KINEMATIC ANALYSIS OF THE BACK SALTO TAKE-OFF IN A TUMBLING SERIES: ADVANCED VS. BEGINNER TECHNIQUES

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The purpose of this study was to differentiate techniques used by beginner and advanced level gymnasts in the take-off of a back salto preceded by a round-off back handspring. Six gymnasts performed multiple trials of the tumbling series, in which horizontal and vertical velocities of the center of mass were calculated, take-off and flight times investigated, and peak heights derived from the analysis. It was found that the advanced gymnasts did possess lower horizontal and higher vertical velocities, shorter take-off times, longer flight times, and higher saltos than the beginning gymnasts.

KEY WORDS: biomechanics, salto, velocity, angle of attack

INTRODUCTION: In analyzing the back salto following a tumbling series, biomechanical considerations of the center of mass must be made to produce an efficient performance. Variables such as angle of attack (the angle at which the gymnast is at takeoff with respect to the horizontal) and velocities at takeoff must be calculated to provide an understanding of proper performance. The purpose of the takeoff of the back salto is to project the gymnast to a maximum vertical height and allow the completion of one revolution about the mediolateral axis (Cornelius, 1996). Given this factor, one would expect to see a sizeable angle of attack, high vertical velocities, and low horizontal velocities. According to Sands (1999), gymnastics skills revolve around Newton's third law, the action-reaction principle. As is true in the back salto, forceful blocking (e.g. little time on the ground and complete extension at takeoff) off the ground prior to flight would allow for maximum vertical height in the skill. However, it has been shown that many gymnasts do not take advantage of this principle, tending to show incomplete extension of their bodies during the take-off phase of many jumps and skills (Sands, 1999). The vertical velocity achieved at takeoff, along with how much time the gymnast spends on the ground during the takeoff phase, are important variables in the amount of vertical height achieved by the gymnast. Greater lift is achieved with shorter takeoff times, although mathematically this would not seem to be the case, since the vertical lift is expressed as vertical force multiplied by time (George, 1980; Schmidt, 1980). George (1980) explains this paradox stating that the magnitude of vertical forces increases at a proportionally greater rate as the time decreases. Accordingly, the position the gymnast is in at take-off also relates to how high the gymnast will be projected, and at what angle. When the feet come into contact with the ground at the end of the preceding skill the feet should be behind the line of gravity so a backward rotation can ensue once the gymnast is off the ground (George, 1980; Schmidt, 1980). Bowers, Fie, and Schmid (1981) support the idea of pushing downward and forward on the ground in the opposite direction of intended rotation to attain the desired skill. Angle of attack (Figure 1) is mentioned as being less than 90° (Bowers, et al., 1981; George, 1980); Hay (1993) states approximately 70° as optimal.

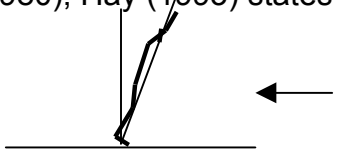

Figure 1 - Angle of attack 80° through CM. Gymnast is moving in direction of arrow.

The purpose of this paper is to provide biomechanical information related to the take-off of a back salto immediately after a round off back handspring has been performed. The differences between beginning and advanced tumblers will be displayed; allowing coaches the ability to see what types of techniques will project gymnasts higher and keep them in the air longer. Implications for injury reduction will be discussed, as well as applied strategies for coaches to use when teaching a beginner the skill. 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 will be reported for each group of gymnasts.

Figure 2 - Stick figures of beginning (left) and advanced (right) gymnasts performing a back salto. Direction of movement for each figure is from right to left.

METHODS: Six gymnasts (*mass* = 33.9kg, *height* = 1.39m) participated in this investigation; 3 advanced level gymnasts (1 level eight and 2 level sevens) and 3 beginning level six gymnasts. A Panasonic AG-180 VHS camcorder (60Hz) was positioned perpendicular to the plane of the movement while the gymnasts completed multiple trials of the tumbling pass.

Markers placed on the right side of the body, (lateral maleolus, lateral epicondyle of the knee, greater trochanter of the femur, head of the humerus, distal end of the humerus, and distal end of the ulna), and unmarked areas (distal end of 5^{th} metatarsal, proximal and distal points of the head) were digitized and used to calculate the body's center of mass.

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.

RESULTS & DISCUSSION: Marked differences between beginner and advanced gymnasts were found for take-off times, velocities, and angles of attack. Take-off times consisted of the instant the feet touched the ground after the back handspring to the instant the feet were no longer touching the ground. 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 (Figure 3) and lower horizontal velocity (Figure 4) 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.

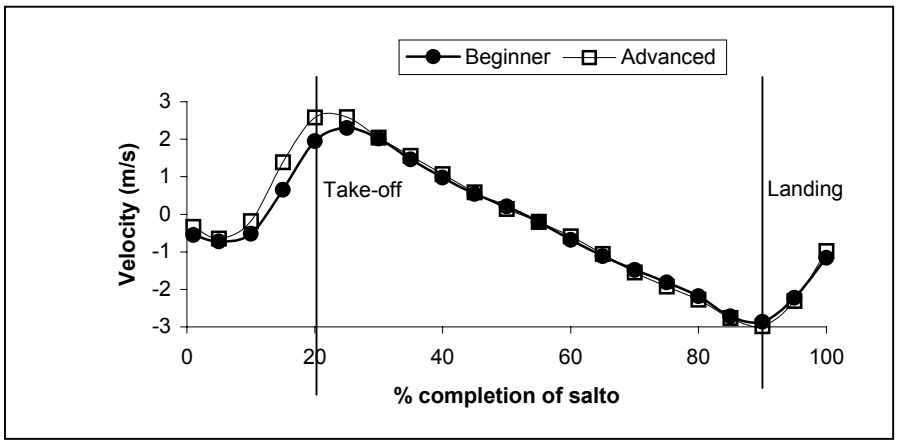

Figure 3 - Average vertical velocities of center of mass.

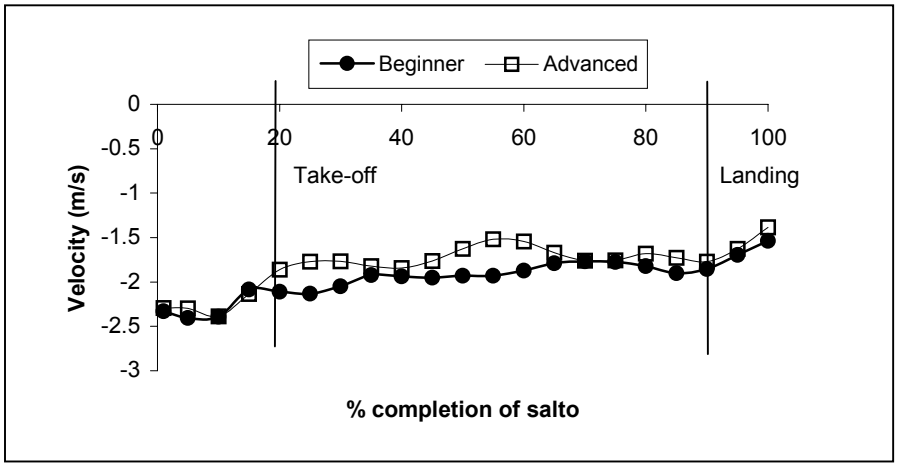

Figure 4 - Average horizontal velocities of center of mass.

The acceleration of the gymnast while in contact with the ground may significantly impact how the skill is performed. The advanced group accelerated vertically through the takeoff phase at a rate of 18.81 m/s^2. The beginning group accelerated at only 10 m/s^2. The horizontal deceleration of the two groups differed as well; the advanced group decelerated at a rate of 1.69 m/s^2, while the beginning group decelerated at a rate of 1.17 m/s^2. A higher horizontal deceleration amounts to better transfer of horizontal velocity to vertical velocity. These changes in velocities were calculated through the center of mass of each gymnast, then averaged together within respective groups.

As portrayed in the results above, there are measurable differences between the advanced and beginning gymnasts in the techniques used to perform a back salto. Measurable differences occurred in take-off and flight times between the two groups. Peak heights of the skill derived from the location of the center of mass in flight also differ. Whereas the advanced gymnasts achieved a height of approximately 137% of their height, the beginners achieved 107% of their height. This difference can be attributed to the longer take-off times of the beginners, as well as the lower vertical velocities at take-off.

CONCLUSION: Two common athletic injuries due to repetitive stress must be mentioned in light of these findings. Low back pain, often associated with hard, repetitive loading (concerned with high vertical velocities reported in the takeoff phase), especially of immature spines, is commonly found in the sport of gymnastics (Barton, Barnes, Hough, & Micheli, 1995). Gymnasts go through rigorous training on a weekly basis, consisting of excessive loads and

repetitive routines. This chronic overloading and insufficient time for recovery may weaken the tissue, lower its maximal strength, and increase the chances of an acute injury (Whiting & Zernicke, 1998). According to Barton, et al. (1995) these factors are some of the most common variables influencing low back pain. Stress fractures may also be common injuries, due to the repetitive stress placed on such a young body. Nattiv (2000) stresses a major risk of such fractures is having a lower percent body fat, something most gymnasts possess. Hough and Ray (1994) also state an implication for increased risk as having diets low in calcium, especially for female athletes suffering from amenorrhea. However, Nattiv (2000) points out that high impact sports seem to produce athletes with higher bone densities, and thus have lower incidence of stress fractures.

One thing coaches can do to prevent both lower back pain and stress fractures is to make good use of a Tumbl-Trak® (essentially, a long trampoline that can be used for tumbling). The trampoline can give athletes more air time, leading to a better kinesthetic understanding of the skill as well as the ability to do more in the air (IG Staff, 2000). It also allows for repetitive skills to be performed without risking the wear and tear on joints that is found on the floor (IG Staff, 2000). For the injured gymnast, skills can easily be performed on the trampoline because of the decreased force applied both in take-off and landing (IG Staff, 2000).

Using the biomechanical considerations of the back salto can 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 takeoff will lead to a higher back salto, allowing more time in flight and thus a higher scoring skill. Using the trampoline to gain height and repetitively work on body positioning for takeoff will greatly aid the beginning gymnast in acquisition of the desired skill. Once the concept is understood and can be performed successfully on the trampoline, the gymnast should move to the floor, and should be able to transfer the exact skill with little difficulty.

Future research on the back salto needs to involve more participants of varying levels, to find an optimal angle of attack, take-off times, and velocities. Further analysis is greatly needed for this skill, as it is a fundamental trick for the floor exercise in higher levels of competitive gymnastics.

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