Effect of Arm Swing Direction on Forward and Backward Jump Performance Based on Biomechanical Analysis

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Abstract. Previous studies have examined the role of arm swing for various types of jumping technique, but none have been found to study about the gender differences in term of the role of arm swing on forward and backward jump. This study aimed to compare the jumping performance between male and female for forward and backward jump. Seven male and seven female subjects performed four trials of forward and backward jump with (FJA, BJA) and without arm swing (FJ, BJ) respectively. Qualisys Track Manager System, EEGO Sports, Visual3D and MATLAB software was used to record and analyze the performance. According to the result, the triceps brachii muscle is the most active muscle compared to other muscles during jumping. The normalized vGRF showed significant correlation with jump height when jumping forward and backward (p<0.01). The arm swing enhanced the jumping performance by increasing the jump height. Males demonstrated greater vGRF and jump height than females. When jump with arm swing, the left knee flexion angle of males increased whereas females decreased. These findings concluded there is different between males and females during jumping.

1. Introduction

Jumping is a fundamental action for human where someone pushes himself off a surface and into the air by using the muscles in one’s legs and feet. Sports activities such as the badminton, volleyball, basketball, tennis, dancing, gymnastics and others involve the forward and backward jumping motion. There are various types of jumping motion and each motion consists of specific biomechanical considerations, for instance, the countermovement jump, vertical jump, squat jump, depth jump and other jumping motion. Although every people can perform the jumping action, a proper execution that can maximize the jumping performance while at the same time minimize the possibility of getting injured is very difficult. As the injuries rate of jumping sport is relatively high, there is a need to analyze the kinetics and kinematics parameters that will contribute to the jumping performance, in order to reduce the injuries rate.

In the past few decades, many researchers have investigated the factors related to the jumping technique and performance from different point of view [1][2]. Arm swing movement has been shown to increase the performance of countermovement jump by increasing the ground reaction forces and jumping height [1]. However, the participants in those researches were all males. There are no studies...
that comparing the effect of arm swing on forward and backward jumping performance for both male and female. Besides, some studies have provided insight into the roles of upper and lower limb joints using the kinetics and kinematics measurement for different jumping action [2][3]. However, the relationship between the kinetic and kinematics parameters during forward jump and backward jump have not been studied in depth. If the interrelationship between kinetic and kinematics parameters cannot be figured out, it may prohibit the effective use of the biomechanical parameters of the lower extremities to prevent injury.

The purpose of this study was to analyze the electromyography (EMG) for upper limb during forward and backward jump for different gender. Besides, this study also aimed to determine the relationship between the selected kinetics and kinematics parameters during forward jump and backward jump. The jumping performance of different genders or forward jump and backward jump with and without arm swing will be studied also.

2. Methodology

2.1. Experimental Design
14 healthy subjects with seven males and seven females (weight: 66.49±13.7540 kg, height: 1.66±0.0914 m, mean±standard deviation) volunteered to participate in this study. The participant has no history of serious injury or neuromuscular disease of the lower limb, specific to the knee and ankle joints. The participant that having back pain injury also excluded from this study.

The electromyography (EMG) data were collected by using the EEGO sports (ANT-Neuro) with amplifier, tablet and channel. The bipolar surface electrodes were placed over middle deltoid muscle, biceps brachii muscles, triceps brachii muscles and brachioradialis muscles. The reference electrodes were placed on the participant’s wrist. Figure 1 shows the placement of all electrodes on upper extremity muscles. The EMG was sampled at 1000Hz and notch-filtered at 3-70Hz. The setting of the tablet was configured before recording the signals. The EMG data will take simultaneously with the kinetic and kinematics data when the subject performed the jumping motion.

QTM system is used to capture the jumping motion. During jumping, the vertical GRF was recorded by two force plates with dimension 400 x 600 mm (Bertec). 40 reflective markers were attached to the shoulder, elbow, wrist, hip, thigh, knee, shank, ankle and feet, as shown in Figure 2. After finished the setup, the subject will then start to perform the maximum voluntary contraction test (MVC), where the subject needed to lift the dumbbell from 180° to 90°. In this case, females used 1.25 kg dumbbell while males used the 1.50 kg dumbbell. Each subject needed to perform five trials of normalization activity. After that, the subject was required to perform four types of jumping exercise, which are forward jumping and backward jumping with and without arm swing. When performing the jumping without arm swinging, the subject’s hand akimbo, which mean the subject needed to put both hands on the hip. Each subject needed to perform four trials per jump condition.

![Figure 1. Placement of electrodes on Upper Limb Muscles](image)
2.2. Data Analysis
The marker trajectories were labeled by using the QTM software. After labeled, the data were being exported to the Visual 3D software in .C3D format to analyze the kinetics and kinematics parameter which are GRF, left knee flexion angle and jump height. The jump height was determined by calculating the difference between the initial standing height with the peak height of the ankle marker during the jump. The jump height of four trials was calculated and the highest jump height was used for subsequent analysis. The raw EMG signals were processed by using the MATLAB software and root mean square (RMS) was calculated for each trial.

The statistical tests were conducted by using the SPSS version 17.0. The Pearson correlation coefficient test was used to analyze the relationship between the kinetic and kinematic parameters of the lower limbs. The paired sample t-test was conducted to determine the differences in variables between genders and the differences in RMS value between jump with and without arm swing.

3. Result and Discussion

3.1. EMG Result
Table 1 represents the RMS value of FJ and FJA whereas Table 2 represents the RMS value of BJ and BJA. From the result, females had greater RMS value than males for middle deltoid muscle, triceps brachii muscle, brachioradialis muscle and biceps brachii muscle during FJ. When jumped with arm swing (FJA, BJA), the male subjects had larger RMS value for brachioradialis muscle than females. Male subjects had greater RMS value for middle deltoid muscle, triceps brachii muscles, and brachioradialis muscles during BJ. It was found that there was no significant difference for the RMS value of all the muscles when compared arm swing and without arm swing as the p-value is larger than 0.05.

The triceps brachii muscle had the highest RMS value among the four upper limb muscles for all types of jumping action. Thus, it can be said that triceps brachii muscle is the most active muscle for jumping action with and without arm swing. The biceps brachii muscle and triceps brachii muscle is agonist-antagonist muscle, thus biceps brachii muscle had smallest RMS value among other muscles[4].

| Table 1. RMS Value of FJ and FJA |
|----------------------------------|
|                                | FJ         | FJA   | p   |
|                                | Male       | Female | Total | Male   | Female | Total      |
| Middle deltoid                 | 0.05±0.05  | 0.11±0.09 | 0.08±0.08 | 0.11±0.1 | 0.13±0.06 | 0.12±0.08 | 0.1 |
| Triceps Brachii                | 0.02±0.25  | 0.26±0.23 | 0.22±0.24 | 0.22±0.35 | 0.57±0.73 | 0.4±0.58 | 0.251 |
| Brachioradialis                | 0.03±0.02  | 0.17±0.36 | 0.1±0.25 | 0.61±1.47 | 0.13±0.19 | 0.37±1.04 | 0.354 |
| Biceps Brachii                 | 0.03±0.05  | 0.06±0.04 | 0.05±0.04 | 0.03±0.03 | 0.06±0.03 | 0.04±0.03 | 0.967 |
### Table 2. RMS Value of BJ and BJA

|               | BJ                  | BJA                 | p   |
|---------------|---------------------|---------------------|-----|
|               | Male     | Female    | Total | Male     | Female    | Total |  |
| Middle deltoid| 0.29±0.6 | 0.13±0.06 | 0.21±0.42 | 0.1848±0.2317 | 0.23±0.19 | 0.21±0.20 | 0.916 |
| Triceps Brachii| 0.28±0.30 | 0.24±0.27 | 0.26±0.28 | 0.3654±0.5473 | 0.61±0.60 | 0.49±0.57 | 0.073 |
| Brachioradialis| 0.09±0.11 | 0.07±0.07 | 0.08±0.09 | 0.1738±0.2682 | 0.11±0.15 | 0.14±0.21 | 0.154 |
| Biceps Brachii| 0.05±0.03 | 0.06±0.05 | 0.05±0.04 | 0.03±0.02 | 0.13±0.2 | 0.08±0.15 | 0.417 |

3.2. Relationship between Selected Kinetic and Kinematic Parameters

Table 3 and Table 4 represent the correlation between kinetic and kinematic parameters for jumping forward and backward. The normalized vertical GRF does not have a significant relationship with left knee flexion angle during forward and backward jump. This means that the knee flexion angle does not necessarily reduce the impact forces during landing [5]. Despite the knee joint angle does not have a significant relationship with GRF, they may still affect the loading on specific joint structures, such as the loading on ACL. On the other hand, the normalized vertical GRF had a significant correlation with jump height for forward jump and backward jump. This finding is in contrast with the previous finding of E. Utama et al. [6] due to different jumping and landing strategy of each person.

The result also shown that there is no significant relationship between the left knee flexion angle and jump height. This is because the vertical GRF that have been generated from the jumping action was largely absorbed by landing technique, causing the jump height does not significantly affect the knee flexion angles.

### Table 3. Correlation between Parameters for Jumping Forward (FJ and FJA)

|                | GRF (%BW) | Left Knee Flexion Angle (°) | Jump Height (m) |
|----------------|-----------|-----------------------------|-----------------|
|                | r =1      | r =0.054, p = 0.784         | r =1            |
| GRF (%BW)      |           |                             |                 |
| Left Knee Flexion Angle (deg) | r =-0.27, p = 0.165 | r =1 |
| Jump Height (m) | r =0.526**, p = 0.004 | r =1 |

**Correlation is significant at 0.01 level (2-tailed).**

### Table 4. Correlation between Parameters for Jumping Backward (BJ and BJA)

|                | GRF (%BW) | Left Knee Flexion Angle (deg) | Jump Height (m) |
|----------------|-----------|-----------------------------|-----------------|
|                | r =1      | r =0.018, p = 0.928         | r =1            |
| GRF (%BW)      |           |                             |                 |
| Left Knee Flexion Angle (deg) | r =0.576**, p = 0.001 | r =1 |
| Jump Height (m) | r =0.129, p = 0.512 | r =1 |

**Correlation is significant at 0.01 level (2-tailed).**
3.3. Kinetic and Kinematic Results

3.3.1 GRF Result. From the result in Table 5 and Table 6, it can be concluded that the normalized vertical GRF of males was greater than females in the four types of jumping condition. The large GRF will require greater muscular strength to dissipate the landing forces as the increase of GRF is likely to increase the demand placed on lower limb joint [7]. The inability to effectively dissipate this energy that associated with the landing may cause overload injury such as ACL and patellar tendinopathy.

Table 5. Kinetic and Kinematic Result of FJ and FJA

| Kinetic   | Male     | Female   | Total   | p    | Male     | Female   | Total   | p    |
|-----------|----------|----------|---------|------|----------|----------|---------|------|
| GRF (BW)  | 3.15±0.73| 2.96±0.67| 3.05±0.68| 0.521| 3.21±0.78| 2.79±0.50| 3.00±0.67| 0.023|
| Jump Height (m) | 0.19| 0.18| 0.19| 0.260| 0.21| 0.18| 0.20| 0.265|
| Kinematic |          |          |         |      |          |          |         |      |
| Left Knee | 9.22±10.00| 14.61±11.13| 11.91±10.55| 0.260| 14.67±15.34| 9.54±9.68| 12.11±12.60| 0.454|

Table 6. Kinetic and Kinematic Result of BJ and BJA

| Kinetic   | Male     | Female   | Total   | p    | Male     | Female   | Total   | p    |
|-----------|----------|----------|---------|------|----------|----------|---------|------|
| GRF (BW)  | 3.05±0.59| 2.80±0.75| 2.93±0.66| 0.071| 2.92±0.62| 2.90±0.54| 2.91±0.56| 0.951|
| Jump Height (m) | 0.20| 0.17| 0.18| 0.004| 0.20| 0.17| 0.18| 0.136|
| Kinematic |          |          |         |      |          |          |         |      |
| Left Knee | 27.47±17.13| 29.95±18.39| 28.71±17.12| 0.811| 37.64±20.95| 24.15±12.54| 30.90±18.0| 0.143|

3.3.2 Knee Angle. From the result, when performed the jumping without arm swing (FJ and BJ), female subjects had greater left knee flexion angle than male subjects and there is no significant difference of the gender in terms of the left knee flexion angle. Hence, it could be said that the male subjects in this study tend to land with almost similar left knee flexion angles of females due to a higher reliance on ankle musculature to attenuate landing forces [7]. On the other hand, males had larger left knee flexion angle than females for both FJA and BJA. This could be explained as the male subjects tended to transfer the impact of landing to lower extremity muscles to absorb the shock [8]. Apart from this, females adopt a more erect position compared to males during initial contact of jump landing [9][10]. A more erect landing position prevented the lower limb musculature to dissipate the landing forces, this will then increase the danger of ACL injury. The result also suggested that the jumping mechanics are different between males and females depending on the type of jumping action [11]. It can also be related to the different landing strategy of both genders.

3.3.3 Jump Height. The results in Table 5 and Table 6 show that males had higher jumping height than females in all four jumping actions. The main reasons of males jumped higher than females are males have higher leg lengths, higher leg muscule volumes, higher muscle forces and higher percentages of fast twitch muscle fibres as compared to females. The jumping with arm swing increased the jump height for both forward and backward jump due to the increased of the take-off height of the COM due to the extreme shoulder flexion and elbow extension. The arm swing movement will increase the take-off velocity, resulting in increased jump height and this can be explained by the “joint torque augmentation”
theory. The use of arm swing during jump enable the participants to gain better control of their balance and land with optimal body posture.

4. Conclusion
The findings of this study suggest that triceps brachii muscle is the most active muscles and biceps brachii muscle had the lowest muscle activity for all the jumping action regardless of with or without arm swing. Moreover, the normalized vertical GRF was significantly correlated with the jump height. The jumping action with arm swing increased the jump height and had better jumping performance than jumping without arm swing. Males had better jumping performance than females. The future studies can carry out the investigation by analyzed the EMG signal of the lower extremity muscle such as vastus medialis muscle and rectus femoris muscle. Moreover, the future study can focus on other kinetic parameters such as the torque of knee, power and work that may be an important factor for jumping performance.

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