elite athletes while executing Hakdariseogi. The hypothesis was that there would be differences in biomechanical variables between two mentioned groups.

## Methods and materials

### Subjects

Twenty Taekwondo athletes in the age range of 16 to 40 years old including ten elite and ten non-elite volunteered to contribute in this study. However, two cases in non-elite group were removed because of inappropriate preparation. General characteristics of athletes containing the average of anthropometrics and experiences information are shown in Table 1.None of the participants had injuries or a history of surgery within the six months before experimental procedure. Informed consent was obtained from all of them. Also the ethical committee of the Science approved the study.

Table 1: Elite and non-elite athletes' general characteristics (The average of anthropometrics and experiences information)

| Group | Number | Age | Weight | Height | Experience |
|---|---|---|---|---|---|
| Elites Taekwondo players | 10 | 26.1 (±9.1) | 67.7 (±13.0) | 168.1 (±9.0) | 19.0 (±6.7) |
| Non-elites Taekwondo players | 8 | 25.0 (±7.6) | 63 (±9.2) | 167.6 (±7.3) | 1.8 (±2.1) |

***Experimental Setup***

The experimental equipments showes in Figure1. Six high-speed motion cameras (Vicon Motion System Ltd., Oxford, UK) with sampling frequency 100 Hz were used to capture positions of markers to calculate kinematics variables of joints including hip, knee and ankle angles of the support leg as well as their angular velocities and angular accelerations during Hakdariseogi task, and one force plate (AMTI force plate, type ACG-O, sampling rate 1000 Hz) was used to gain ground reaction forces and moments utilized in calculations of support leg joints' kinetics.

**Experimental procedures**

Participants performed testing at the Human Motion Analysis laboratory at Science and Research branch of Islamic Azad University. Before starting experiments, instruments calibration was carried out according to manufacturers, manual . The subjecs received enough description about the whole process. Then, anthropometric characteristics were measured. Subjects' weight was measured by a digital scale and other anthropometric information required for software calculations, by a caliper and a meter , after that a 15 min individual warm-up, all subjects did Kumgang Poomsae as a practice before starting the real test. 39 reflective markers were attached onto subjects' body by using double sided adhesive tape as represented in Figure 1. Plug-in-Gait model, which is the most widely used model for gait analysis in clinical experiments was implemented in this study (Leboeuf, Decatoire et al. 2015, Goldfarb, Lewis et al. 2021, Schneemann and Albertsen 2022) .Athletes stood barefoot on the force plate and executed Kumgang Poomsae while maintaining their balance during Hakdariseogi stance.

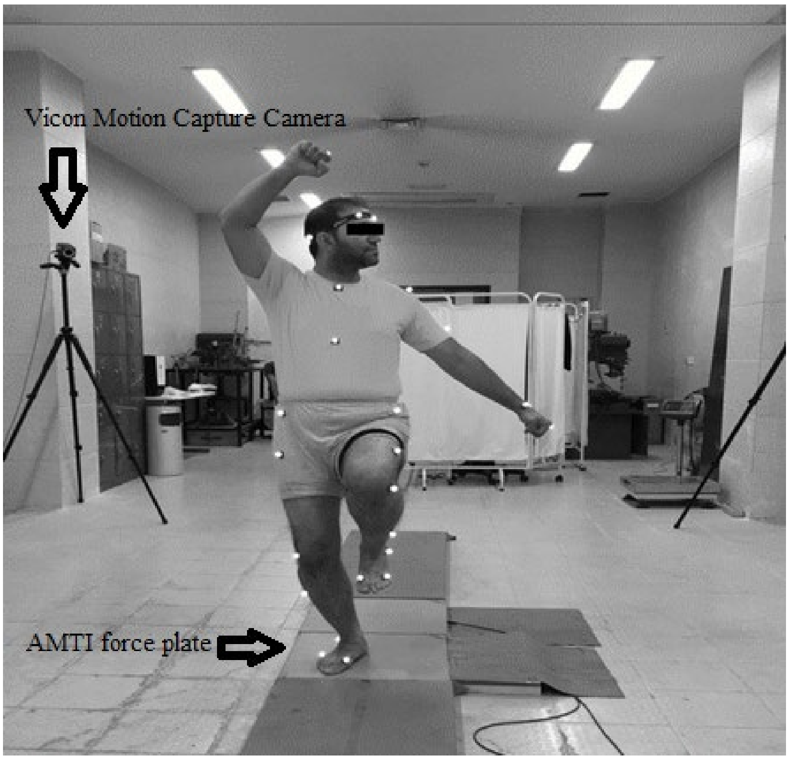


Figure 1: Human Motion laboratory consist of 6 high-speed motion capture and two force plates Also placement of reflective markers in Plug-in-Gait model on subjects' body in anterior view.

***Data processing***

The motion data taken from the markers were processed using Nexus 2.5.1 software in order to provide joints' trajectories(Figure 2), the biomechanical model and calculate kinetics and kinematics variables as the input data for MATLAB software . MATLAB R2017b was used to plot biomechanical curves during Hakdariseogi. In this study, Hakdariseogi was divided into two phases: balance and movement. From the moment the non-supporting leg heeled off and placement next to the support leg and coincident the support leg and hands perform the desired motions in Hakdarisogi, the movement phase was considered, and from the moment the athletes stood steadily on the support leg for a few moments and the non-supporting leg and hands no longer moves, the balance phase was considered.So,calculations were done for support leg during movement and maintaining balance. In addition, SPSS ver. 26 was applied to provide statistical analyses.

In order to check the normality of data distribution related to each of the variables, the Kolmogorov-Smirnov test was used. The results of the test showed that the distribution of the variables is normal except for the hip angular acceleration ones in the balance phase as well as the knee angular acceleration and ankle angular acceleration variables in both balance and movement phases. In other the words, based on the significance level obtained from the test related to the research variables and whether their values are larger or smaller than the numerical value of 0.05, it can be concluded that at the 95% confidence level, the data distribution is normal or non-normal.

To compare the average of each variables in elite and non-elite group independent samples t-test or Mann-Whitney U-test were used based on the movement and balance phases and based on the normality or non-normality of the data distribution(It should be noted that parametric tests such as t-Student test was used for normal data and non-parametric tests such as Mann-Whitney U-test was used for non-normal data like angular acceleration data in this article).

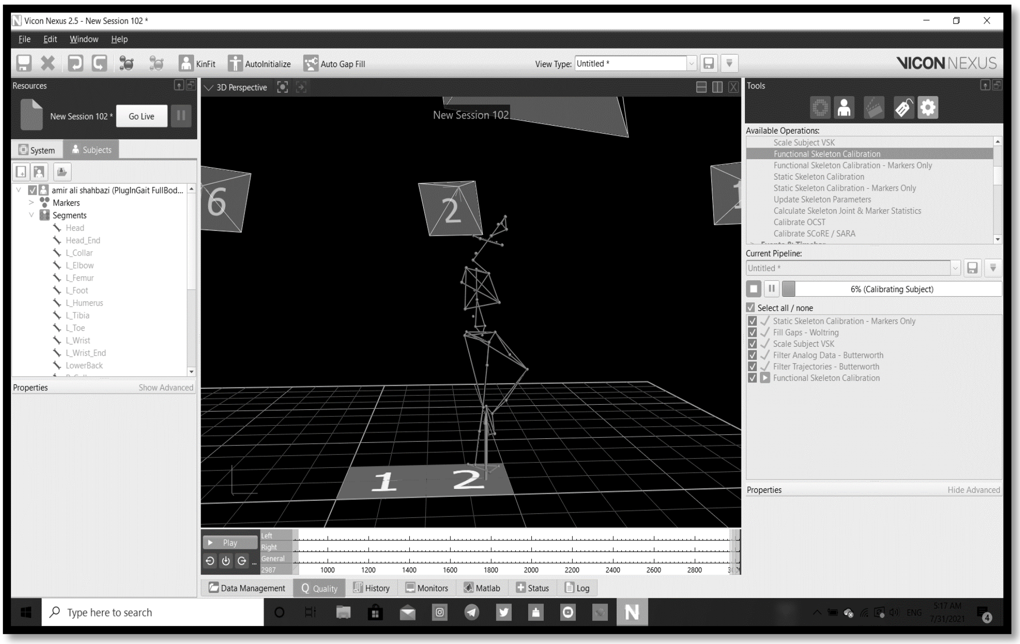


Figure 2: Three-dimensional biomechanical model of the subject in Sagittal view (An example view of the user environment of Nexus software version 2.5.1)

## Results

This study compared the biomechanical variables ( kinematics and kinetics) of the support leg's joints in elite and non-elite Taekwondo athletes during the Haktariseogi task. Kinematics variables including angles, angular velocities, angular accelerations and kinetics variables like moments were calculated for hip, knee and ankle joints in movement and balance phases of Hakdariseogi for two mentioned groups.These variables were represented as a function of normalization the percentage of time. also the mean and standard deviation and p-value for support leg joints in two phases were obtained for elite and non-elite athletes ( these statistical values for all variables and also t-test and Mann-Whitney U-test results are shown in Table 2). Hip and knee flexion/extension, ankle dorsiflexion/plantar flexion curves of support leg were compared between two groups. Figure 3 indicates these kinematics results. according to statistical results ($p<0.05$), there was a significant difference between two groups in joints' angles. The independent sample t test showed that the average of these variables in the elite group was more than non-elite one during both movement and balance phases.

Table 2: Results of the statistical analysis of the investigated variables (angle, angular velocity, angular acceleration and moment) in the elite and non-elite Taekwondo athletes' joints in both movement and balance phases ,including the mean and standard deviation(SD) , results of t and U testes and P-value.

| **variables** | **Phase(s)** | **Mean** | **SD** | **t test** | **Utest** | **P-value** |
|---|---|---|---|---|---|---|
| | | Elite / non elite | Elite / non elite | | | |
| Hip Angle | Movement | 17.371 / 2.148 | 14.44 / 10.79 | -2.475 | … | 0.025 |
| | Balance | 14.09 / 0.29 | 15.111 / 9.110 | -3.391 | … | 0.005 |
| Knee Angle | Movement | 20.03 / 2.61 | 18.046 / 8.802 | -2.492 | … | 0.024 |
| | Balance | 20.78 / -1.63 | 19.091 / 7.610 | -3.391 | … | 0.005 |
| Ankle Angle | Movement | 26.98 / 14.88 | 12.887 / 6.117 | -2.622 | ... | 0.021 |
| | Balance | 24.77 / 12.31 | 11.142 / 4.813 | -2.936 | … | 0.010 |
| Hip Velocity | Movement | -2.47 / -0.15 | 3.771 / 3.021 | 1.412 | … | 0.177 |
| | Balance | -0.30 / -0.14 | 0.186 / 0.120 | 2.054 | … | 0.057 |
| Knee Velocity | Movement | 2.39 / -6.85 | 8.084 / 4.643 | -2.864 | … | 0.011 |
| | Balance | -0.30 / -0.15 | 0.415 / 0.299 | 0.851 | … | 0.408 |
| Ankle Velocity | Movement | -8.04 / -6.73 | 11.914 / 6.512 | 0.280 | … | 0.783 |
| | Balance | -0.12 / -0.17 | 0.341 / 0.169 | -0.318 | … | 0.755 |
| Hip Acceleration | Movement | 3.06 / 22.27 | 22.030 /25.889 | … | 1.702 | 0.108 |
| | Balance | -0.16 / -0.51 | 1.267 / 0.680 | … | 25.0 | 0.183 |
| Knee Acceleration | Movement | 52.46/12.15 | 108.737/35.530 | … | 29.0 | 0.360 |
| | Balance | -0.60 / 0.35 | 1.404 / 0.840 | … | 25.0 | 0.183 |
| Ankle Acceleration | Movement | 16.44 / 5.71 | 38.015 / 9.238 | … | 37.0 | 0.829 |
| | Balance | -1.42 / 0.29 | 2.388 / 0.297 | … | 5.0 | 0.002 |
| Hip Moment | Movement | 786.09/454.09 | 445.152/339.451 | 1.740 | … | 0.101 |
| | Balance | 834.78 / 407.06 | 415.702 /361.905 | 2.294 | … | 0.036 |
| Knee Moment | Movement | -62.54 /-229.65 | 535.401 /317.251 | 0.778 | … | 0.448 |
| | Balance | -225.92/-67.81 | 316.631/545.427 | 0.725 | … | 0.479 |
| Ankle Moment | Movement | 792.09 /725.00 | 106.314 /173.982 | 1.010 | … | 0.829 |
| | Balance | 889.81 /652.15 | 124.656 /134.203 | 3.886 | … | 0.001 |

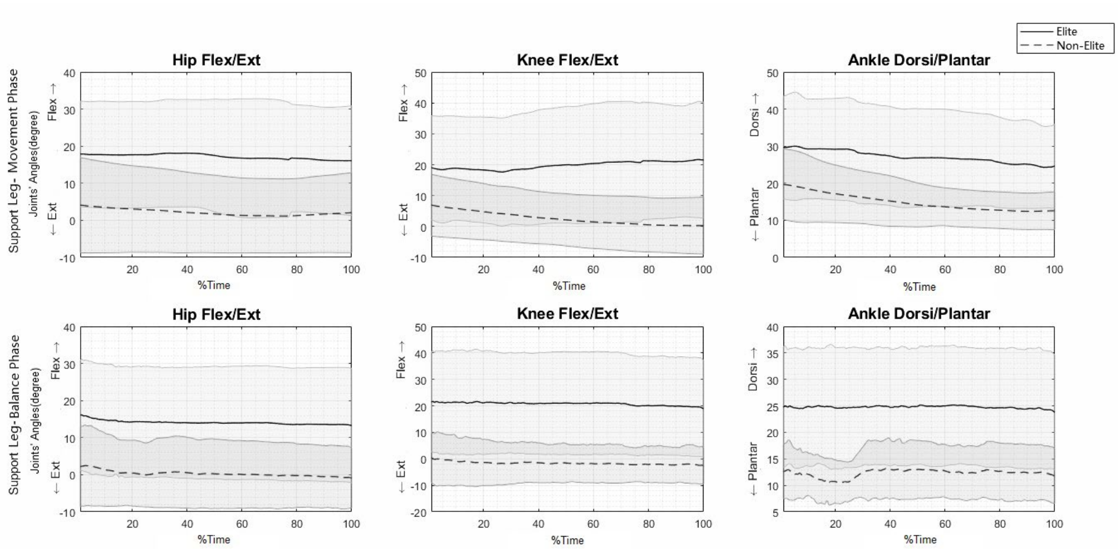


Figure 3. Mean and Standard deviation of support leg's joints' (hip, knee and ankle)angles. A comparison between elite (solid line) and non-elite (dash-dot line) athletes in movement and balance phases in the sagittal plane. The directions of flexion and extension as well as plantar flexion and dorsiflexion are shown in the figure.

Figures 4 and 5 demonstrate the angular velocities and accelerations patterns of hip, knee and ankle joints. The results of the independent sample t-test indicated that the amount of knee angular velocity in elite athletes was higher than non-elite athletes during the movement phase ($p<0.05$). In addition, the average of the ankle angular acceleration is statistically meaningful according to findings of the Mann-Whitney U-test both in elite and non-elite players during maintaining balance ($p<0.05$).

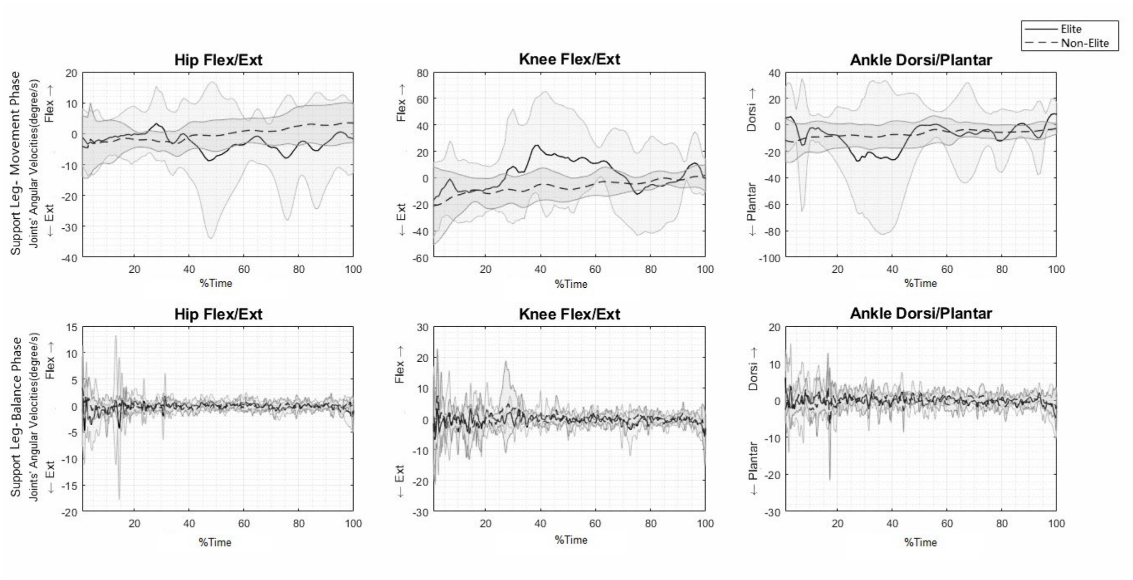


Figure 4. Mean and Standard deviation of support leg’s joints’ angular velocities. A comparison between elite and non-elite athletes in movement and balance phases in the sagittal plane.

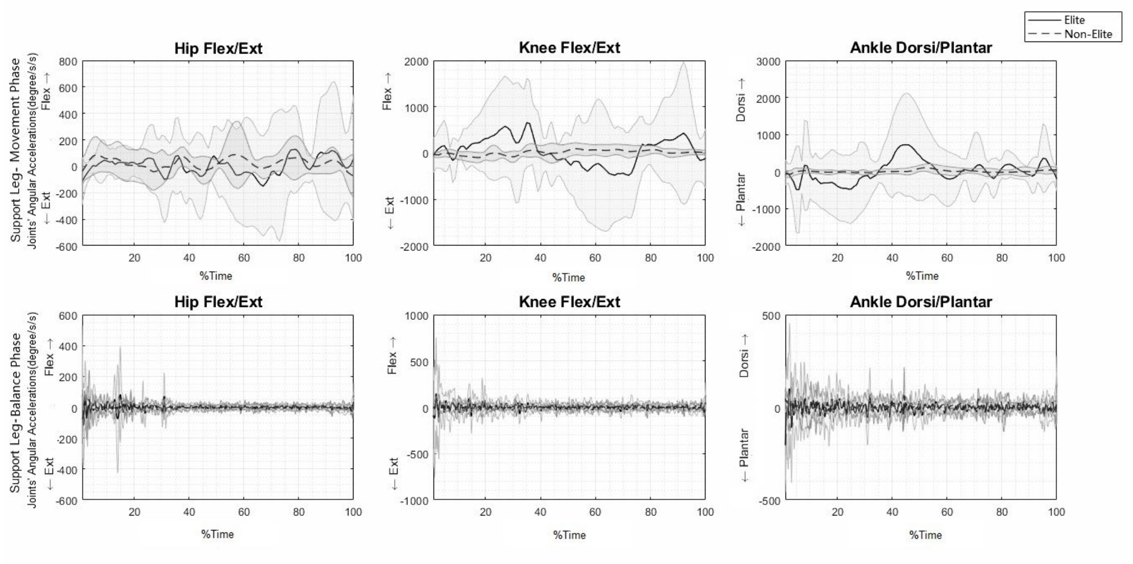


Figure 5. Mean and Standard deviation of support leg’s joints’ angular accelerations. A comparison between elite and non-elite athletes in movement and balance phases in the sagittal plane.

Moments for hip, knee and ankle were obtained. illustrates the patterns of moment changes in both groups. Based on statistical results displayed in Figure 6.it can be confirmed that the average amount of hip and ankle moment was greater in elite athletes during balance phase ($p<0.05$). Data analysis indicates that there were no meaningful differences in other moment variables between elite and non-elite athletess ($p>0.05$).

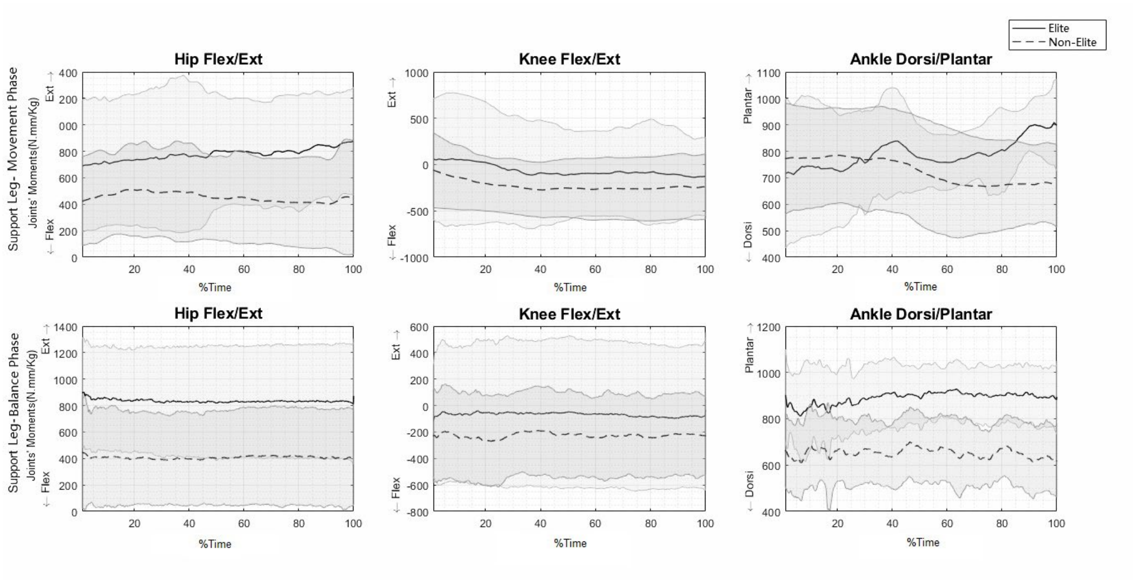


Figure 6. Mean and Standard deviation of support leg's joints' moments. A comparison between elite and non-elite athletes in movement and balance phases in the sagittal plane.

## Discussion

The purpose of this study was to analyze biomechanical variables of the support leg in taekwondo athletss while executing Hakdariseogi of the "Kumgang" Poomsae and to compare them between elite and non-elite athletes. The main outcome of this study was that in some conditions, elite athletes have more strength and stability with greater angles and moments in their hip, knee and ankle joints during Hakdariseogi. Taekwondo athletes must maintain postural stability and balance control in order to perform the correct pattern of the task. So they require to maintain a suitable series of kinematics chains.(Weinberg, Seabourne, and Jackson1981) (Zago et al. 2015). According to the figures 3,4 ,5 and 6 some kinematics and kinetics variables such as joints angles and moments in hip, knee and ankle joints have greater values or greater signal amplitudes in elite group, which indicates that elite group cases performed tasks in greater range of joints angles ,angular velocities and angular accelerations and moments. Figures 4 and 5 indicate greater amplitudes of angular velocity and acceleration curves, and high variability in the angular velocity and acceleration of three joints in elite group. This might be concluded that professionals can perform the same Hakdariseogi task more quickly and in higher range of values than non-elite group.

Figure 3 shows that all joint angles in the directions of hip flexion, knee flexion, and ankle dorsiflexion are greater in both movement and balance phases of the support leg in elite group. Moreover, figure 6 indicates that some joint moments in the reverse directions (i.e. hip extension, knee extension, and ankle plantar flexion) are greater in the support leg of elite group (particularly in the balance phase). This means that elite group generates more muscle activity to create more joint moments against joint angle direction for better control and stability, and neutralizing the external moments (such as ground reaction forces). This is due to the basis of musculoskeletal biomechanics which has been used and developed in prior studies and researches (Chao  et al.2009,Holder et al.2020,Smith et al .2022). Generally, the greater net joint moment value in a given direction about joint, can indicate the greater muscle activities which produce joint moment in the same direction rather than those in the opposite direction (Holder et al. 2020). Thus, according to the Figure 6, the greater hip extensor moments in whole movement and balance phases may be due to the greater activities of hip extensor muscles (e.g. gluteus maximus and hamstrings) in the elite group. Similarly, the greater ankle plantar flexor moments in the last movement and whole balance phases can be related to the greater activities in ankle plantar flexor muscles (e.g. soleus and gastrocnemius) in elite group. This means that support moment of support leg's joints (which extensor moment is positive) is greater in elite group, indicating more muscle contraction against GRF and greater balance and steadiness. The comparison of angular velocities with moments, indicates that in which direction about joint, the muscles are concentrically or eccentrically active in the movement phase of Hakdariseogi. For example, in the middle of the movement phase, the ankle angular velocity and moment are both in the plantar flexor direction in elite group. So it can be stated that ankle plantar flexor muscles are more concentrically active in this situation. At the end of the movement phase of elite group the ankle angular velocity becomes a bit positive which is in dorsiflexor direction, but the moment is in plantar flexor direction. So the ankle plantar flexor muscles are more eccentrically active in this situation. Whenever the joint angular velocity becomes zero (specially in balance phase). The muscle contractions become isometric.

**Conclusion**

The purpose of this study was to compare the kinematics and kinetics variables in the support leg's joints between elite and non-elite Taekwondo athletes in a special task named Hakdariseogi in two phases of movement and balance. All data processed for the support leg in the sagittal plane.The comparison of these variables in some cases showed remarkable results. Due to years of training and high experience, elite group performed the desired movement with mastery, skill, high control and balance. Elite athletes in some variables had higher biomechanical values such as joints angles and moments in hip, knee and ankle joints and also knee angular velocity. These results can inform coaches and help them improve training program and transforme non-elite athletes into elite athletes faster.

It is suggested that to examine more cases with gender separation and classified age ranges for better comparison between elite and non-elite in the future. Also, both support and un-support legs can be analyzed and the force plate can be used for the un-support leg before heel-off phase to obtain more kinetics results for both legs. Also, the center of mass(COM) and the center of pressure(COP) can be obtained in future studies and the balance of athletes can be participated by these variables.Furthermore, the electromyography can be used particularly for the important lower limb muscles activity measurement during Hakdariseogi task, as well as musculo-skeletal modeling and calculating muscle forces. This can be a lead for non-elites that, how to active and strengthen their lower limb muscles according to the pattern of elites and enhance their skills.

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