CHAPTER - II

REVIEW OF RELATED LITERATURE

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CHAPTER - II

REVIEW OF RELATED LITERATURE

In this chapter a brief review of related literature related to present study found in books, journals, periodicals, proceedings, souvenir, e-journals and e-proceedings etc., have been presented. This review of literature has been arranged subject-wise for better understanding as 2.1 Take-off in Backward Salto, 2.2 Take-off in Handspring Vault, 2.3 Take-off in Long Jump and 2.4 Critical analysis of review.

2.1 TAKE-OFF IN BACKWARD SALTO

Smith (1983) studied kinematic and kinetic parameters on two subjects (A & B) using video graphic technique and force platform. He reported that somersault parameters, length and height were consistent with the take-off entry and exit body positions and concluded that the Cg of gymnast-A pivoted through approximately 20° during take-off and at the instant of departure from the floor the gymnast was at an angle or approximately 10° before the vertical. This gymnast produced a large horizontal force (F_x - 1160 N) to block backward momentum, and the gymnast was only in contact with the floor for 0.13 seconds. The result predictably was a short high Somersault. Gymnast B existed from the flic-flac with a higher body position than Gymnast A, was incontact with the floor for 0.01 seconds longer, departed from the floor at an angle of approximately 8° past the vertical, underwent a pivotal rotation of approximately 30° and produced relatively (in terms of body weight) much smaller blocking horizontal force component (307 N). Additionally there
were technical faults in the execution which included insufficient arm lift (hardly past the horizontal) and a tendency for the head to move backwards, leading to a slight hollow in the gymnast’s back. The resulting somersault was predictably longer and lower than the somersault produced by Gymnast A and therefore Gymnast B had less time in the air.

In this study Cuk and Ferkolj (2000), they analysed the following variables which can best define the difficulty of elements: time of flight, maximum height (where 0 is at the level of body center of gravity just before take-off), amount of rotation around transversal axis up to the highest point, average angular velocity around transversal and longitudinal axes and the distance between take off and landing position on using several SVHS Cameras, which covered the whole floor area. Ten male gymnasts performed ten different acrobatic jumps backward during the European championship in 1996 in Koebenhaven (Denmark) using for recording the elements with several SVHS cameras, which covered the whole floor area. They analyzed 25 frames per second, with a CMAS 3D system and calculated the kinematic parameters according to the Sušanka (Karas, Sušanka, & Otahal (1987)) body model with 15 segments implemented in the CMAS. Each element was analyzed from the moment of three frames before touch-down prior to take-off up to first touch-down at landing plus three frames. They reported for Stretched Backward Salto, time of flight was 0.84s, maximum height was 0.70m, transversal rotation up to the highest point was 135°, average angular velocity around transversal axis was 357°/s and distance of the flight was 2.67m, and concluded that Elements were performed by different gymnasts, with different techniques of take-off, therefore were difficult to compare, elements were performed successfully without major mistakes, according to the present Code of Points, the difficulty of elements was mostly related
to the required and actual time of flight, expert knowledge to determine difficulty was quite efficient in case of acrobatic jumps backward, easier elements could also be performed with excellence and with high values of the measured variables, results were quite informative for further investigation and comparison with other similar types of sports, results could be also used for training purposes e.g. control of movement after certain forced angular velocity.

The basic relations between selected biomechanical parameters of the CG trajectory and angular momentum of the gymnast in seven most typical, but significantly different types (according to the number of rotations and the position of the body) of backward somersaults were assessed by Hraski (2002). Successful single executions of seven different types of backward somersault had been subjected to further analysis: tuck (TCK), pike (PKE), layout (LYO), layout with twist 3600 (L36), double tuck (DTC), double layout (DLY) and double tuck with twist 3600 (036). All types of backward somersault were executed from the typical preparatory tumbling series: approach, round off, and back handspring on highly ranked, world-class gymnast. Two video cameras operating 60 frames per second were used during the training organized for the purpose of this research. Acquisition and processing of the data were done according to standards of the APAS procedure (3D analysis, DLT, Cubic Spline), concerning specifically about the analyzed movements. He reported for Tuck Backward Salto, vertical height of Cg was 225.6cm, horizontal displacement of Cg was 240.7cm, horizontal velocity at take-off was 285cm/s, vertical velocity at take-off was 418cm/s, velocity at take-off was 506cm/s, take-off angle 45°, angle at touch-down was 48°, Cg angle at take-off was 73°, duration of the flight was 1.02s, duration of the flight relative to Cg was 0.97s, horizontal velocity at touch-down was 326cm/s,
vertical velocity at touch-down was 86cm/s, change of the horizontal velocity at take-off was -41cm/s, change of the vertical velocity at take-off was 332cm/s, duration of the take-off was 0.1167s, Cg height at touch-down was 75cm, Cg height at take-off was 102.4cm and Cg height at landing was 79.8cm. In this study, on the base of correlation analysis applied on the biomechanical data extracted from the execution of seven different types of backward somersaults, functional relations among parameters responsible for defining the CG trajectory and angular momentum had been analyzed. The main results of the analysis point to the conclusion that average angular momentum in the flight phase would be greater with higher position of CG at touch-down, the greater horizontal and lower vertical velocity at touch-down and take-off, smaller change of the velocity during the take-off, lower take-off angle, as well as with lower height of the flight. It can be also concluded that the generation of angular momentum required by the completion of multiple rotations around transverse axis, necessarily expanded a certain amount of the vertical component of the analyzed movements.

Munkasy and Smith (1991) conducted a study looking at the biomechanical analysis of the U. S. Junior National gymnastics team performance of tuck, full twisting, and layout double back somersaults. Specifically, the researchers investigated the relationship between selected biomechanical variables describing gymnastic tumbling performance and a subjective score based upon gymnastic judging criteria on Nineteen male Junior National Olympic Team gymnasts (Age: 15.82±1.43 years, Height 1.60±0.10 m, Mass: 53.12±10.70 kg) using a high speed video camera (NAC HSV400) operating at 200Hz, positioned perpendicular to the direction of movement, recorded each tumbling pass. The video information was digitized on an IBMPC compatible computer using the
automatic mode of the PEAK Motion Measurement System. Results of their study indicated that in case of tucked double back somersault there was a significant correlation \((p<0.01)\) between the score and pre-flight duration. In case of the other movements only pre-flight duration with respect to the full twisting movement showed significant relationship and concluded that the significance of this finding from an applied point of view is that coaches wanted to know their athletes would have to complete double and even triple back somersaults. Their emphasis was often on the take-off and flight of the flips as opposed to its approach.

Geiblinger, Morrison and McLaughlin (1995) reported on take-off characteristics of double back somersaults on the floor. Analysis of the data for both male and female gymnasts revealed, that the most important performance factor determining somersault height was the vertical velocity of the CM, at 4.20 m/s for males and 3.54 m/s for females at take-off. The horizontal velocity at touch-down was 4.32 m/s and 4.05 m/s and decreased to 3.21 m/s and 2.30 m/s at take-off and the mean take-off period was 130 m/s and 120 m/s, respectively for males and females. The touch-down and take-off angles of the CM to ground contact and the horizontal were 64±6°, and 88±3° for males, and 69±4° and 87±5° for females.

In their study Burgess and Noffal (2001) examined the technical differences on the basis of kinematic analysis between beginner and advanced tumblers in case of back salto take-off in a tumbling series. The specific objectives of the study were to identify respective angles of attack, vertical and horizontal velocities at takeoff, accelerations on the ground during takeoff, takeoff and flight times, and peak heights as a % of body height of each group consisted with six gymnasts \((mass = 33.9 kg, height = 1.39 m)\) participated in this investigation. A Peak Performance
Measurement System was used to obtain two-dimensional (2D) coordinate data from the video recordings. The first digitized point was 5 frames prior to the gymnast’s feet coming in contact with the floor for takeoff, the last 5 frames post contact in landing. A Butterworth filter was used and optimized cut-off frequencies were determined automatically by Peak using the Jackson Knee Method. They reported average take-off times for the beginner and advanced gymnasts, respectively, were 0.18s and 0.13s. Flight times were 0.63s for the beginners and 0.73s for the advanced. Angle of attack, determined by the position of center of mass at toe-off in relation to the horizontal, was 90.3° in the beginners and 81.7° in the advanced. Horizontal and vertical velocities also differed between the groups. A higher vertical velocity and lower horizontal velocity was optimal for the gymnast at takeoff in order to achieve maximal height in the skill. Accordingly, vertical velocities of 1.95m/s and 2.58 m/s, and horizontal velocities of –2.11 m/s and –1.86 m/s were reported for the beginning and advanced groups, respectively. Horizontal velocities were decreasing during the takeoff phase, whereas vertical velocities were increasing. Noticeable differences in these changes occurred between the two groups. The advanced group accelerated vertically through the takeoff phase at a rate of 18.81 m/s². The beginning group accelerated at only 10 m/s². Peak heights of the skill derived from the location of the center of mass in flight also differed. Whereas the advanced gymnasts achieved a height of approximately 137% of their height, the beginners achieved 107% of their height. This difference could be attributed to the longer take-off times of the beginners, as well as the lower vertical velocities at take-off and concluded that the biomechanical considerations of the back salto could lead toward a better overall understanding of the skill by both coaches and athletes. Working on a shorter take-off time, decreasing the
angle of attack, and increasing the vertical velocity at take-off would lead to a higher back salto, allowing more time in flight and thus a higher scoring skill.

Zeljko (2002) also investigated a correlation between selected kinematic parameters and angular momentum in backward somersaults. The obtained results showed that average angular momentum in the flight phase was greater with the greater horizontal and lower vertical velocity at take-off and lower value of the flight height.

McNeal, Sands and Shultz (2007) examined muscle activation characteristics of tumbling take-offs. The study revealed that overall, backward take-offs had longer contact times than forward take-offs, and demonstrated earlier pre-activation and greater relative activity in the gastrocnemius than vastus lateralis before floor contact. During impact in backward take-offs, the gastrocnemius and vastus lateralis showed greater relative activity than the biceps femoris. In contrast, forward take-offs were characterized by shorter contact durations and similar pre-activation durations in the gastrocnemius and vastus lateralis. Relative activation of the gastrocnemius was similar to that of the vastus lateralis in the time immediately preceding contact with the floor in forward take-offs. During impact, the twisting limb muscles reduced their relative activation compared with the non-twisting limb in backward twisting take-offs, which might serve to generate angular momentum about the longitudinal axis due to asymmetrical force application to the contact surface. To achieve twist in the forward direction, an asymmetrical activation was achieved which was opposite to that found for backward twisting take-offs. The twisting limb had greater relative activation than the non-twisting limb. These results demonstrated that the specific nature of the take-off environment determined the activation patterns of the lower extremity in
tumbling gymnasts. The characteristics of the take-off largely determined the potential of the aerial skill to follow, and therefore exercises directed at improving the take-off needed to be very specifically designed to elicit similar kinetic and temporal responses. Simply performing basic, uniplanar stretch–shortening cycle exercises such as jumps without regard to manipulation of direction and twist during the jump were not likely to be as effective in improving the take-off as performing basic tumbling-type activities in differing directions and with or without twist during flight. It was interesting to determine foot pressure differences between limbs, especially on the twisting take-offs, to explore further the possible asymmetry in force application. Additionally, future studies might explore further the role of visual feedback and muscle activation during tumbling.

Sadowski et al. (2009) attempted to compare the values of velocity and joint angles obtained during performance of double salto backward stretched with a stable landing and its combination with salto tempo, on seven top level acrobats (track jumpers) participated in the study. Mean values of body height, mass and age had a value of: 170 cm ± 4.0 cm, 72.4 kg ± 3.6 kg, 20.4±1.7 years, respectively. The studies were conducted on a standard acrobatic path (type PTS 2000). Two digital video cameras (240 Hz) and APAS 2000 (Ariel Dynamics Inc.) were used during studies. Markers were placed in ankle, knee, hip, arm, elbow and wrist joints. All marker positions were tracked and reconstructed using the APAS system. Two sequences with the following elements were analysed: round-off - double salto backward stretched (A) and round-off - double salto backward stretched - tempo salto (B). They found that in version A the athlete created prerequisites for “gliding” double salto backward stretched by means of the body segments motions, whereas in version B the athlete executed faster motions of the body segments accentuating his actions.
upon backward rotation of the body. During the final phase of double salto backward stretched in combination with tempo salto the athlete performed courbette “under himself” (almost straight feet were placed in front of vertical line), pushed directly back and in 0.1 sec executed stable arm swing upward-backward to tempo salto.

**Heinen, Vinken and Olsberg (2010)** conducted a study to measure the effect of two different guidance procedures on movement kinematics in the two routines round-off back somersault, and round-off back handspring on the floor. Participants were 6 female gymnasts from a local gymnastics club, aged 16 to 22 years, with a mean age of 18.2 years ($SD = 2.0$ years). They had a minimum of six years of gymnastics experience with regular practice and participation in regional championships. An optic movement analysis system was used to determine the movement kinematics on the basis of video sequences of all performances. One digital video camera with a sampling rate of 300Hz was placed 15 meters away from the tumbling track and orthogonal to the movement direction of the gymnasts. The horizontal and vertical coordinates of eight points (body landmarks) defining a seven segment model of the human body (Davlin, Sands & Shultz, 2004) were recorded for each frame using the movement analysis software WIN analyze 3D (Mikromak, 2008). They applied a digital filter (cut-off frequency = 6 Hz) for data smoothing and calculated a mean temporal error of $\pm 0.0033$ s and a mean spatial error of $\pm 0.006$ m. Body-segment parameters were calculated on the basis of the individual anthropometric properties of each participant (Yeadon & Morlock, 1989). The results showed that the optimal guidance procedure in the back somersault would be to use the sandwich-grip to help the gymnast to optimize the support phase. During the landing phase, the iliac crest/thigh grip should be used in the first instance. Researchers further concluded that
both guidance procedures would fulfill similar demands in the round-off back handspring routine, to optimize an already mastered routine. However, in case of coach’s interest to particularly optimize the angular momentum about the somersault axis and the second flight phase, then the sandwich-grip should be applied in the first instance. According to their view manual guidance seems to be a powerful technique for influencing the movement kinematics of complex motor skills in gymnastics if it is applied in a differential and professional manner, and its effects on movement kinematics seem to be strongly task dependent.

Sands (2011) conducted a study on “Kinematic responses of female gymnasts during backward somersault take-offs on a spring strip using two types of metal coil springs”. In this study researcher’s primary goal was to compare two different spring floor-types. One used by American Athletic, Incorporated in a cylindrical spring while the new spring was invented, and currently marketed, by S. Weller, King Bars Sports. In the study researcher also investigated the role of the spring floors in jeopardizing the Achilles tendon and triceps surae muscle group during the impact for a tumbling take off from a round off and back handspring (flic flac) to a back somersault. Ten female gymnasts from the Grand Junction, Colorado area volunteered as subjects. All were experienced gymnasts with competitive levels ranging from level seven to level ten within the USA Gymnastics Junior Olympic competitive level hierarchy using three force platforms were interfaced to a desktop computer via MSA-6 MiniAmp:Strain Gage Amplifiers (AMTITM Watertown, MA, USA, Version 2.02.00). The amplifiers were interfaced through a GiganetTM processor to the desktop computer and Vicon-NexusTM (Centennial, CO, USA, Version 1.7.0.6035) software. Sampling from the force platforms was at 1000Hz. Kinematic 3D data capture and analyses were performed automatically by
detection of forty three, 14.5mm reflective markers using ten, ViconTM T-Series T040 infrared cameras. The cameras were placed around the tumbling take off area with four cameras on tripods low to the ground and six cameras on rails mounted on the walls above the athlete. The Vicon-NexusTM system was set to capture athlete marker motion at 200Hz. He reported for performing Backward Salto that total the floor contact time was 0.13s, take-off horizontal velocity in medial-lateral axis was 0.04-0.07m/s, take-off horizontal velocity in anterior-posterior axis was 3.04-3.24 m/s, take-off vertical velocity was 4.21-4.29 m/s, take-off resultant velocity was 5.29-5.34m/s, knee angle at floor contact was 25.40˚-25.95˚, horizontal velocity in anterior-posterior axis at floor contact was 4.08-4.13m/s. The results of this comparative study indicated that little or no statistical difference between the spring floor-types based on the variables studied. This confirmed one of my hypotheses in undertaking the study. The second hypothesis provided was also confirmed was that spring floor design had succeeded in eliminating knee reversals, intermediate recoils, and reductions of horizontal component velocities. The future of gymnastics apparatus design and implementation must include vibration and elastic response among the variables assessed.

Heinen (2011) conducted a study on “Evidence for the Spotting Hypothesis in Gymnasts”, that the goal of this study was to investigate the visual spotting hypothesis in ten experts and ten apprentices as they perform back aerial somersaults from a standing position with no preparatory jumps (short flight duration condition) and after some preparatory jumps with a flight time of 1s (long flight duration condition). In the study differences in gaze behavior and kinematics were expected between experts and apprentices and between experimental conditions. Gaze behavior was measured using a portable and wireless eye-tracking
system in combination with a movement-analysis system. Experts exhibited a smaller landing deviation from the middle of the trampoline bed than apprentices. Experts showed higher fixation ratios during the take-off and flight phase. Experts exhibited no blinks in any of the somersaults in both conditions, whereas apprentices showed significant blink ratios in both experimental conditions. The researchers also asserted that gymnasts could use visual spotting during the back aerial somersault, even when the time of flights delimited and the knowledge about gaze–movement relationships might help coaches to develop specific training programs in the learning process of the back aerial somersault.

**Hedbavny and Kalichova (2011),** conducted a study dealing with the problem of take-off phase of back somersault twisting with various numbers of twists along longitudinal body axis. Actually the purpose of the study was to evaluate the changes in angels during transition phase from back handspring to back somersault using 3D kinematic analysis of the somersaults. They used Simi Motion System for the 3D kinematic analysis of the observed gymnastic element performed by Czech Republic female representative and 2008 Summer Olympic Games participant. The results showed that the higher the number of twists, the smaller the touchdown angle in which the gymnasts lands on the pad in the beginning of take-off phase. In back somersault with one twist (180°) the average angle is 54°, in 1080° back somersault the average angle is 45.9°. These results may help to improve technical training of sports gymnasts.

**Mkaouer et al. (2012) conducted a study to compare the take-off’s kinetic and kinematic variables between three types of jumps from a standing position; Counter movement jump with arm swing (CMJa), Standing back somersault with landing on the spot (BSIs) and Standing back somersault with rare displacement and landing (BSId). The**
investigation was carried out on five elite level male gymnasts (age 23.17 ± 1.61 yrs; height 165.0 ± 5.4 cm; weight 56.80 ± 7.66 kg) by using two high-speed cameras (NAC HSV-500C3; 250 Hz) in NTSC format with VCR C3D and SVHS tape. A motion analysis software (Movias, NAC Corp, Santa Rosa, CA) was used to process the data. 20 retro-reflective body markers were attached to the gymnasts’ bodies allowing digitisation using a video based data analysis system (Movias for Windows 2.0.4). The body segments’ centres of mass were computed using Matshui model (1983). Take-off angle (αT), shoulder angle (αS), hip angle (αH) and knee joint angle (αK) were analysed and compared at the different take-offs. Angular displacements of these respective joints (θS, θH and θK) and their angular velocities (ωS, ωH and ωK) were calculated in the sagittal plane. Data acquisition and testing were carried out in a laboratory setting. All tests were performed within a 3-day period, starting at 4:00PM up to 6:00PM under the following environmental condition: average temperature 23°C (minimum 20, maximum 26°C). The force plate was synchronized with the two high-speed cameras. The first camera was placed in front of the subject and the second sideways, each at 5m from the centre of the force plate. Data analysis revealed that the take-off angle (αT) relative to the vertical axis was significantly decreased in the BSld condition in comparison to the two other conditions (P<0.01): by 5.01% and by 13.45% compared to BSls and to CMJa respectively. Similarly, the angle of shoulder joint at respectively). This increase is indeed a basic condition allowing backward rotation, and is supported by the fact that power generated on the horizontal axis was greater during the BSld compared to BSls and CMJa (279.00 ± 60.34 W; 138.08 ± 35.00 W; 137.54 ± 27.62 W respectively). In contrast, the peak power produced on the vertical axis was more important during CMJa and BSls than during BSld (4774.12 ±
231.98 W; 4269.72 ± 245.65 W; 4010.94 ± 368.00 W respectively) (Figure 5). Take-off ($\alpha_S$) was also significantly decreased by 18.22% during the BSld compared to the CMJa ($P<0.05$). The angle of knee joint at take-off ($\alpha_K$) was significantly decreased at almost a similar percentage during the same skill compared to CMJa (18.72%) ($P<0.01$) (Figure-6). Furthermore, the angular displacement of the shoulder joint ($\theta_S$) was significantly increased by 9.65% in the CMJa condition compared to BSld ($P<0.01$). More considerable change was noticed in the hip joint. Its angular displacement ($\theta_H$) has significantly increased compared to the two other conditions ($P<0.01$): by 34.50% and by 14.70% compared to BSld and to BSls respectively. Angular displacement of the arms was larger during the CMJa compared to the BSld ($157.51\pm6.77^\circ$ and $128.81\pm7.63^\circ$ respectively) and the flexion of the hip joint was also more important ($55.48\pm2.05^\circ$; $47.32\pm2.36^\circ$ and $36.33\pm2.65^\circ$ respectively for CMJa, BSls and BSld). Angular velocity of the knee joint ($\omega_K$) was likewise increased during the CMJa compared to the other situations by 27.95% v BSld ($P<0.01$) and by 19.70% v BSls ($P<0.05$). The angular velocity of the shoulder joint ($\omega_S$) was itself, significantly increased in the BSld condition with respect to the two others ($P<0.05$): by as high as 65.53% compared to BSls and by 71.86% compared to CMJa (Figure 7). Lastly, the centre of mass’s (COM) vertical velocity (vy) and the angular velocity of the knee joint ($\omega_K$) did not vary during the different take-offs. So also the hip joint’s angle ($\alpha_H$) at take-off and its angular displacement ($\theta_H$) remained. Kinematic analysis in the study showed that gymnasts performed a more important flexion of the knees and an inclination of the trunk during the CMJa than during the two other standing back somersaults. This range of motion seemed to allow for better vertical force, displacement and peak power. In addition, it allowed a minimum loss of force and power on the horizontal axis. As expected,
the take-off that passes through the COM, allowed better amplitude of movement than the take-offs thrown off centre forward. The CMJa and BSIs showed the highest level of vertical displacement, force and peak power followed by BSld. This implies that, for a better performance of the standing back somersault, it is necessary that the impulse pass through the nearest point to the COM. Investigating kinetic and kinematic variables together, allowed the endorsement of linear regression equations enabling the prediction of some data from others. As practical implications, the researchers recommend coaches to carefully monitor the position of gymnast's shoulders and to avoid a backwards inclination at the take-off during a standing back somersault.

2.2. TAKE-OFF IN HANDSPRING VAULT

Cheetham (1983) conducted a study on “The Men’s Handspring Front One and a Half Somersault Vault: Relationship of Early Phase to Postflight”. He measured which factors in the early phase of the handspring front one and a half Somersault vault was significantly related to the postflight variables. A group of eight male gymnasts were participated in the study. Seven of these gymnasts were from the Arizona State University competitive gymnastics team and the other was a former Australian Olympian. Videographic analysis technique was used. He reported that in this study, time of board contact or duration of take-off was 0.11s, horizontal velocity of Cg on board contact or touch-down phase was 7.32m/s, horizontal velocity of Cg on leaving the board or push-off phase was 4.53m/s, vertical velocity of Cg on board contact or touch-down phase was -0.95m/s and vertical velocity of Cg on leaving the board or push-off phase was 4.02m/s and concluded that the all vaulters were found to have a positive vertical velocity of the center of gravity on horse
contact, and all but one vault exhibited an impulse by the gymnast on the horse.

Kreighbaum (1983) conducted a study on “Biomechanics Research in Gymnastics: Past, Present and Future”. He reported that kinematic descriptions of various activities in gymnastics gleaned from the analysis of film data were the bases for the next category of biomechanics of gymnastics research. As per report of the study a wealth of information about velocities of approaches, angles of joints during different phases of the activity, angles and durations of contact with apparatus, angles of take-off from the floor or the apparatus, and the velocities of segmental movements can be gained from these studies. The most popular event to be analyzed was vaulting. Bajin (1974, 1976, 1978, 1979, and 1980) led the way in disseminating kinematic information about world class vaulters. In his study Bajin (1976) suggested that the amplitude of hip joint flexion was the critical aspect of a good score in performing a Yamashita vault over the side horse. In analyzing the handspring with 1/1 turns around the longitudinal axis, Bajin (1976) stated that all other factors being satisfactory, flight duration was a positive factor for scoring. Lengths of the pre-and post-flights, durations of the vault, and horizontal speed during the pre-and post-flights were measured for three world class vaulters. In comparing three world class vaulters performing the Tsukahara vault, Bajin (1978) concluded that if contact was made with the horse lower than 350-450, the end of the vault would demonstrate serious mechanical difficulties. Secondly, the time between hand placements must be as short as possible and the gymnast must make at least a 900 turn during the pre-flight. Bajin (1980) analyzed the men's two and one half salto vault and concluded that a speed of 75 m/sec. during the hurdle, a duration of at least 1.15 sec. during the post-flight and an angular velocity of at least
1,000/sec. during the turn were needed. In a less technical study, Nakajima (1974) studied 48 Japanese vaulters performing the Hecht vault and Fukushima (1975) investigated the take-off, pre-flight and rebounding method for two vaulters using two methods of repulsion from the horse. The two most complete studies of vaulting in this category of research were done by Dainis (1979) and Bruggemann (1979). Dainis studied the kinematic variables and energy changes for female vaulters performing a handspring vault and correlated these to judges' scores. Results indicated that a good handspring vault is performed with good upward velocity off of the board, a body angle of 450 at initial horse contact, and a strong repulsion from the horse at approximately the vertical position. Bruggemann (1979) studied the handspring and the Tsukahara vaults of male and female vaulters. A 16 mm camera, a force platform under the board, and an accelerometer on the horse, provided the researcher with the kinematic variables. In addition, a rating team judged the performances. The results revealed that a well-performed handspring could be characterized by a relatively high running velocity which was transferred to rotatory energy during support on the board. For the Tsukahara vault, in which attention was directed to a long second flight and a large rotatory impulse around the transverse axis, Bruggemann concluded that it seems to be disadvantageous to lift the center of gravity too much by the first hand; the best performers have a ratio of 1. In addition, a greater amount of horizontal velocity was lost during the board contact than horse contact. Most of the rotatory impulse was gained during the board phase and was changed only slightly during the support phase on the horse.

Hodgins et al. (1995) examined algorithms for the animation of men and women performing three dynamic athletic behaviors: running, bicycling, and vaulting. For each simulation, the researchers compare the
computed motion to that of humans performing similar maneuvers both qualitatively through the comparison of real and simulated video images and quantitatively through the comparison of simulated and biomechanical data. They reported for Handspring Vault in first flight phase or take-off time was 0.235s, horizontal velocity in board touch-down phase was 6.75m/s, horizontal velocity in board lift-off phase was 4.61 m/s, vertical velocity in board touch-down phase was -1.15m/s and vertical velocity in board lift-off phase was 3.34 m/s. One goal of this research was to demonstrate the dynamic simulation of rigid-body models could be used to generate natural looking motion.

**Greenwood and Newton (1996)** conducted a study to measure the kinetic characteristics of the take off phase of vaulting and the forces occurring within the springboard itself on eight male gymnasts, all members of the Great Britain Under 15 squad (mean mass 47.5Kg & SD 7.8Kg). Each of them performed five handspring vaults under laboratory conditions. Data were taken by using piezoelectric devices. They reported that the duration of Take-off of handspring vault in springboard was 0.01-0.13s. The obtained results suggested that the data recorded did not necessarily represent the forces which the gymnast was subjected to, but their magnitude should be of concern in relation to both potential trauma and overuse injuries, particularly in young gymnasts. The negative values recorded after take-off, represented force which was not being transferred to the gymnast and therefore could be regarded as inefficiency in the system, which had possible design implications.

**Prassas (1999)** conducted a study on “Biomechanical Research in Gymnastics: What is done, What is Needed”. The study revealed that the great majority of floor exercises consist of jumping/rotating elements interconnected by simpler transitional skills. Understandably then, most
research in floor exercises examined the takeoff and (on occasion) landing characteristics of various types of somersaults, mostly backward. Hwang, Seo and Liu (1990) investigated takeoff mechanics of three different types of backward somersaults performed at the 1988 Seoul Olympic Games including the contribution of the different body parts to the total angular momentum i.e., the required "spin". It was found that, in all cases, the legs' contribution to the total angular momentum was dominant. Similarly takeoff mechanics were found by Kerwin, Webb & Yeadon (1998) who investigated the production of angular momentum in double backward somersaults performed during the 1996 Olympics. Angular momentum and center of mass (CM) kinematics of single and double backward somersaults were investigated by Brüggemann (1983). Knoll (1993) examined the same parameters when studying implications for round-off and flic-flac techniques concluding that maximum height and takeoff angular momentum must be optimized. Most recently, takeoff and landing characteristics of double back somersaults on the floor performed at the 1994 World gymnastics championship were studied by Geiblinger, Morrison and McLaughlin (1995a; 1995b); the (kinematic) results presented were in agreement with previous literature. In summary, there is a wealth of information and good understanding of somersaults' takeoff requirements. Landings, however, have not been studied as much and, consequently, they are not as well understood. In addition, there is a lack of information on the extremely high loads placed on the muscle/tendon system during the short contact time in both takeoffs and landings. These loads are augmented when combinations such as backward somersaults immediately followed by forward ones are performed. Vaulting is the only apparatus involving a single movement. Partially for this reason, it might be the apparatus most researched (at least in proportion to the number of
skills performed on it) and best understood. Studies by Bajin (1979), Dainis (1979), Brüggemann (1984), Takei (1989; 1990; 1991a; 1991b; 1992; 1996; 1998), Takei and Kim (1992), Li (1998), and Krug, Knoll, Koethe, and Zocher (1998) examined springboard parameters, parameters while in contact with the horse, and/or landing parameters. In addition, the correlation between mechanical variables and the scores given to the vaults were investigated. As a result, it is generally accepted that, in vaulting, running approach horizontal velocity and takeoff springboard linear and angular parameters are more important than parameters during horse contact that means that it is very difficult to compensate for errors made during takeoff, while in contact with the horse. It is also generally accepted that the initial (takeoff) angular momentum is invariably reduced during contact with the horse and converted to vertical velocity. A model for gymnastics vaulting developed by Dainis (1981) for the airborne and horse-support phases of vaulting may be one worth the effort for every coach to study it and understand it.

In his research study Knoll (2002) tried to identify identical functional relationships at push-off on vaulting and also investigated the variation of joint angles and reaction forces in the push-off. Video recordings (50 frames/s) were used in order to collect kinematic data during the 1999 and 2001 World Gymnastics Championships in Tianjin and Gent. Videographic analysis techniques were used to analysis. He reported that the angular momentum of the first flight phase was greater than the angular momentum of the second flight phase. Thus the biomechanical mechanism was also valid for vaults. The reduction of the angular momentum of preparing elements found in upswing, take-off and push-off to dismounts and flight elements were also found in vaulting. First flight phase in all good vaults was approximately of the same size. Second flight phase was
reduced progressively from handspring forward and salto stretched to handspring forward and double salto tucked to forward handspring, whereas the post-flight height increased in the same vault type order. The push-off technique was of paramount importance for the reduction of the angular momentum of first flight phase. A faster execution of preceding elements was of secondary importance.

Keranen, Moisio and Linnamo (2007) conducted a study on “Artistic Gymnastics Vaults Vertical Take-off Velocity Measured by Electromechanical Film”. The purpose of the study was to measure accuracy of the vertical takeoff velocity from the takeoff force-time curve. An electromechanical film (EMF) was used during the study. Eight elite gymnasts participated in the study and APAS movement analyse system was administered for data analysis. They reported that the takeoff time was 0.111±5 ms (APAS) and 0.108±3 ms (Electromechanical film or EMF). The athlete’s centre of mass vertical direction changed from negative to positive at 23±4 m/s. The vertical takeoff velocities were 4.09±.24 m/s (APAS), 4.08±.31 m/s (First method or VY1) and 4.09±.32 m/s (Second method or VY2). These values did not differ from each other (p = 0.965). The results revealed that the EMF based force measuring system could offer instant feedback for athletes and coaches.

Chen et al. (2009) conducted a study to investigate how the kinematic factors during the horse (table) contact phase influence the post-flight performance in handspring vaulting. A six-segment planer simulation model comprising the lower arm, upper arm, head-trunk thigh, shank and foot was customized to an elite gymnast. A high-speed camera operating at 200Hz was used to record the vaulting motion. The trail with the greatest CM velocity at take-off from horse was chosen for kinematical analysis and as the input values of the model. Equations of motion were
generated by the software AUTOLEV (www.autolev.com). The results suggested that smaller wrist angle, greater wrist angular velocity, straight elbow, greater shoulder angular velocity, greater maximum shoulder torque and smaller hip angle at horse contact were crucial in achieving the optimal performance. Compare with the five-segment model with a visco-elastic shoulder of a previous study, the six-segment model without a visco-elastic shoulder could still closely match the real performance and better mimic the actual pushing movements of the arm.

Atikovic and Smajlovic (2011) conducted a study to assess which biomechanical parameters explain and define the initial vault difficulty values (DV). The study sample included 64 vaults from the code of points (COP) of the International Gymnastics Federation (FIG, 2009). Data were collected by using Videographic analysis. They reported that for the Handspring Vault in Table Vault, body’s centre of gravity (BCG) velocity on Springboard was 6.95 m/s. The time of first flight phase or duration of take-off was 0.26s and alpha in x axis in first flight phase or body lean at touch-down phase was 160°. According to the researcher’s view in future analysis, it would first be necessary to establish latent dimensions that can define the vaults and followed by a factor analysis of whether the vaults are explained only with three variables from the manifest variable space (degrees of turns around transversal axis, degrees of turns around longitudinal axis and body's and moment of inertia around transversal axis in second flight phase). They also added that from the factor analysis, it could be possible to determine independent factors that define the vaults and, with the results of the factor analyze, it would also be possible to propose better evaluation of the vault difficulty.

In their study Farana et al. (2012) compared the Key Parameters of difficult Handspring and Tsukahara Vaults performed by elite male
gymnasts. Five top level male gymnasts who participated in the 2010 Grand Prix Ostrava in Czech Republic performed 6.2 points. Data were collected by using Videographic techniques with the 3D spatial movement analysis. Two digital camcorders (Panasonic NVMX500EG, Japan) with a frame rate of 50 Hz were used. The shutter speed was set to 1/500s. The angle between the optical axes of the cameras was near to 90°. The calibration pole was defined with a calibration bar and was defined by a virtual cube of 7x4x3 m (Figure 1). The data was digitized by the SIMI MOTION (SIMI Reality Motion Systems, Germany) software. Temporal, Spatial, Velocity and angular variables were measured in critical phases of a vault. To establish the differences between means, the effect size (ES) was calculated. They reported that for Handspring Vault, duration on Springboard was 0.09±0.02 s, Horizontal displacement of Cog in first flight was 6.01±0.26m, Height of Cog at Springboard Take-off was 1.20 ± 0.10m, Resultant velocity at Springboard Take-off was 6.01±0.45m/s, Horizontal velocity at Springboard Take-off was 4.93±0.43m/s, Vertical velocity at Springboard Take-off was 3.67±0.35m/s, Angles at Touch-down in the Vaulting Table was 39.48°±4.18° and Angles at Take-off from the Vaulting Table was 79.12°±4.66°. They found that the greatest differences between both groups of vaults were caused by the different technique of the first flight phase and thus the execution of the contact and take-off from the vaulting table. In both groups of vaults, the take-off from the table was executed with high vertical and horizontal velocity that ensured a sufficient height of the vault and landing distance from the vaulting table. Although both vaults had the same difficulty score, the HSP (Handspring Vault) group required larger amplitude of the second flight phase and could be, in terms of performance, considered difficult. In case of HSP vaults the gymnasts needed more time in the second flight phase to
initiate and complete the twists around the longitudinal axis. Understanding of the mechanical and technical differences between two groups of vaults could help coaches to develop a training strategy for effective learning of the vaults.

2.3 TAKE-OFF IN LONG JUMP

Jin et al. (2000) conducted a study to measure Horizontal and Vertical velocity at Take-off. In this study participants were three elite male and female long jumpers (A, B & C), who participated 23rd Olympic Games final. Data were collected by using Videographic technique. They reported that the Horizontal velocity of Cg at the time of Take-off was 9.6 m/s to 10.00 m/s and Vertical velocity of Cg at time of Take-off was 3.0 m/s to 3.2 m/s in case of male jumpers and the analysis of last four steps, relating to maximum value of horizontal velocity were as follows; female A and C (the final step), B (the last four steps), male A, B and C (the last second step) when observations were made on twelve women broad jumpers who participated in the finals of 23rd Olympic Games, relating to the maximum value of horizontal velocity, the results were similar. Six jumpers used the second last step, two jumpers used the fourth last step, three jumpers used the third last step, on jumper used the final step. Female athletes showed a tendency towards the fourth last step, while male athletes showed a tendency towards use of the second last step. This showed that there was a great difference between each of them. Vertical velocity of body’s center of gravity during taking off, showed minimum value for male athlete A, B and C with the second last step. The vertical velocity results were directly proportional to their results during taking off. Two factors that restrict velocity are stride and step frequency. The step frequencies of the last four steps were directly proportional to their result.
Thus for maximal results in the broad jump, the fourth last step technique should be adopted in combination with the high step frequency method.

Bridgett et al. (2005) studied on vertical take-off velocity and take-off angle of a senior male long jumper (age 27 years; weight 80 kg; height 1.88 m) with a personal best performance of 8.30 m and a junior male long jumper (age 17 years; weight 62 kg; height 1.75 m) with a personal best performance of 7.58 m. Data were collected by using Videographic techniques. They reported that the junior athlete tended to use a slightly greater average vertical take-off velocity (3.8 m/s) than the senior athlete (3.4 m/s) and the senior athlete used a lower take-off angle (mean =21.4°, S =1.6°) than the junior athlete (mean =23.5°, S =1.0°). They concluded that the optimum take-off technique for a long jumper changes with increasing run-up speed. As the athlete ran faster he used a straighter knee angle at touchdown, the take-off angle decreased, take-off velocity increased, and the leg angle at touchdown remained almost unchanged. The two athletes used different approaches to the long jump take-off. The senior athlete had a higher horizontal velocity at touchdown and a higher resultant take-off velocity, but a lower vertical take-off velocity, a smaller take-off angle and a greater loss in energy than the junior athlete. Maximizing the vertical take-off velocity might be as successful as minimizing the loss in horizontal velocity during the take-off.

Linthorne (2008) administered a research work to measure horizontal and vertical velocity during take-off and the take-off duration in Long Jump, using Videographic technique. Results suggested that the Horizontal velocity at Take-off was 8.8 m/s, Vertical velocity at Take-off was 3.4 m/s and Take-off duration was 0.11 s for elite long jumpers. Results also indicated that the explosive extension of the hip, knee and ankle joints during the last half of the take-off was accompanied by a
vigorous swinging of the arms and free leg. These actions placed the athlete’s COM (Centre of Mass) higher and farther ahead of the take-off line at the instant take-off, and were also believed to enhance the athlete’s take-off velocity. Some athletes used a double-arm swing to increase the take-off velocity, but it was difficult to swing smoothly without loss of running velocity from a normal asynchronous sprint arm action during the run-up to a double-arm swing at take-off.

2.4. CRITICAL ANALYSIS OF REVIEW

Review of related literature indicates that a good number of studies have been conducted by leading researchers to study and analyze the mechanical characteristics of Take-off action in different gymnastics exercises involved in Floor Exercise and Table Vault. The important mechanical parameters studied have been- Duration of Take-off, Change of Horizontal and Vertical velocities of Main body as well as Arm and free Leg during Take-off, Change of body height during Take-off, Change of angles at different joints of the boy including hip, ankle and elbow during Take-off etc.

The results of conducted investigation as reported by different authors lead to following conclusions:

i) The time of Take-off in Backward Salto and Handspring Vault varies from 0.11s to 0.14s and 0.09s to 0.23s respectively. [Cheetham (1983), Smith (1983), Hodgins et al. (1995), Burgess et al. (2001), Hraski (2002), Keranen et al. (2007), Atikovic et al. (2011), Sands et al. (2011) and Farana et al. (2012)].

ii) Body lean at Touch-down phase in Backward Salto varies from 81.7° to 132° and in Handspring Vault varies from 30° to 160°.
iii) Horizontal velocity at Touch-down phase in Backward Salto and Handspring Vault varies from 3.26 m/s to 4.16 m/s and 6.75 m/s to 7.32 m/s respectively. [Cheetham (1983), Hodgins et al. (1995), Hraski (2002), Atikovic et al. (2011) and Sands et al. (2011)].

iv) Horizontal velocity at Push-off phase in Backward Salto and Handspring Vault varies from 2.74 m/s to 3.04 m/s and 4.53 m/s to 4.93 m/s respectively. [Cheetham (1983), Hodgins et al. (1995), Burgess et al. (2001), and Hraski (2002)].

v) Horizontal velocity at Take-off phase in Long Jump varies from 8.8 m/s to 10.00 m/s. [Jin et al. (2000), Bridgett et al. (2005) and Linthrone (2008)].

vi) Vertical velocity at Touch-down phase in Backward Salto varies from 0.86 m/s to 2.58 m/s and in Handspring Vault varies from -0.95 m/s to -1.15 m/s. [Cheetham (1983), Smith (1983), Hodgins et al. (1995), Hraski (2002), and Sands et al. (2011)].

vii) Vertical velocity at Push-off phase in Backward Salto varies from 4.07 m/s to 4.39 m/s and in Handspring Vault varies from 3.34 m/s to 4.09 m/s. [Cheetham (1983), Smith (1983), Hodgins et al. (1995), Hraski (2002), Keranen et al. (2007), Hedbavny et al. (2011), Sands et al. (2011) and Farana et al. (2012)].

viii) Vertical velocity at Take-off phase in Long Jump varies from 3.0 m/s to 3.8 m/s. [Jin et al. (2000), Bridgett et al. (2005) and Linthrone (2008)].
ix) Angular velocity in Backward Salto varies from 35.7 rad/s to 36.17 rad/s. [Cuk et al. (2000), Chen et al. (2009) and Heinen et al. (2011)].

x) Greatest height in Backward Salto varies from 0.7m to 2.25m. [Smith (1983), Cuk et al. (2000), Hraski (2002), and Hedbavny et al. (2011)].