JOURNAL OF
EMERGING INVESTIGATORS

Article

Determination of Optimal Relevant Joint Angles for Vertical Jump Height Across Teenagers with Differing Amounts of Jumping Experience

Ingyu Bahng and Keehoon Bahng
Korea International School, Pangyo, South Korea

SUMMARY

Reaching one's maximum jump height requires optimizing one's jump techniques. In order to find this optimal jump technique, three high school participants with varying vertical jump (VJ) abilities recorded videos of themselves with varying degrees of maximum/minimum shoulder, knee, and hip angles—with or without respect to the horizontal—at the isometric phase of a regular countermovement (CM) VJ or countermovement jump (CMJ). We hypothesized that VJ height would increase as each joint's angular displacement increases from its initial position. We generated six graphs—two graphs per joint and each graph with three separate lines—using the VJ height measurements with the respective independent variables to determine the optimal relevant joint angles for maximum VJ height. Results showed that the shoulder angle without respect to the horizontal (SA), knee angle with respect to the horizontal (KAH), and the hip angle with respect to the horizontal (HAH) possessed a more consistent correlation with VJ height across the subjects compared to the same respective angles with opposite relations to the horizontal. We found that the optimal respective joint angle differs across subjects with varying levels of sport and VJ experience: participants with greater relative experience showed a better capability to absorb CM force exerted from greater limb displacement from its initial position.

INTRODUCTION

The vertical jump (VJ) is a movement performed in a wide range of different sports, and VJ height is most commonly defined as one's standing reach subtracted from the highest point reached during a standing jump (1, 2). The CMJ is the type of VJ that will be tested in this experiment. By definition, a CMJ is a jump in which the person performs an initial downward motion during the eccentric phase by bending the knees and hips, which is referred to as the CM, before he/she immediately travels back up in the concentric phase. In some sports—most prominently in volleyball and basketball—a high VJ height commonly indicates an athlete's potential success (1, 2). For example, a higher jump in volleyball allows for a higher point of maximum contact as one is spiking the ball downwards over the net, providing an advantage over enemy blockers. Despite the apparent benefits that come with jumping higher, much confusion still exists on how to actually increase one's VJ height—especially with thousands of different articles, books, and programs circulating social media and the internet which, at times, even deliver wrong information.

While maximum strength and speed are the common predictors of a person's VJ capabilities, quick improvements to technique can significantly boost VJ performance and therefore VJ height (3, 4, 1). One of these technical aspects is the angle of the shoulder, hip, and knee joints at the isometric phase of a jump (Figure 1B) (3, 1). Therefore, establishing a strong basis of knowledge on the biomechanics of a VJ, regardless of one's current VJ ability, is critical to achieving a greater VJ height in addition to one's strength, speed, and power.

We hypothesized that VJ height would increase as each joint's angular displacement increases from its initial position. In this experiment, we tested to determine which type of relationship—with or without respect to the horizontal—in regards to SA, HA, and KA separately is the most relevant to VJ height and to determine the optimal angle value of the relevant joint variables at isometric position of a VJ that maximizes VJ height. We did this through video and graphical analysis. This experiment covers three teenage male subjects who will be identified as S1, S2, and S3. Overall, our results indicated that the optimal joint angle of one joint differs across individuals with varying VJ training experience, the magnitude of CM generated from the other two joints, the maximum CM one can efficiently absorb, and other possible factors like torso stability.

RESULTS

We filmed three videos of each participant performing five jumps to measure their VJ height through video scale analysis. In each video, participants increased or decreased one variable angle in intervals while keeping the other two joint angles constant to the best of their ability. All calculated margins of error have a 95% confidence interval. We plotted each participants' data points on a graph and applied a sine fit function to each participant's set of data points. We chose a sine fit function because the independent variables—SA, SAH, HA, HAH, KA, KAH—were angular measurement values; therefore, a trigonometric function seemed the most appropriate. Because sine functions imply that as joint angles

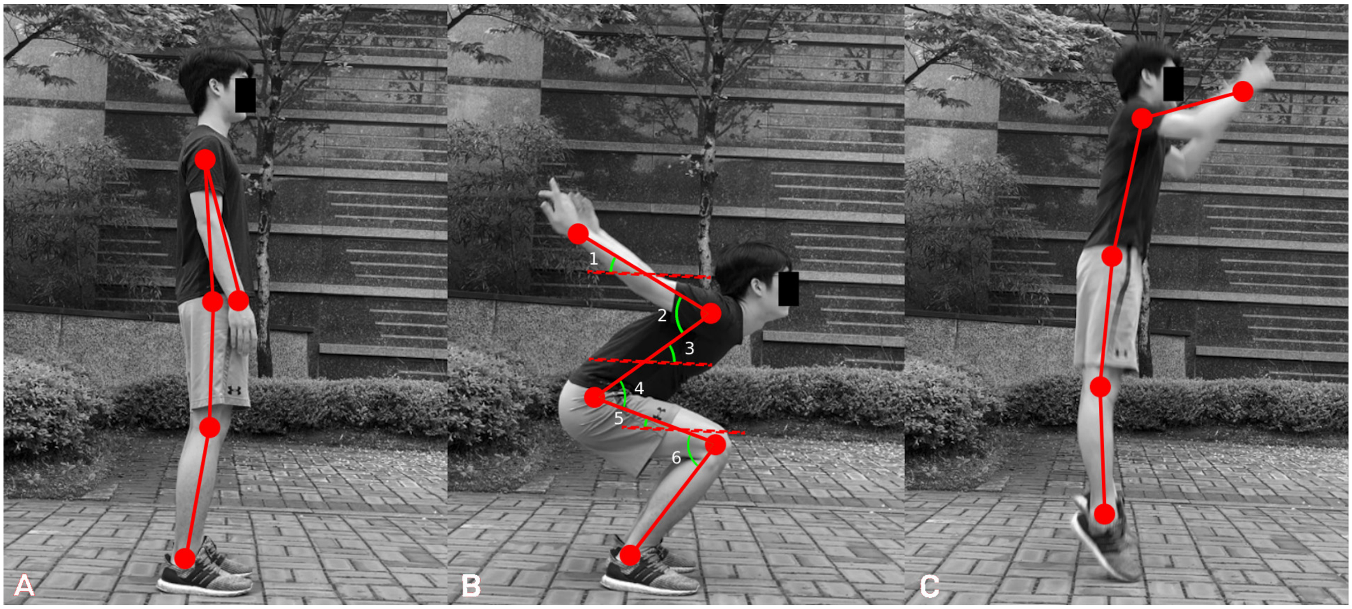

Figure 1: Three different time frames during a VJ. (A) Regular standing position. (B) Muscles loaded with maximum potential energy and center of mass is at the lowest point, isometric portion of the jump. (B1) shoulder angle with respect to the horizontal. (B2) shoulder angle. (B3) hip angle with respect to the horizontal. (B4) hip angle. (B5) knee angle with respect to the horizontal. (B6) knee angle. (C) No longer in contact with the ground, no more upwards acceleration, only force acting is gravity. (A-B) Eccentric portion of the jump. (B-C) Concentric portion of the jump.

Term	Abbreviation
Shoulder Angle	SA
Hip Angle	HA
Knee Angle	KA
Shoulder Angle with respect to the Horizontal	SAH
Hip Angle with respect to the Horizontal	HAH
Knee Angle with respect to the Horizontal	KAH
Root Mean Square Error	RMSE
Vertical Jump	VJ

Table 1: Abbreviations used in this paper.

continuously decrease or increase, the VJ height fluctuates, we limited each reference graph to a domain that reflected a rough minimum and maximum joint angle value in real life. We did not use tangent, cosecant, secant, and cotangent fit functions because the presence of vertical asymptotes do not accurately reflect the relationship between joint angles and VJ height.

The SA v. VJ height (Figure 2A) showed more consistent sine fit function lines across the all three subject's data than SAH v. VJ height (Figure 2B) did. While the correlation values of the fit functions were nearly perfect across both graphs, the Root Mean Square Error(RMSE) values for Figure 2A was smaller than that of Figure 2B. Also, in Figure 2B, S2's line and period show an inconsistent representation of the relationship between SAH and VJ because of its much smaller sine fit function period in comparison to those of S1 and S3. Therefore, Figure 2A will be the reference graph with regard to the relationship between VJ height and shoulder joint angle. For the purposes of practicality and analysis, 0° to 90° is the SA range we will focus on.

Each participant's sine auto fit functions for their respective data points show a maximum VJ height by roughly 65° to 75° SA, but overall line shape differs in relation to each subject's VJ training experience. While S2 and S3 show near similar line shapes, both increasing to and peaking at around 70° from 0° SA, S1—a relatively more experienced jumper—shows a VJ height increase from no arm swing (SA=0°) to roughly a 60° arm swing, where VJ height then levels out until 90° instead of immediately decreasing like those of S2 and S3.

The HAH v. VJ Height (Figure 3B) showed more consistency across S1 and S3's sine fit function lines than HA v. VJ Height (Figure 3A) did. Both the correlation values and overall RMSE values were greater and smaller respectively for Figure 3B compared to Figure 3A. Also, in Figure 3A, S3's line and unrealistically small period reflect an incorrect relationship between HA and VJ height. Therefore, Figure 3B will be the reference graph with regard to the relationship between VJ height and hip joint angle. We excluded S2 from this joint angle relationship because his data points only spanned a small range of HAH values relative to the two other participants which showed inaccuracies with his maximum VJ height. For the purposes of practicality and analysis, -20° to 70° is the HAH range we will focus on.

S1's line shows an increase in VJ Height from -20° to 10° HAH and a decrease from 20° to 70° HAH; the VJ height

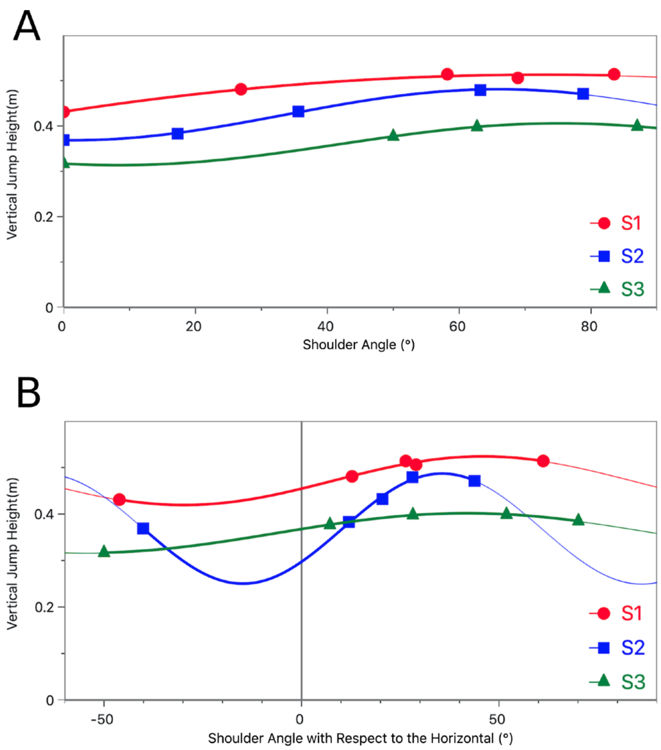

Figure 2: Shoulder angle vs. vertical jump height. (A) Shoulder Angle v. Vertical Jump Height. knee angle with respect to the horizontal(KAH; S1)=19.3±4.85°, hip angle with respect to the horizontal(HAH; S1)=35.2±2.97°, correlation(S1)=0.9927, root mean square error(RMSE; S1)=0.0085m. KAH(S2)=27.5±2.85°, HAH(S2)=32.4±3.94°, correlation(S2)=0.9996, RMSE(S2)=0.0030m. KAH(S3)=37.6±4.19°, HAH(S3)=42.5±3.29°, correlation(S3)=1.000, RMSE(S3)=0.0000m. Range: [0°, 90°]. S1's prior training supported his faster ability to swing his arms than S2 and S3 which most likely led to S1 being able to compensate for a loss of power from an exaggerated arm swing past the angle of optimal vertical jump performance. (B) Shoulder Angle with respect to the Horizontal v. Vertical Jump Height. HAH and KAH constants are same as that of Figure 2A's. correlation(S1)=0.9928, RMSE(S1)=0.0085m. correlation(S2)=0.9965, RMSE(S2)=0.0084m. correlation(S3)=0.9999, RMSE(S3)=0.0007m. Range: [-60°, 90°]. No consistent correlation was seen between shoulder angle with respect to the horizontal and vertical jump performance because of S2's sine fit function's relatively small period.

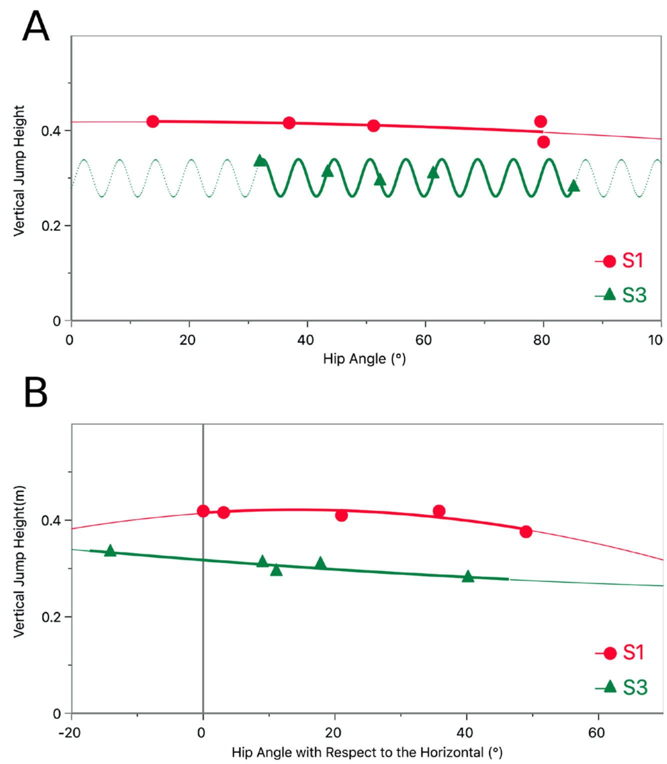

Figure 3: Hip angle vs. vertical jump height. (A) Hip Angle v. Vertical Jump Height. shoulder angle(SA; S1)=0°, KAH(S1)=28.8±8.03°, correlation(S1)=0.5617, RMSE(S1)=0.0302m. SA(S3)=0°, KAH(S3) =42.1±3.68°, correlation(S3)=0.9824, RMSE(S3)=0.0075m. Range: [0°, 130°]. No reliable and consistent correlation was seen between hip angle and vertical jump performance because of S3's sine fit function's unrealistically small period and S1's relatively small correlation value. <B> Hip Angle with respect to the Horizontal v. VJ Height. SA and KAH constants are same as that of Figure 3A's. correlation(S1)=0.8738, RMSE(S1)=0.0178m. correlation(S3)=0.9197, RMSE(S3)=0.0157m. Range: [-10°, 70°]. S1's prior training supported his faster ability to accelerate eccentrically than S3 which led to S1 being able to reach an optimal vertical jump height with his hip angle alone, given his controls, while S3 could not. S2 was excluded from this joint angle relationship because his data points only spanned a small range of HAH values relative to the two other participants which showed inaccuracies with his maximum VJ height.

neither increases nor decreases to a noticeable extent from 10° to 20° HAH. On the other hand, S3's VJ height demonstrates a strict decrease as HAH increases throughout the entire range.

The KAH v. VJ Height (Figure 4B) showed more defined and realistic patterns across the subjects' three sine fit function lines than KA v. VJ Height (Figure 4A) did. Overall, the correlation values and RMSE values of Figure 4B were greater and smaller respectively than those of Figure 4A. Also, in Figure 4A, S2's line shows a negative VJ height as KA approaches 0° which is practically impossible. Therefore, Figure 4B will be the reference graph with regard to the relationship between VJ height and the angle around the knee joint. For the purposes of practicality and analysis, the KAH range we will focus on is from -10° to 70°.

The shape of the lines vary in relation to each subject's experience with VJ training and/or weightlifting. S1 shows a strictly negative relationship between KAH and VJ whereas S2 and S3's relationship is roughly positive from -10° to 20°, peaked at 20°, and negative from 20° to 70°.

The generated graphs pointed towards SA, HAH, and KAH having a more consistent correlation with VJ height across the three subjects. We also found that the optimal joint angle differed across the subjects in relation to their VJ and weightlifting background in which S1's angle values allowed for him to be able to reach his near maximum VJ height with overall less joint angular displacement relative to that of S2 and S3. Overall, our results indicated that the optimal joint angle of one joint differs across individuals with varying VJ training experience, the magnitude of CM generated from the

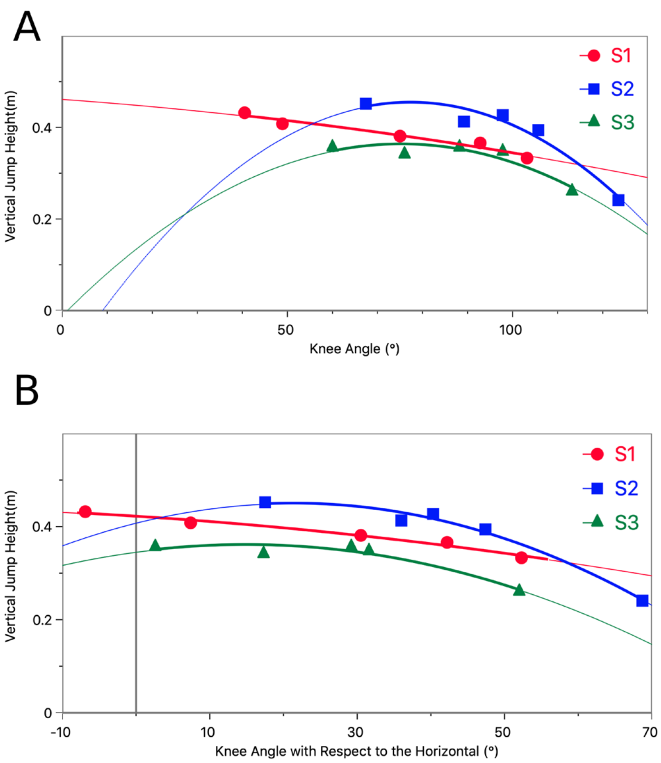

Figure 3: Knee angle vs. vertical jump height. (A) Knee Angle v. Vertical Jump Height. SA(S1)=0°, HAH(S1)=50.6±8.43°, correlation(S1)=0.9785, RMSE(S1)=0.0157m. SA(S2)=0°, HAH(S2)= 56.8±13.7°, correlation(S2)=0.9755m, RMSE(S2)=0.0367m. SA(S3)=0°, HAH(S3)=43.6±6.60°, correlation(S3)=0.9265, RMSE(S3)=0.0307m. Range: [0°, 100°]. No realistic correlation was seen between knee angle and vertical jump performance because of the presence of negative vertical jump height intercepts. (B) Knee Angle with respect to the Horizontal v. Vertical Jump Height. SA and HAH constants are same as that of Figure 4A's. correlation(S1)=0.9896, RMSE(S1)=0.0110m. correlation(S2)=0.9917, RMSE(S2)=0.0214m. correlation(S3)=0.9576, RMSE(S3)=0.0235m. Range: [-20°, 70°]. S1's prior training supported his ability to absorb a greater amount of countermovement force compared to S2 and S3 which led to S2 and S3 being able to reach optimal vertical jump performance with their knee angles alone, given their controls, while S1 could not.

other two joints, the maximum CM one can efficiently absorb, and other possible factors like torso stability.

DISCUSSION

In the concentric portion of a VJ with arm swing, three joints—hip, knee, and shoulder—and surrounding muscles generate a significant portion of the power needed to propel the body upward(3, 1). In this experiment, we produced graphs depicting lines that show the relationship between VJ height and the angles of the three previously mentioned joints. Overall, results show a gradual shift across participants in their relationships between each joint angle and VJ height as we see an increase or decrease in their VJ training experience.

Psycharakis et al. demonstrates that CMJs are superior over regular squat jumps in regards to VJ height because of the CMJ's ability to attain a higher level of initial force and stimulation in the leg muscles' stretch shortening cycle due to a need for greater deceleration during the eccentric phase(5, 6, 7, 8). We should also note that as the magnitude of the CM speed increases during the eccentric phase, the peak applied force one exerts on the ground during the isometric phase of the jump and the total landing phase impulse enlarges as well (5, 6, 7, 8). With that being said, performing a more aggressive arm swing downward during the eccentric portion of a CMJ should increase the net downward force exerted from the CM before one's center of mass starts accelerating upward during the concentric phase. This increase in initial downward force onto the ground may contribute to a greater VJ height.

A greater SA indicates a more aggressive arm swing downwards, which can explain the apparent increase in VJ height from 0° to 60° in Figure 2A across all three subjects. Here, the peak VJ height or negligibly close to the peak VJ height across all subjects show that the optimal SA is roughly 60°. S2 and S3's immediate decrease as SA increases away from their optimal angles show that SA can actually be detrimental to one's VJ once it passes a certain SA value. However, since S1's VJ height levels out rather than drops right away, we should note that this difference in VJ height and SA relationship may be due to the varying level of VJ training experience. This non-immediate decrease could be because S1's shoulder joint muscles are more elastic or are able to more effectively absorb greater amounts of initial CM force during the eccentric phase and use it to help in the production of upward force in the concentric phase of the VJ (5, 4). That is, to maybe compensate for a likely loss of power from an overly exaggerated and unnecessarily large arm swing, and thus there is no increase or decrease in VJ height until SA reaches 90°. Another potential reason that can further explain S1's non-immediate VJ height decrease is the correlation between the timing of the peak downward work during the CM of the eccentric phase and the moment when the center of mass reaches its lowest position possible (3, 5). Because S2 and S3 had not gone through any intentional VJ training in the months preceding this experiment, they may have more difficulty compared to S1 in performing consistently unified CMJs with greater degrees of arm displacement from the initial standing position.

While S1's VJ height peak in regards to HAH is roughly 15°, S3's line shows a constant negative correlation between VJ height and HAH, making the location of the absolute maximal VJ height -20° in the range -20° to 70°. Here, two possible reasons can explain why we see no relative maxima in S3's data.

The first reason is relative core strength. Sharma et al. showed that core stabilization training improved trunk stability which significantly elevated jumping capabilities in volleyball players while spiking and blocking (9). A smaller HAH value in this case would mean more total CM force downwards during the eccentric phase. Psycharakis et al. demonstrates that a greater CM—to a certain extent—has a positive correlation with VJ height (5, 6, 7, 8). A potential reason for no relative maxima in S3's data is that S3 has a stronger core and therefore better trunk stability compared to S1, which can explain why S3 does not show a peak VJ height: S3's core strength hasn't reached its maximum load capacity. In other words, S3's trunk can handle much more downward force from its CM during the eccentric phase than that of the maximum HAH value jump used to generate S3's line in Figure 3B. However, S1 is a much more experienced weightlifter and jumper before the experiment began—which implies that S1's trunk/core stability is much more developed than that of S3—therefore this explanation is highly unlikely.

The second and most likely explanation to the absence of a relative maxima in S3's line is the relative forces of the hip CM with regard to its maximum downward velocity and acceleration during the eccentric phase. Serrano et al shows that elite weightlifters' ability to exert high force across a small time frame—and therefore power—is largely correlated with an "extreme fast-twitch myofiber abundance" relative to the average man/woman(10). A positive correlation also exists between this fast-twitch myofiber abundance and the number of years the elite weightlifter has been playing in his/her sport (10). S1 has been weightlifting—bodybuilding and Olympic lifts—for roughly four years whereas S3 has only recently started; through this, we can assume that S1 is more capable of explosive movements compared to S3 because of S1's most likely larger fast twitch muscle fiber abundance than S3. Consequently, S3 may not have been able to reach his maximum CM force (before it starts to be a detriment rather than a benefit) because of a lack of fast twitch muscle fibers, limiting the maximum speed of his torso as HAH decreases (5, 10). In other words, S1's torso may be able to travel fast enough to achieve the optimal CM force value during his eccentric phase—and therefore have an optimal HAH value as well—whereas S3's torso alone cannot, making S3's optimal HAH value outside of the practical HAH range for a VJ.

S1's VJ height increases as the KAH decreases throughout the entire chosen KAH range of -10° to 70°. This continually decreasing pattern is very much the same pattern we saw before with S3's VJ height in relation to HAH, and is most likely for the same reason as well: the inability to produce the magnitude of optimal CM force during the eccentric phase with respect to the subject's explosive capabilities or fast twitch muscle fiber abundance. An inability to produce enough CM with respect to one's explosive capabilities explains why S1's VJ height data never reaches its relative maxima in the practical KAH range.

For S2 and S3, the presence of a relative maxima indicates that the CM force generated by simply the bending of the and knee is enough to reach their respective optimal CM force. However, we see that as the KAH decreases away from the respective best KAH values, the drawbacks it has on S3's VJ height is less in magnitude than the drawbacks it has on S2's VJ height. This drawback difference may be because S3 has done some weight and VJ training prior to the experiment while S2 has not. Therefore, S3 most likely has more explosive capabilities in regards to fast twitch muscle fiber abundance than S2, allowing S3 to be more elastically capable and be able to produce more upwards force in the concentric phase as more downward CM force—which increases as KAH decreases—is exerted in the eccentric phase of the jump (5, 7, 10). However, as the KAH increases away from S2 and S3's respective optimal KAH value, the negative effects it has on VJ height is similar across the two subjects. This equal drawback does not fit into the reasoning behind when the KAH decreased away from the optimal KAH value, but rather it is most likely a result of a multitude of external factors: the exact mathematical relationship between CM force and KAH, behavior of fast twitch muscle fibers under low levels of resistance, etc. This area warrants further research.

Three large limitations of this experiment are the sample size, sample profile, and the absence of reproducing the results of the experiment. Three subjects is clearly not enough to accurately measure the entire teenage male population. Factors like whether or not a participant exercises regularly, has a stable diet, plays jump relevant sports, etc., may further deviate the results from an accurate measure of the target audience. All three subjects participate in some degree of physical exercise on a regular basis which is not a proper representation of all teenage males. Additionally, the age range of the participants—16 to 18 years—covers a fraction of the intended teenage age range. As for the absence of reproducible results, it introduces the possibility of the results being influenced by external factors during the day of recording, such as more muscle soreness in one of the joints of any participant from a workout a day prior. Factors like muscle soreness can negatively influence the collected data in the sense that not all external variables are controlled, which undermines the results' reliability to make a cause and effect claim.

Nonetheless, this experiment showed the correlation between VJ height and the three respective joint angles; all of which we isolated by making the non-independent variable joint angles controlled. The results did not support the original hypothesis of a higher VJ height through a greater joint angle displacement. Instead, results support that the optimal joint angle of one joint differs across individuals with different degrees of VJ training experience, magnitude of CM generated from the other two joints, maximum CM during the eccentric phase one can efficiently absorb, and other possible factors like torso stability. The only joint angle that showed a consistent optimal angle value was the SA, hovering at around 60°. In future experiments that wish to reproduce these results through the same procedure, experiment conductors should record each participant's natural maximum vertical jump before and after recording to take into consideration the possibility that the subjects may get more fatigued or learn to jump better as they progress through the video. With this extra information, it can allow for data to be adjusted accordingly to keep fatigue or jump improvement variables controlled. Future research and studies regarding the overall relationship between muscle/skeletal anatomy and VJ height should focus on the interconnected relationship between the optimal CM force one can absorb with respect to his/her joint angles and preceding VJ and weightlifting experience, rather than isolating and independently examining the each joint variable's influence on VJ height.

MATERIALS AND METHODS

S1 is a highly active, healthy 16-year-old male. At the time of this experiment, S1 has been playing volleyball for nearly three years in a position that requires constant max effort jumping (MEJ) and short, explosive cutting maneuvers (SECM). He has also gone through daily high intensity VJ training and weightlifting workouts for the past six months and four years respectively.

S2 is a moderately active, healthy 18-year-old male. In the past, he played volleyball for four years in a role that requires constant MEJ and SECM. At the time of the experiment, he had been playing basketball as a casual hobby for three years already. He does not have any recent experience with VJ training or weightlifting.

S3 is a moderately active, healthy 18-year-old male. In the far past, he played soccer as a school representative during his elementary and middle school for eight years. At the time of the experiment, he has been playing volleyball for nearly three years in a position that also requires SECM. He has some recent experience with low intensity weightlifting.

Each subject weighed roughly the same at 64 kilograms and had roughly the same height at 174 centimeters. Based on prior experience in sports and activities—and the recentness of each sport or activity—related to VJ or VJ-like movements, it can be assumed that S1 has the most VJ training experience and S2 has the least, making S3's relative VJ training experience between that of S1 and S2.

All three participants recorded three videos, each with five VJs, with the camera roughly half a meter high and three meters away from the participant's feet. The camera used to film was an iPhone 11 camera at 60 frames per second. In the first video, subjects performed five VJs with increasing SA while keeping the HAH and KAH constant. In the second video, subjects performed five VJs with increasing KA while keeping the SA and HAH constant; arm swing was absent in order to keep the AA constant at exactly 0°. Lastly, in the third video, subjects performed five VJs with increasing HA while keeping the SA and KAH constant; arm swing was absent in order to keep the SA constant at exactly 0°. Prior to filming the videos, each participant underwent a short dynamic warmup (ten high knees, ten butt kicks, ten pogo jumps).

When the angles around the waist and knee were the control variables, HAH and KAH were chosen over HA and KA respectively because HA and KA have a strong positive correlation with one another, whereas HAH and KAH does not necessarily.

An image of the lowest point during each jump across all nine videos were taken, and respective shoulder, hip, and knee angles—as well as the angles with respect to the horizontal—were measured with a protractor. The height of each VJ was determined through Logger Pro's video scale measurement tool. Each collection of data points was plotted (joint angle v. VJ height) for a total of six graphs with three separate lines each(two graphs per joint angle, with and without respect to the horizontal), each line representing one subject. A sine fit function was used to generate a line predicting the change in VJ height as a given joint angle increases or decreases. A sine fit function was chosen because the independent variables were angular measurement values, therefore a trigonometric function seemed the most appropriate. Because the sine functions implied that as joint angles continuously decrease or increase, the VJ height fluctuates, each reference graph were limited to a domain that reflected a rough minimum and maximum joint angle value in real life. Tangent, cosecant, secant, and cotangent fit functions were not used because the presence of vertical asymptotes does not accurately reflect the relationship between joint angles and VJ height. The sine graph was also generated through Logger Pro.

ACKNOWLEDGMENTS

I would like to thank my parents and the JEI editorial team for supporting me throughout the process of writing this paper. I would also like to thank my brother Muchang Bahng and my friend Minjun Kim for participating as the two other participants of this study.

REFERENCES

1. Umberger, Brian R. "Mechanics of the Vertical Jump and Two-Joint Muscles: Implications for Training." Strength And Conditioning Journal, vol. 20, no. 5, 1998, p. 70.
2. "Vertical Jump." World of Sports Science, Encyclopedia.com, 22 June 2020, www.encyclopedia.com/sports/sports-fitness-recreation-and-leisure-magazines/vertical-jump.
3. Aragón-Vargas, Luis F., and M. Melissa Gross. "Kinesiological Factors in Vertical Jump Performance: Differences among Individuals." Journal of Applied Biomechanics, vol. 13, no. 1, 1997, pp. 24–44.
4. Garrett, William E., and Donald T. Kirkendall. "Measurement of Work and Power in Sport." Exercise and Sport Science. Lippincott Williams & Wilkins, 2000, pp. 44-45.
5. Cavagna, Giovanni A. "Storage And Utilization Of Elastic Energy In Skeletal Muscle." Exercise and Sport Sciences Reviews, vol. 5, no. 1, Jan. 1977, pp. 125–126.
6. Linthorne, Nicholas P. "Analysis of Standing Vertical Jumps Using a Force Platform." American Journal of Physics, vol. 69, no. 11, 2001, pp. 1198–1204.
7. Peng, Hsien-Te, et al. "Effects of Relative Drop Heights of Drop Jump Biomechanics in Male Volleyball Players."

International Journal of Sports Medicine, vol. 40, no. 13, 2019, pp. 863–870.
8. Sánchez-Sixto, Alberto, et al. “Larger Countermovement Increases the Jump Height of Countermovement Jump.” Sports, vol. 6, no. 4, 2018, p. 131.
9. Sharma A, Geovinson SG, Singh Sandhu J. “Effects of a nine-week core strengthening exercise program on vertical jump performances and static balance in volleyball players with trunk instability.” J Sports Med Phys Fitness. vol. 52, no. 6, 2012, pp. 606-615.
10. Serrano, Nathan, et al. “Extraordinary Fast-Twitch Fiber Abundance in Elite Weightlifters.” Plos One, vol. 14, no. 3, 2019, doi.org/10.1371/journal.pone.0207975.

Article submitted: August 3, 2020
Article accepted: September 12, 2020
Article published: December 20, 2020