Original Article

Prediction of Vertical Jump Height from Anthropometric Factors in Male and Female Martial Arts Athletes

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Abstract

Background: **Vertical jump is an index representing leg/kick power. The explosive movement of the kick is the key to scoring in martial arts competitions. It is important to determine factors that influence the vertical jump to help athletes improve their leg power. The objective of the present study is to identify anthropometric factors that influence vertical jump height for male and female martial arts athletes.**

Methods: **Twenty-nine male and 25 female athletes participated in this study. Participants were Malaysian undergraduate students whose ages ranged from 18 to 24 years old. Their heights were measured using a stadiometer. The subjects were weighted using digital scale. Body mass index was calculated by kg/m2. Waist–hip ratio was measured from the ratio of waist to hip circumferences. Body fat % was obtained from the sum of four skinfold thickness using Harpenden callipers. The highest vertical jump from a stationary standing position was recorded. The maximum grip was recorded using a dynamometer. For standing back strength, the maximum pull upwards using a handle bar was recorded. Multiple linear regression was used to obtain the relationship between vertical jump height and explanatory variables with gender effect.**

Results: **Body fat % has a significant negative relationship with vertical jump height (P < 0.001). The effect of gender is significant (P < 0.001): on average, males jumped 26% higher than females did.**

Conclusion: **Vertical jump height of martial arts athletes can be predicted by body fat %. The vertical jump for male is higher than for their female counterparts. Reducing body fat by proper dietary planning will help to improve leg power.**

Keywords: *body fat, explosive power, martial arts, vertical jump*

Introduction

The vertical jump is a movement where an athlete jumps vertically to achieve the highest point above the ground. Vertical jump performance is measured by the vertical displacement of the centre of mass between when one is standing on the ground and while at the apex of the jump (1). The performance of the athlete in the vertical jump is closely related to biomechanics. Velocity, force, acceleration and momentum are the biomechanical principles involved in any type of vertical jump (1–3).

A countermovement jump is one of the vertical jump types. In a countermovement jump, the important stages of the vertical jump are the countermovement, propulsion and take off phases (2). During the countermovement phase, the centre of mass is initially moved downwards until it reaches its lowest point. The gravity force acting upon the body is in the downward direction. There is equal force acting in the opposite direction of the gravity force, which is known as ground reaction force (2). When the gravity force is greater than the ground reaction force, the acceleration and velocity are negative (2). The ground reaction force must be larger than the gravity force in order for the acceleration to become positive while the velocity changes from negative to zero (2). A zero value of the velocity indicates that the velocity is at the propulsion phase.

During the propulsion phase, the ground reaction force is large. The ground reaction force corresponds to the acceleration (4). At the propulsion phase, high acceleration is important to produce a large initial velocity (5). The acceleration can be increased by lowering the body position during the countermovement phase. This position enables the force from the muscles of the lower limb to be generated from the hip, knee and ankle extension (4). This extensor muscle performs an eccentric contraction. The propulsion phase begins when the concentric contraction follows the eccentric contraction (2,6).

The change in velocity from zero at propulsion phase to a positive value at take-off phase leads to a change in the momentum. The change in momentum should be maximized to generate maximum velocity at take-off.

Power is the product of force applied on the athlete and the velocity of the athlete (2,7). Vertical jump is commonly used as an index for the power of the lower limb or explosive leg power (7–11). In martial arts, it is essential to have outstanding leg power, which is useful for jump kicks, standing kicks and airborne kicks (7–9,12,13). This is because most of the scores in competitions are collected from the degree of kicking (9,12). In addition, 98% of the scores in the Taekwondo Sydney Olympics are based on the kicks (9,14). Likewise, the skills needed for success in Karate and Silat are rapid and explosive movement of kicks and punches (7,15,16).

The role of vertical jump as an index of leg power has encouraged several researchers (1,2,4–6,8–11,17–20) to study which factors contribute to vertical jump height. These factors may vary for different kinds of sports and types of training received by the athletes (21). However, the assessment of vertical jump height on martial arts athletes has yet to receive extensive attention. Therefore, it is crucial to identify the contributing factors for martial arts athletes. The influential factors for vertical jump height reflect the contributing factors for the leg power. Hence, coaches will be able to determine how to increase the leg power if the contributing factors for the vertical jump are known.

Many studies have been carried out to determine the physiological and biomechanical factors for vertical jump (1,2,5,6,9,17,21). Abdominal and muscle strengths contribute to the vertical jump height. However, this is provided that the training of the abdominal and muscle strengths is accompanied by muscle control activities (1,12). The review done by Kroon (3) for elite volleyball players showed that the strengths in arms and shoulders reinforce the strength in the trunk to project maximum jump height. Similarly, for taekwondo athletes, it is recommended to strengthen trunk muscle to optimize kick strength (8,13). Nevertheless, Reeves et al. (20) found that the length and mass of upper arms have no significant relation with vertical jump in recreational athletes. Moreover, Wyon et al. (19) have conducted vertical jump evaluation on ballet dancers and found that gender difference in vertical jump as well as the relationship between vertical jump and calf and thigh girth sizes are significant.

Apart from the biomechanical and physiological factors, anthropometric characteristics also play significant roles in vertical jump performance. Studies on anthropometric characteristics have been carried out by a number of researchers (7–11,18–20). Roschel et al. (7) have identified a significant negative relationship between the sum of skinfold thickness and vertical jump among karate athletes. This finding is in accordance to that of Davis et al. (18), who stated that the body fat percentage among recreational athletes is negatively associated to the jump height. In addition, Markovic and Jaric (10) studied the relationship between vertical jump height and body mass, and the result showed that body mass is independent of vertical jump height. Davis et al. (18) reported that there is no significant relationship between vertical jump and body height. Similarly, the study done by Aslan et al. (11) has highlighted that body height has no significant effect on vertical jump among sub-elite athletes.

Understanding the physical aspects in martial arts is necessary to identify the appropriate methods of training and support for the athletes to excel in any competition. However, only a few studies on the performance of martial arts athletes in vertical jumps have ever been published. Therefore, the purpose of this study is to determine the effects of anthropometric factors on vertical jump height among martial arts athletes. Vertical jump performance on a gender basis should be taken into account because research has shown that the achievements of male and female athletes are different (19). Thus, the first hypothesis of this study is the vertical jump height among male athletes is greater than that of their female counterparts. The second hypothesis is that there are significant effects of anthropometric indices on vertical jump height. In other words, it is expected that the leg power among the martial arts athletes is accurately predicted by the anthropometric indices.

Materials and method

The athletes involved in this study were martial arts athletes who participated in the 2008 Asian University Games. The participants were from Silat, Taekwondo and Karatedo fields. Participants were athletes who had won a medal at the national level in the previous year; all were Malaysian undergraduates. The participants were aged between 18 to 24 years old. Furthermore, the athletes participated in University Sports Centre classes on a regular basis. Participants had no current medical problem and no recent injuries. Permission had to be given by the sport doctor to participate. The athletes were of elite level. There were 29 male athletes and 25 female athletes. The data used in this study is secondary data that consist of the value of anthropometry, body composition, and physical strength of the athletes. The data were obtained from the Sports Academy, Universiti Putra Malaysia, in 2008.

The response variable was the vertical jump; the explanatory variables were height, weight, body mass index (BMI), waist-hip ratio (WHR), body fat percentage (body fat %), grip strength and standing back strength. The height was measured to the nearest 0.1 cm using a stadiometer (Seca). The subjects wore light clothing and were weighted to the nearest 0.1 kg using a calibrated digital scale (Seca). The BMI was calculated by dividing the weight in kilograms by the squared of the height in metres (i.e., kg/m^2). The WHR was measured by placing the measuring tape around the waist and hip. The ratio of waist to hip circumferences was rounded to the nearest 0.1 mm. Body fat % was obtained from the sum of four skinfold thickness measurements, which are subscapular, biceps, triceps and suprailiac by using Harpenden callipers (22). Grip strength was measured with the Takei A5401-Digital Hand Grip Strength Dynamometer (Takei, Japan). The subjects performed three grip tests with one minute for recovery after each. The maximum grip with the dominant hand was recorded (23,16). For standing back strength, the subjects stood on the frame (Takei A5402-Back and Leg Dynamometer, Takei, Japan) and pulled the handle bar in front of the subjects upwards (24). The maximum pull out of three attempts was recorded. Lastly, for vertical jump height (in cm), the athletes stood with feet and toes behind the line (Takei 5414 jump-DF digital vertical jump measuring instrument, Takei, Japan). The athletes performed a countermovement jump. Three jumps were allowed with one minute for recovery between attempts.

The Shapiro-Wilk normality test was used prior to conducting linear regression. The test was used to check whether the response variable is normally distributed. The linear regression assumes that the response variable has normal distribution. Thus, the Shapiro-Wilk normality test should be able to fail to reject the null hypothesis that the variable is normally distributed.

Multiple linear regression with backward method was used to test the relationship between the vertical jump height and the explanatory variables with the effect of gender. The effect of gender is done by using dummy variables. The female and male groups are as ascribed values of 0 and 1, respectively. The multicollinearity is inspected from the value of tolerance and variance inflation factor (VIF). The statistical analysis was performed using R programming language version 2.12.0.

Results

Table 1 depicts the mean and standard deviation of the variables according to gender. The mean height of male athletes is 167.93 ± 6.64 cm. The mean height of females is 9.69 cm shorter (158.24 ± 4.77 cm) than that of males. The BMIs of male and female athletes fall in the normal scales (25), which are 22.20 ± 2.77 kg/m^2 and 21.23 ± 3.06 kg/m^2, respectively. Although male athletes have higher mean weight (62.83 ± 10.55 kg) than females do (53.31 ± 8.93 kg), they have lower mean body fat % (15.98 ± 5.06%) than female athletes (26.79 ± 4.62%). Male athletes have higher mean WHR (0.82 ± 0.03) and mean vertical jump (62.93 ± 7.34 cm), as well as greater mean grip strength (42.65 ± 8.14) and mean standing back strength (113.19 ± 22.96). In contrast, the mean for WHR, vertical jump, grip strength and standing back strength of female athletes are 0.78 ± 0.04, 42.71 ±4.96 cm, 29.56 ± 4.78 and 70.38 ± 14.38, respectively.

The vertical jump variable is not normally distributed. Therefore, the variable is normalised by using the natural logarithm, (ln) scale. The P value for ln(vertical jump) is greater than 0.05 ($P > 0.05$). This indicates that the Shapiro-Wilk normality test fails to reject the null hypothesis. Therefore, the ln(vertical jump) is normally distributed, which is in compliance with the linear regression assumption.

Table 2 presents the linear regression for gender and body fat % against the ln(vertical jump). Multiple linear regression is performed by including all the explanatory variables in the first model. The backward method is used to select the best model. The model is selected based on the lowest Akaike information criterion (AIC) value. Therefore, the model with the lowest AIC value is body fat % and gender factors against the ln(vertical jump). In addition, according to tolerance and VIF values, the multicollinearity problem does not exist if the value of tolerance is above 2 and that of VIF is below 10 (26). Table 2 shows that there is no multicollinearity between body fat % and gender.

As shown in Table 2, gender and body fat % significantly influence the ln(vertical jump) (P < 0.001). The dummy variable for the female group is 0. Thus the intercept for female is 4.05 while that of male is 4.05 + 0.26 = 4.31. The adjusted coefficient of determination, R^2, represents the variability proportion of gender and body fat % effects that are accounted for in the variation of vertical jump. The R^2 value is 0.7905. Thus, gender and body fat % explain 79.05% of the variation in vertical jump.

Discussion

The purpose of this study is to determine the effects of anthropometric factors on vertical jump height among martial arts athletes on a gender basis. The first hypothesis is that the vertical jump height among male athletes is greater than that of their female counterparts. The second hypothesis is that there are significant relationships between anthropometric factors and vertical jump height.

Based on multiple linear regression, several potential models have been tested. The simplest model with the lowest AIC is chosen. The chosen model is the main effect of gender and body fat % on the ln(vertical jump). In reference to Table 2, the linear equations for male and female athletes are displayed as equations (i) and (ii), respectively. For linear regression where the response variable is transformed into natural-logarithm, one unit change in the predictor leads to the percent change in the response variable by $(e^{\beta}-1) \times 100$, where β is the coefficient for the predictor variable (27). Therefore, based on equations (i) and (ii), a decrease of a unit in body fat % will increase the vertical jump height by 1%. Given the same amount of body fat %, male athletes have approximately 26% higher vertical jump height than female counterparts.

$$\ln(\text{Vertical Jump}_{\text{male}}) = 4.05 + 0.26(1) - 0.01(\text{body fat }\%)$$
$$\ln(\text{Vertical Jump}_{\text{male}}) = 4.31 - 0.01(\text{body fat }\%) \qquad \text{(i)}$$

$$\ln(\text{Vertical Jump}_{\text{female}}) = 4.05 + 0.26(0) - 0.01(\text{body fat }\%)$$
$$\ln(\text{Vertical Jump}_{\text{female}}) = 4.05 - 0.01(\text{body fat }\%) \qquad \text{(ii)}$$

Gender effect certainly plays a significant role on the vertical jump (28). Noorul et al. (8), found that male athletes in taekwondo have higher leg power than their female counterparts. Male athletes are able to jump higher because they have larger thigh and calf girth as opposed to those of female athletes (19). According to Dizon and Grimmer-Somers (9), stronger athletes have larger sizes and girths of thighs. Consequently,

Table 1: Mean (standard deviation, SD) measures of athletes according to gender

	Male	Female
	Mean (SD)	Mean (SD)
Height (cm)	167.93 (6.64)	158.24 (4.77)
Weight (kg)	62.83 (10.55)	53.31 (8.93)
BMI (kg/m²)	22.20 (2.77)	21.23 (3.06)
Body fat %	15.98 (5.06)	26.79 (4.62)
Waist-hip ratio	0.82 (0.03)	0.78 (0.04)
Grip strength	42.65 (8.14)	29.56 (4.78)
Standing back strength	113.19 (22.96)	70.38 (14.38)
Vertical jump (cm)	62.93 (7.34)	42.71 (4.96)

Table 2: Linear regression for gender and body fat % on the ln(vertical jump)

	Estimate	Std Error	*t* value	*P* (> |t|)	Collinearity statistics	
					Tolerance	VIF
Intercept	4.05	0.082	49.36	< 0.001	–	–
Gender	0.26	0.043	6.13	< 0.001	0.44	2.26
Body fat %	−0.01	0.002	−3.86	< 0.001	0.44	2.26

Adjusted R^2 = 0.7905.

male athletes are able to jump higher most likely because they are stronger than female athletes. The difference of jump height in gender is also related to the body fat %. Generally, female athletes carry a larger body fat %, especially due to that stored in the hip and chest, than male athletes do. Therefore, male athletes, who have a lower body fat %, have the advantage in vertical jumps (8).

Body fat % is the amount of body fat stored in the body and does not take into account the lean body mass and muscle mass (29,30). Table 2 shows that body fat % and vertical jump have a negative association. An individual with lower body fat % definitely has a higher vertical jump (8,9). This is because the athletes with lower body fat % and greater power are more likely to generate greater velocity of kicking (7). The study done by Davis et al. (18) has reported that body fat % is the best predictor of vertical jump for recreational male athletes aged between 20 to 37 years old. This result corresponds to that of Roschel et al. (7), who stated that the sum of skinfold thickness has significant negative association with vertical jump height. Body fat % is related to the work performed during vertical jump. Since work is the product of average force acting on the subject and the displacement of the jump, heavier athletes need more work to move the body to the same displacement achieved by lighter athletes (2,7). So, in order to perform better, the coaches and dieticians should have guided the athletes to burn the body fat with proper training and dietary planning. Food consumption should be monitored so that the body fat will be flushed away without losing the nutrition.

Our finding is similar to that in work by Davis et al. (18), which showed that height and body weight have no significant relationship with vertical jump. Height is a nonadjustable factor that might be disadvantageous for shorter athletes. Nevertheless, height should not be of concern, because the technique used to improve the power will be able to compensate for height influence (9). This result is in accordance with that of the study done by Wyon et al. (19) for ballet dancers, which hypothesised that vertical jump is affected by individual height, while their result confirmed otherwise. Similarly, among sub athletes' performance, there is no significant relationship between height and vertical jump (11).

The results of the present study show that weight, BMI and WHR factors do not have significant effects upon the vertical jump. Markovic and Jaric (10) have shown that body mass is independent of vertical jump height. Other than that, the assessment based on weight and BMI alone tends to be misleading, because neither scale differentiates the proportion of body fat mass, lean body mass, and muscle mass out of the total of body mass (28–30). An athlete who has more muscle than a non-athlete will be more likely categorized as an overweight by weight and BMI scales, even though not actually overweight (14). Thus, there is contradiction in the vertical jump height between those who are actually overweight and who are wrongly categorized as overweight. In the view of weight and BMI, overweight athletes will jump lower than lighter athletes do. However, an athlete who is not overweight but being labelled as overweight has a higher vertical jump. This contradiction implies the failure to predict the vertical jump height of the athletes. On the other hand, WHR describes the shape of body, which does not seem to have direct influence over the vertical jump. The body size factor does not accurately portray the exact body composition of the athletes; hence, the relationship is not significant.

Lastly, even though attention to the factors of improving the leg power is important, care should be taken to avoid any injury and overtraining among the athletes (17). Further research is useful to identify which training is suitable and safe to boost the kick skills for different level of martial arts athletes. After all, success in martial arts competitions requires good anthropometrical status, appropriate training and techniques in biomechanical and physiological aspects, strategies, disciplines and determination.

Conclusion

Leg power is associated with the explosive kick. To be successful in martial arts, an athlete needs to improve jumping, standing and airborne kicks. The vertical jump is an important indicator of the degree of leg power among martial arts athletes. The vertical jump for male athletes is significantly higher that of their female counterparts. Body size, body height, grip strength and standing back strength do not significantly contribute to the vertical jump height of martial arts athletes. In contrast, body fat % is an anthropometrical factor that has a significant negative relationship with vertical jump height of martial arts athletes. Reducing the amount of body fat with proper physical training and dietary planning will be helpful to improve the leg power or the kicks.

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Conflict of interest

Nil.

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Conception and design, analysis and interpretation of the data, drafting of the article, and administrative, technical or logistic support: NZA
Critical revision of the article for the important intellectual content, final approval of the article, statistical expertise and obtaining of funding: MBA

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