Study of Lower Limb Angular Kinematics and Height of the Center of Gravity in Volleyball Overhead Pass

[1] Sumanta Kumar Mondal; [2] Bindusar Mondal; [3] Papan Mondal; [4] Nirmalendu Gayen
[1] Professor, Department of Physical Education and Sport Science, Vinaya Bhavana Visva-Bharati, Santiniketan, West Bengal, India
[2] Assistant Teacher of Physical Education, Karamkal S N Vidyabhaban, Birbhum, West Bengal, India
[3] Associate Professor, Department of Physical Education, Jadavpur University, Kolkata, India
[4] Assistant Teacher of Physical Education, R. Mitra+2 District CM School of Excellence, Deoghar, Jharkhand, India
[1] ORCID: 0000-0003-1699-812X

Corresponding Author: Sumanta Kumar Mondal

Abstract:
Purpose: The study aimed at measuring the hip, knee and ankle joint angles at the time of overhead pass in volleyball and to measure height of C.G. at different stages of the execution of the overhead pass. **Method & Materials:** 6 male volleyball Players who represented Visva-Bharati University in AIU (Association of Indian Universities) Tournament, were selected as subjects. The age range of the subject was 20-25 years. The variables of the study were hip, knee and ankle joint angles and height of CG at Contact, Release and Follow through points. A video camera having the capacity of 120 fps was employed to capture motion of overhead pass.CG location was identified by employing joint point method and height of CG was calculated by using reference scale. **Statistical Analysis:** Descriptive Statistics and 't' test were employed to analyze the data. The level of significance was set at 0.05 level. **Result:** The Mean Difference was significant between the angles of Contact & Release and Release & Follow Through of left ankle joint and Release & Follow Through of right ankle joint. Mean Difference was also significant between the angles of Release & Follow Through of right knee joint. Significant Mean Difference was also observed between the angles of Release & Follow through of right hip joint. In CG height mean difference was only significant between the phases of Release and Follow Through. Extension of lower limb angles and consequently the increase in the CG height were resulted to generate and transfer power to the ball [Yu Ozawa et al. (2022)[15]& Maolin Dong et al. (2024)[16]]. **Conclusion:** Among the three lower limb angles ankle joint has greater angular displacement in ball contact and release action in volleyball overhead pass than other two joints and displacement of lower limb joints are more during release to generate force. Increase height of CG during release and follow through is the indication of lower limb extension.

Keywords: Angular Kinematics, Volleyball, Overhead Pass

Introduction

Two teams consisting of six players take part at a time in the game of volleyball and both teams are separated by a net fixed in the middle of the court. Each teamtries to ground the ball on the opponent's court within the organized rules. Six basic skills dominate the game of volleyball and they are commonly termed as serving, passing, set, attacking, blocking and digging(The 6 Basic Fundamentals in Volleyball - Javelin Sports, 2023)[1].To become a good player a player has to master these basic skills including techniques, tactics and mental skills.

The overhead pass or lifting is one of the important& artistic skills in volleyball. Overhead pass is applied to receive the serve of the opponent or to set the ball for a powerful hit. In overhead pass the wrist is dorsiflexed at first when the ball is falling and then flexed to push the ball(Ozawa et al., 2021)[2]

The overhead pass techniques can be also used by any player to play the ball within three permitted touches inside their own court. To execute the overhead, pass the body is positioned in such a way that it is directed to the forehead. The passer needs to stagger his body with right foot ahead of the left foot when body weight is rest on the left foot. Passer has to keep his feet, hips and shoulders right-angled to the direction of the ball. Then he needs to bring the hands to the head and thumbs are pointed to backward direction at forehead. The hands are brought behind the line of the ball and finger tips are extended to make contact with the ball. The elbows are extended as the knees are extended and thumbs moved forward until both the palms face the target. After the contact is made a balanced position is required to be maintained by keeping the body weight on right foot. Afterward the passer returns to ready position to prepare for next play (Schmidt, 2015)[3].

Many studies on biomechanical analysis of volleyball skills have been made. Ozawa et al. (2021)[4], conducted a study on Biomechanical Analysis of Volleyball Overhead Pass). Roberto (2009)[5], conducted a study entitled A Review of Blocking in Volleyball: From the Notational Analysis to Biomechanics. Reeser et al. (2010)[6], conducted a study on Upper limb Biomechanics during the Volleyball Serve and Spike. Taei et al. (2024)[7], conducted a study on Biomechanical Analysis of Volleyball: A Review. The study conducted by Ozawa et al. (2025)[8]was focused on Biomechanical Analysis of Distance Adjustment in Volleyball Overhead Pass. Gayen et al. (2013)[9] conducted a study entitled "A Study of Angular Kinematic During Receiving in Volleyball. However, combining CG height with lower limb angular kinematics on university level players has got to be explored yet. Hence researcher was interested to undertake this study.

Material and Methods

Participants:

Six Inter university level male volleyball players of Visva-Bharati (A Central University and an Institute of National Importance), India, were selected as subjects. The average age of the subjects was 22.5 years. Subjects were informed about the objectives of the study and their medical health was checked. All subjects agreed to participate in the study voluntarily

Inclusion criteria

- Only male volleyball players were selected.
- University level volleyball players who represented Visva-Bharati volleyball team in East Zone Inter University Volleyball Tournament under Association of India Universities were selected as subject.
- Following Kinematic parameters were selected for the study
  - At contact phase hip, knee and ankle joint angles.
  - At the instant ball leaves the hand, hip, knee and ankle joint angles.
  - At follow through the hip, knee and ankle joint angles.
  - CG height at ball contact, ball leaves the hand and end of the overhead action.
- All players should have a five years of training age.

Exclusion criteria

- The financial condition of the researcher.
- Availability of sophisticated measuring device.
- Food habit, socio-economic factors and players day to day activity

Instruments and Tools Used -Video camera sutilized in this study were obtained from standard supplier, properly calibrated and synchronized.

Administration of the test:

Prior to the administration of tests all subjects were given the opportunity to practice the overhead pass many times to be acquainted with what they were supposed to perform at the time of actual testing. All subjects were tested during the evening hours to provide a uniform testing condition.

Ankle, knee & hip angle at contact, release & follow through phases:

Purpose: Measurement of ankle, knee and hip joint angles.
Equipment: Video camera
Procedure: Two subjects were engaged at a time during the testing. One subject performed the overhead pass and another subject stood in the opponent's court to supply the ball to

the player whose overhead action was captured. Two cameras having 120 Hz were placed at sagittal plane towards the left and right sides of overhead passer. Cameras were placed at 14.5 meter away from the subject at a height of 1.5 meter from the ground to measure the ankle, knee and hip joints angles during the three different phases of overhead pass action namely, ball contact, release and follow through. Researchers drew stick figures joining the reference points adopting the technique of joint point method employing Kinovea Software Version 0.8.15(copy right @2006-2011Joan Charman and Centre)[10]. The joint angles were expressed in degrees. C.G. height was calculated by using reference scale, for example a hurdle at certain height was used as a reference scale for C.G. height. Location of C.G. was identified by using joint point method.

Fig.1: Showing the Ball Contact Position in Overhead Pass

Fig.1 describes the position of the player at ball contact to measure the angular kinematics during ball contact of overhead pass

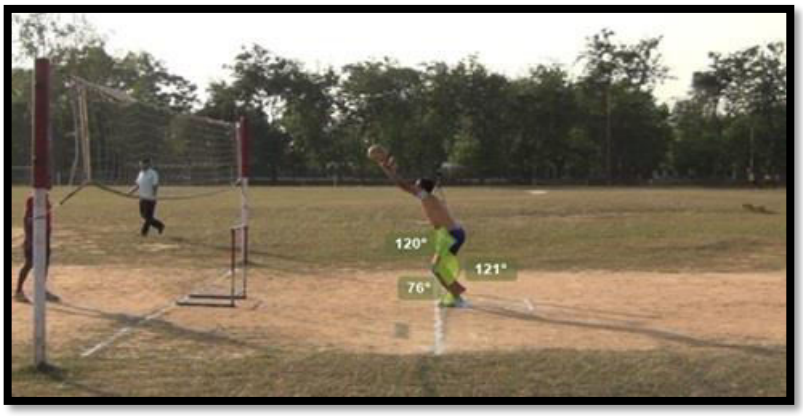

Fig. 2: Showing the Ball Release Position in Overhead Pass

Fig.2 describes the position of the player at ball release position to measure the angular kinematics during ball release point of overhead pass

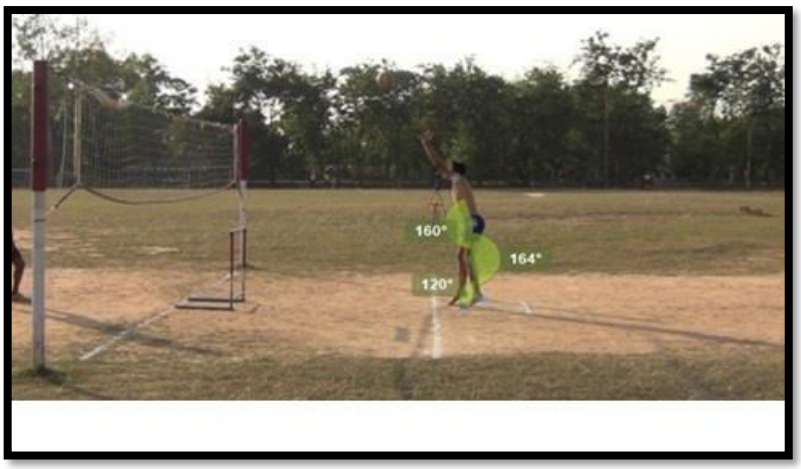

Fig. 3: Showing the Follow through Position in Overhead Pass

Fig.3 describes the position of the player at follow through position to measure the angular kinematics during follow through position of overhead pass

Determination of C.G. Height:

For the purpose of the study three moments were selected i.e.

- Contact
- Release
- Follow Through

The Center of Gravity (CG) of each subject while performing the overhead pass was located by observing the following steps.

1. Photograph of each subject at exact instant of ball contact, release and follow through of overhead pass was chosen and all segments were marked in consideration of reference point (Clauser et al. 1969)[11].
2. Subjects were represented by stick figures. Researcher drew straight lines in between the respective reference points. (The trunk line was obtained by locating the midpoint of the line joining the right and left hip joint,which was intersected to the midpoint of the trunk level of the suprasternal notch).
3. Each segment length was measured and then divided into appropriate ratio as indicated in C.G table 1.

Table 1
Location of Centre of Gravity of Body Segments (Clauser et.al. 1969)[12]

S.L NO.	Segment	C.G Location Expressed as percentage of Total Distance Between Reference Points.
1	Head	53.6% to chin-neck intersect and 46.4% to vertex
2	Trunk	62%to hip axis and 38% to suprasternal notch
3	Upper Arm	48.7% to elbow axis and 51.3% to shoulder axis
4	Fore Arm	39% to elbow axis; 61% to wrist axis.
5	Hand	18% to knuckle three and 82% to wrist axis
6	Thigh	62.8% to knee axis and 37.2% to hip axis
7	Calf	62.9% to ankle axis and 37.1% to knee axis
8	Foot	55.1% to hip of the longest toe and 44.9% to heel

4. OY line to the left and OX line below the stick figure were ruled out to indicate Y and X axes.
5. A form with 5 columns was prepared and relative weight of the body segments were entered in column 1. The relative weight of the body segments taking into account total body weight as iis given in C.G. **Table-2**

Table-2
Weights of Body Segments Relative toTotal Body Weight (Clauser et al. 1969)[13]

SL. NO.	Segment	Relative Weight
1	Head	0.073
2	Trunk	0.507
3	Upper Arm	0.026
4	Fore Arm	0.016
5	Hand	0.007
6	Thigh	0.103
7	Calf	0.043
8	Foot	0.015

6. From OY axis the perpendicular distance of the CG of each segment was measured and then entered in the respective place in the Column II.
7. The moment about OY was calculated by multiplying the proportionate weight of each segment to the distance of its CG from the OY axis and each segment's moment was

entered in column III.

8. The contents of Column III were added to find out the sum of moments about OY axis.
9. Parallel to the OY line an imaginary line O'Y' was markedat a distance of sum of the moments about OY axis.The CG of the subject would lie on that line.
10. Step from 5-9 were repeated to calculate total moments on OX axis. A O''X' line parallel to OX was drawn and the CG of the subjects would lie on O''X' at a computed distance from OX. Since the C.G lay on both O'Y' and O''X' and these two lines have only one intersection point it wasthere that the C.G was situated (James G Hay, 1985)[14].

Height of CG of every subject in contact, release and follow through phases of overhead pass action in volleyball was measured adopting the above-described procedure.

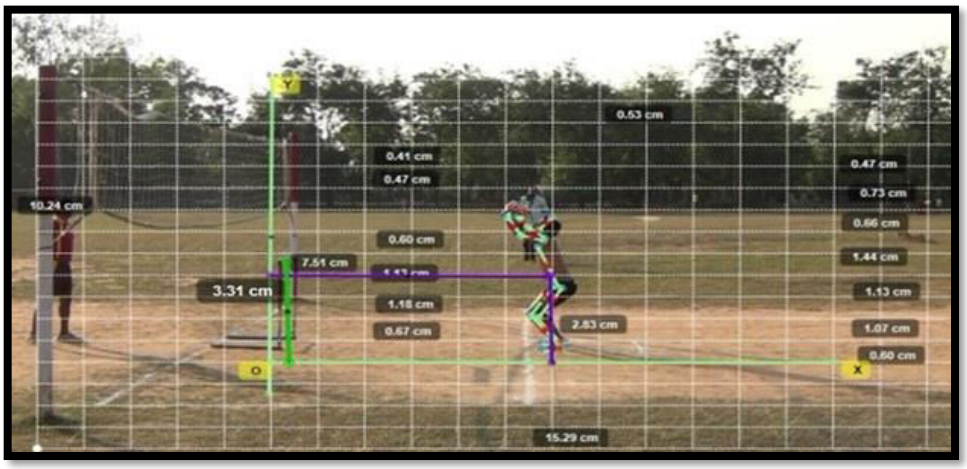

Fig.4: Showing Height of CG at the Contact Position in Overhead Pass

Fig 4 describes the method of identifying the location of CG at contact for measuring the CG height at release during overhead pass

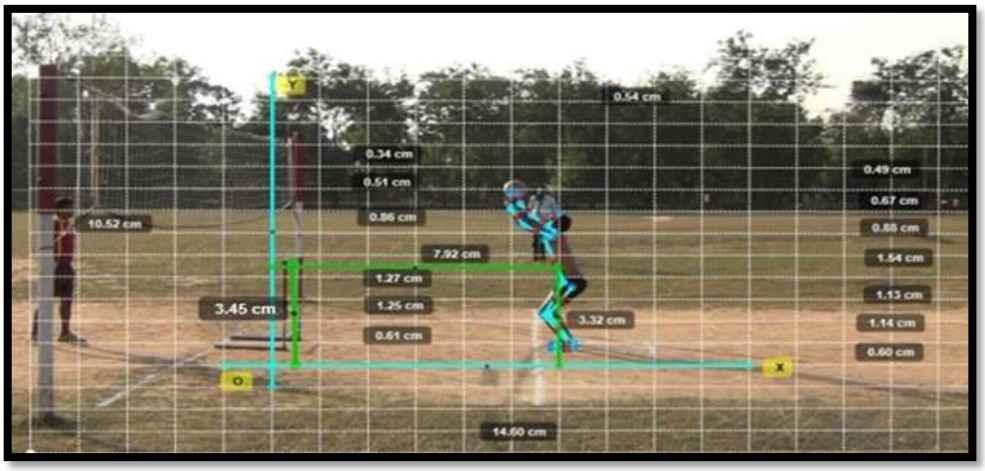

Fig. 5: Showing Height of CG at the Release Position in Overhead Pass

Fig 5 describes the method of identifying the location of CG at release for measuring the CG height at release during overhead pass

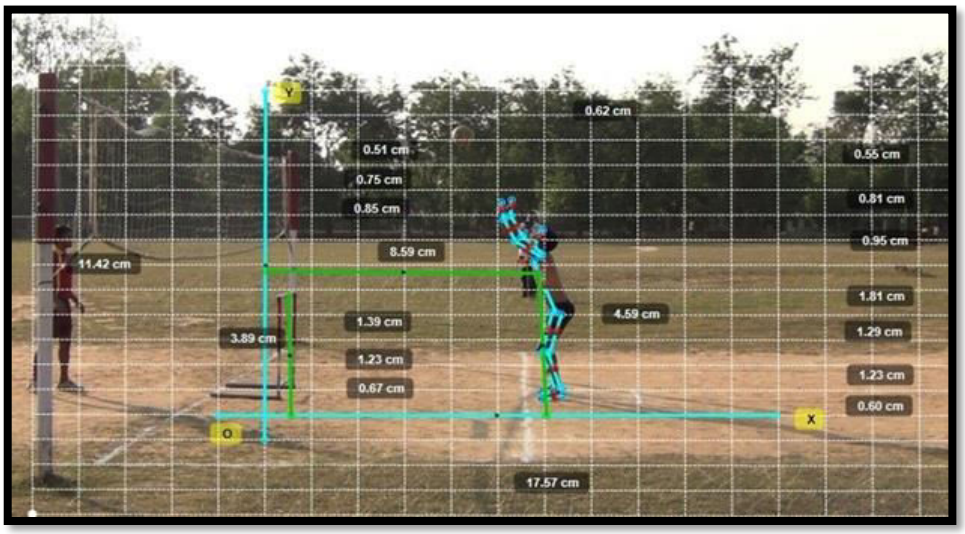

Fig. 6: Showing Height of CG at the Follow Through position in Overhead Pass

Fig 6 describes the identifying the location of CG at follow through for measuring the CG height at follow through during overhead pass

Statistical Procedure:

For the analysis of data descriptive Statistics and 't' test were employed. The significance level was set at 0.05 level.

Result:

Mean and standard deviation of the angles of ankle, knee, and hip joints and height of CG at Contact, Release and Follow Through points were obtained by employing the procedure of descriptive statistics. Table 1, 2, 3 & 4 respectively reveal the finding pertaining to these.

Table 1

Mean and SD of Ankle Joint Angles at Contact, Release & Follow Through (in degree)

Joint	Points	Mean (Deg.)	SD (Deg.)	
Left Ankle	Contact	72.66	10.61	
	Release	88.5	12.86	
	Follow through	115.66	22.25	
Right Ankle	Contact	87.5	10.57	
	Release	88.66	13.83	
	Follow through	115.83	15.48	

Table 1 depicts that Mean and SD values of left and right ankle joints in contact, release and follow through phases of overhead pass were 72.66±10.61, 85.5±12.86& 115.66 ±15.48 and 87.5±10.57, 88.66±13.83& 115.83±15.48 respectively.

Table 2
Mean and SD of Knee Joint Angles at Contact, Release & Follow Through (in degree)

Joint	Points	Mean (Deg.)	SD (Deg.)
Left Knee	Contact	110.33	19.31
	Release	130	18.03
	Follow through	153.66	25.20
Right Knee	Contact	110.16	22.06
	Release	125.66	20.15
	Follow through	150.5	12.66

Table 2 reveals that Mean and SD values of left and right knee joints in contact, release and follow through phases of overhead pass were 110.33±22.06, 130.00±20.15& 153.66±12.66 and 110.16±22.06, 125.66±20.15 & 150.5±12.66 respectively.

Table 3
Mean and SD of Hip Joint Anglesat Contact, Release & Follow Through (in degree)

Joint	Points	Mean (Deg.)	SD (Deg.)
Left Hip	Contact	119.83	16.48
	Release	130.66	17.31
	Follow through	153.16	20.60
Right Hip	Contact	130.33	11.74
	Release	136.16	13.45
	Follow through	153.16	11.95

Table 3 indicates that Mean and SD values of left and right hip joint angles in contact, release and follow through phases of overhead pass were119.83±16.48, 130.66±17.31 & 153.16±20.60 and 130.33±11.74, 136.16±13.45 & 153.16±11.95 respectively.

Table 4
Mean and SD of Height of CG at Contact, Release & Follow Through (in degree)

Location	Points	Mean (mt)	SD (mt)
CG	Contact	.93	.07
	Release	.96	.06
	Follow through	1.11	.06

Table 4 shows that Mean and SD values of CG height at contact, release and follow through phases of overhead pass were 0.93±0.07, 0.96±0.06 and 1.11±0.06 respectively.

The graphical representation of means values of the angles of Ankle, Knee, and Hip joints and height of CG at Contact, Release and Follow through points were made by the researchers and these are presented below in figure 7,8,9 & 10 respectively.

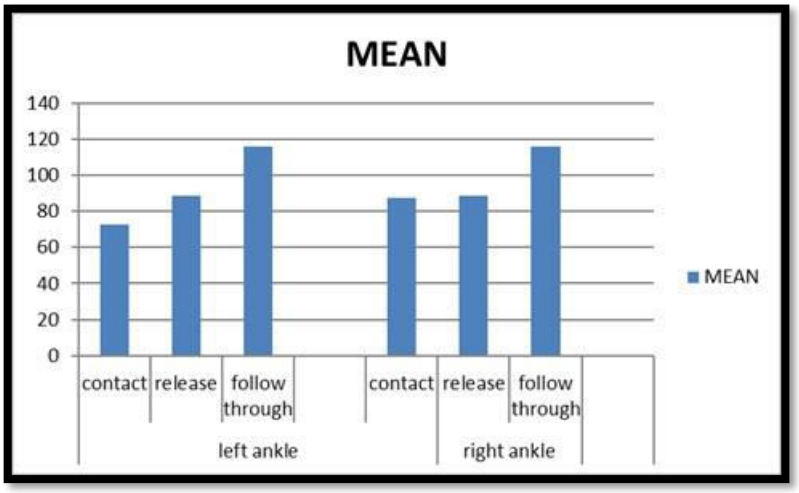

Fig.7: Mean Values of Left and Right Ankle Angle at Contact, Release & Follow Through

Fig.7 describes the mean values of left and right ankle angles at contact, release and follow through graphically

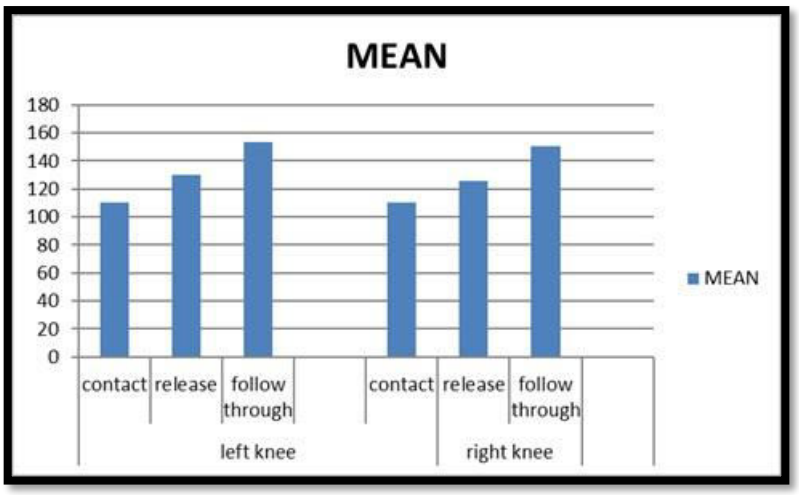

Fig. 8: Mean Values of Left and Right Knee Angle at Contact, Release & Follow Through

Fig.8 describes the mean values of left and right knee angles at contact, release and follow through graphically

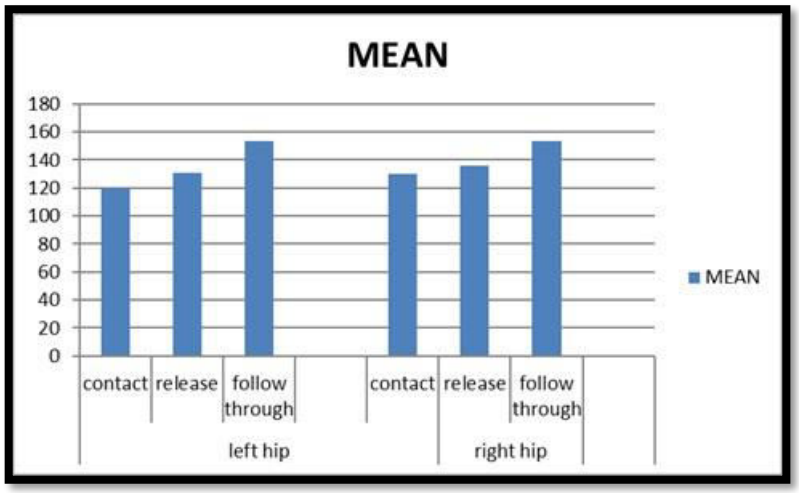

Fig. 9: Mean Values of Left and Right Hip Angle at Contact, Release & Follow Through

Fig.9 describes the mean values of left and right hip angles at contact, release and follow through graphically

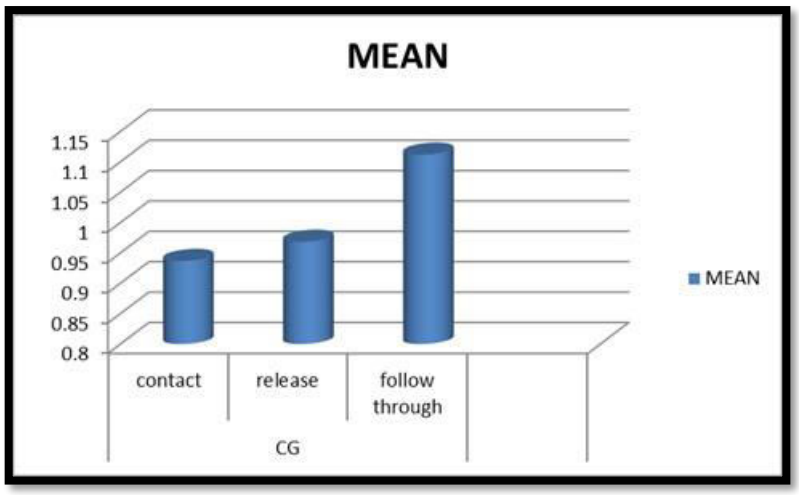

Fig.10: Mean Values of CG Height at Contact, Release & Follow Through

Fig.10 describes the mean values of CG height at contact, release and follow through graphically

To find the significance of angular displacement between the angles of different joints and location of CG between Contact & Release and Release& Follow Through phases 't' test wasutilized and result of the analyses are shown in Table 5, 6, 7 & 8 respectively.

Table 5
Significance of Mean Difference between the Angles at Contact & Release and Release & Follow Through of Ankle Joint

Joints	Angle of Joint at the time of	Mean Difference	Std. Error Difference	t-ratio	Sig.
Left Ankle	Contact	15.84	6.80	**2.32***	.05
	Release				
	Release	27.16	10.48	**2.59***	.05
	Follow Through				
Right Ankle	Contact	1.16	7.10	0.16	
	Release				
	Release	27.17	8.47	**3.20***	.01
	Follow Through				

***Significant at 0.05 levels; $t_{(0.05)}$ =2.22**

Table 5 indicates that significant angular displacement in left ankle joint angle occurred between the contact & release and release and follow through phases of overhead pass as obtained 't' values 2.32 and 2.59 are significant at 0.05 level of confidence. On the contrary, in case of right ankle joint angle significant displacement occurred only between release and follow through phases of overhead pass as obtained 't' value is 3.30, whereas, angular displacement between the contact and release phase was not significant as the obtained 't' value 0.16 was less than the 't' value 2.22 required to be significant at 0.05 level.

Table 6

Significance of Mean Difference between the Angles at Contact & Release and Release & Follow through of Knee Joint

Joints	Angle of Joint at the time of	Mean Difference	Std. Error Difference	t-ratio	Sig.
Left Knee	Contact	19.67	10.40	1.89	.10
	Release				
	Release	23.66	12.74	1.85	.10
	Follow Through				
Right Knee	Contact	15.5	12.24	1.26	
	Release				
	Release	24.84	9.71	**2.55***	.10
	Follow Through				

***Significant at 0.05 levels; $t_{(0.05)}$ =2.22**

It is evident from Table 6 that no significant angular displacement took place in left knee between the phases of contact & release and release &follow through as obtained 't' values ('t'=1.89 & 1.85) were less than 2.22 required to be significant at 0.05 level. On the contrary, in right knee, significant angular displacement took place between release & follow through phases ('t'=2.55) whereas between contact and release phases the angular displacement occurred was not significant ('t'= 1.26)

Table 7
Significance of Mean Difference between the Angles at Contact & Release and Release & Follow through of Hip Joint

Joints	Angle of Joint at the time of	Mean Difference	Std. Error Difference	t-ratio	Sig.
Left Hip	Contact	10.83	12.08	0.89	
	Release				
	Release	22.5	10.98	2.04	.10
	Follow Through				
Right Hip	Contact	5.83	7.18	0.81	
	Release				
	Release	17	7.34	**2.31***	.05
	Follow Through				

***Significant at 0.05 levels; $t_{(0.05)}$ =2.22**

It is observed from Table 7 that no significant angular displacement occurred in the left hip joint between the phases of contact & release and release & follow through ('t'= 0.89 & 2.04) during the execution of overhead pass. On the contrary, significant result was found the angular displace of righthip between release and follow through action ('t'=2.31), but no significant result was obtained between the contact and release phase ('t' = 0.81).

Table 8
Significance of Mean Difference between the Height of Cg at Contact & Release and Release & Follow through of Knee Joint

	Height of CG at the time of	Mean Difference	Std. Error Difference	t-ratio	Sig.
CG	Contact	.03	.03	1	
	Release				
	Release	.15	.03	**5***	.001
	Follow Through				

***Significant at 0.05 levels; $t_{(0.05)}$ =2.22**

Table 8 exhibits that CG height of the players did not undergo any significant change between contact and release phases of overhead pass action ('t'=1.00), whereas it had experienced a significant change between the phases of release and follow through actions of overhead pass ('t'= 5.00).

Discussion of Findings:

It was found in the result that significant angular displacement occurred during the action of contact & release and release & follow through phases in left ankle joint and release& follow through in right ankle joint whereas in right knee and right hip significant angular displacement was only evident in between the action of release & follow through. Result of the study further reveals that CG height of the player had no significant change in between the action of contact & release, but significant change in the height of the CG was found in between the action of release & follow through. The significant angular displacement in all lower limbs' angles and significant increase of CG height of the player in-between the release and follow through phases of overhead pass suggest that power is generated and applied to the ball during release by extending lower limb angles, consequently CG height also increased [Yu Ozawa et al. (2022)[15]&Maolin Dong et al. (2024)[16]]

Conclusions:

- Ankle joint experience a greater angular displacement at the execution of contact and release action compared to knee and hip joints.
- All lower limb joints (ankle, knee and hip) undergo a noticeable extension during the execution of release and follow through action to develop an impulse force.
- Increase height of CG at release and follow through action of overhead pass in volleyball is also an indication of lower limb angular displacement.

Reference:

1. The 6 Basic Fundamentals in Volleyball—Javelin Sports. (2023, March 6). www.javelinsportsinc.com
2. Ozawa, Y., Uchiyama, Shuichi, Ogawara, Keita, Kanosue, Kazuyuki, & and Yamada, H (2021)., Biomechanical Analysis of Volleyball Overhead Pass. Sports Biomechanics, 20(7), 844–857.
3. Schmidt, B. (2015). Volleyball: Steps to Success. Faculty Publications.
4. www.digitalcommons.hope.edu
5. Ozawa, Y., Uchiyama, Shuichi, Ogawara, Keita, Kanosue, Kazuyuki, & and Yamada, H. (2021), Biomechanical Analysis of Volleyball Overhead Pass. Sport Biomechanics, 20(7), 844–857.

6. Roberto, L. (2009). A Review of Blocking in Volleyball: From the Notational Analysis to Biomechanics. Journal of Human Sport and Exercise, 4.
7. Reeser, J. C., Fleisig, G. S., Bolt, B., & Ruan, M. (2010). Upper Limb Biomechanics During the Volleyball Serve and Spike. Sports Health, 2(5), 368,
8. Taei, M., Baharuddin, M. Y., & Aminudin, S. (2024). Biomechanics Analysis of Volleyball: A Review. 7, 98–104.
9. Ozawa, Y., Yamada, H., Ozawa, S., Vogt, T., &Kanosue, K. (2025). Biomechanical Analysis of Distance Adjustment in Volleyball Overhead Pass". Sports Biomechanics, 24(2), 440–457.
10. Gayen, Nirmalendu, Gayen, Arup and Mondal,SK(2013),"A Study of Angular Kinematic During Receiving in Volleyball, International Journal of Health, Physical Education and Computer Science in Sports, 10 (1), 32-36.
11. Joan Charman and Centre, Kinovea Software Version 0.8.15 (copy right @2006-2011)
12. C.E. Clauser, J.T. McConville, and J.W. Young (1969), Weight, Volume and Center of Mass of Segments of the Human Body, Wright-Patterson Air Force Base, Ohio: AMRL Technical Report 69-70.
13. C.E. Clauser, J.T. McConville, and J.W. Young (1969), Weight, Volume and Center of Mass of Segments of the Human Body, Wright-Patterson Air Force Base, Ohio: AMRL Technical Report 69-70.
14. C.E. Clauser, J.T. Mc Conville, and J.W. Young(1969) Weight, Volume and Center of Mass of Segments of the Human Body, Wright-Patterson Air Force Base, Ohio: AMRL Technical Report 69-70.
15. Hay, James G(1985), The Biomechanics of Sports Techniques, Prentice Hall 3rd Edition, January,136-137.
16. Ozawa, Y., Uchiyama, Shuichi, Ogawara, Keita, Kanosue, Kazuyuki, & and Yamada, H.(2022)
17. Biomechanical Analysis of Volleyball Overhead Pass. Sport Biomechanics, 20(7), 844–857.
18. Donga, Maolin et.al.(2024) "Contribution of Upper and Lower Extremity of Male Athletes (10), 198-206.