A TWO-DIMENSIONAL KINEMATIC ANALYSIS OF A "BUNNY HOP" PERFORMED BY A SKILLED MOUNTAIN BIKER

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INTRODUCTION

Many skilled mountain bikers are capable of going over obstacles in their path by performing a maneuver called a "bunny hop". A bunny hop is a jump (usually over an obstacle) performed by a mountain biker riding a bicycle in which there is no ramp or other means of launching the cyclist. No scientific research was found in which a bunny hop was analyzed. The only studies that analyzed skills that were similar to this motion were biomechanical analyses of the triple jump, biomechanical analyses of drop landings from various heights and biomechanical analyses of vertical and horizontal standing jumps. Research by Dowell and Lee (1991) and King (1991) revealed a significant difference in vertical jump height with and without the use of arm swing for transfer of momentum. It is likely that transfer of momentum within an airborne system is a key element in the performance of a bunny hop. A two-dimensional kinematic analysis of a skilled mountain biker bunny-hopping over an obstacle provided quantitative and qualitative information regarding what movements to make and when, to those wanting to learn or improve the bunny hop. The purpose of this study was to determine the movements of a skilled mountain biker during the temporal stages of a bunny hop over an obstacle. The stages were divided into: the pre-jump phase, the airborne phase and the post-jump phase.

METHODS AND PROCEDURES

One male subject was used for this study. The subject's age, height and mass was 21 years, 185 cm and 75 kg, respectively. The subject was classified as a skilled mountain biker based on his being capable of performing a bunny hop over a 12 x 23 x 33 cm (length x width x height) obstacle (shoe box).

The two CCD video cameras (Panasonic WV-D5100HS) and the obstacle were set up prior to the arrival of the subject. One front view camera was placed 15 meters in front of the obstacle and in line with the subject's plane of motion. The side view camera was placed perpendicular to the subject's sagittal plane of motion, in line with the obstacle, 15 meters away. Both cameras were genlocked and leveled with their optical axes 1.5 meters above the floor. The subject had 15 meters on each side of the obstacle for the approach and for deceleration.

After signing an informed consent form, reflective adhesive markings (1cm x 1cm) were placed on selected joints and points on the left side of the subject and bicycle. While the subject was warming up, the cameras started recording with a shutter speed of 1/1000 second and a filming speed of 60 fields (30 frames) per second. A SMPTE time code was generated on the two video tapes simultaneously. Two flood lights were aimed at the obstacle and positioned on either side of the camera recording the sagittal view. A leveled 2-meter stick was filmed to translate the scaling factor from pixels to meters for two minutes.

The trials were performed with a 12.0 kg Specialized Stumpjumper™ mountain bike equipped with toe clips which allow the subject's feet to be strapped to the pedals. The bike was owned by the subject and he was familiar with the geometry, weight distribution and feel of the bike. The bicycle was also equipped with a front suspension system which consisted of a shock on the fork to absorb front wheel bumps. When the subject was ready, he performed ten trials of a bunny hop over the obstacle.

After viewing the tapes of both the side and front views of the ten trials, trials were eliminated if the subject either hit the obstacle, did not go directly over the obstacle or twisted (as observed by the front view).

The quantitative analysis was done by manually digitizing one representative trial using the tape from the side view camera and Peak Performance Technologies motion analysis software. Once digitized, the raw data were conditioned (smoothed) using a Butterworth filter with an optimum cutoff frequency for each of 31 points on the subject and bicycle. From the conditioned data, linear and angular displacement, velocity and acceleration values were obtained for the ankle, knee, hip, shoulder, elbow, wrist, head, two selected points on the vertebral column, the bike crank, and both wheel hubs during the pre-jump, airborne, and post-jump phases of the bunny hop. The airborne phase was defined as the period of time from which the second wheel left the ground to when the first wheel returned to the ground.

RESULTS

The 31 points that were defined in the spatial model were digitized for 82 fields of videotape, a total time of 1.394 seconds. The time between each field was 0.017 seconds. The pre-jump phase was 0.578 seconds, the airborne phase lasted 0.476 seconds, and the post-jump phase 0.340 seconds.

The linear displacement data indicated that the subject lifted the front wheel 0.034 seconds prior to lifting the rear wheel yet landed the front at the same time as the rear. During the airborne phase the wheels essentially remained aligned horizontally; that is, there was no upward or downward tilting of the bicycle during its aerial path.

The subject and bicycle traveled at an average horizontal velocity of 4.6032 ± 0.1052 meters/second as measured by the velocity of the rear hub of the bicycle for the entire 1.394 seconds. Horizontal velocities did not tend to vary during the 1.394 seconds for all of the points analyzed. A likely cause for this was that the subject achieved a desired speed for the bunny hop prior to the first field of digitizing and did not attempt to accelerate or decelerate (pedal or brake) during the maneuver.

The vertical behaviors of the upper and lower portions of the bike-rider system during the three phases revealed their timed manipulation to accomplish the task of clearing the obstacle. Figure 1 shows the vertical displacement of selected points on the upper and lower portions of the bike-rider system. Points on the upper system rose prior to and only during the early part of the airborne phase, while the lower system rose at takeoff and continued to rise to its peak height while the upper system was lowering. The early airborne data show the greater upward displacement of the 12.0 kg bike compared to a lesser downward displacement of the upper portion of the bike-rider system which had more mass.

All points on the subject above the knee (representing the upper portion of the bike-rider system) achieved maximum upward velocity 0.085 seconds prior to takeoff, between fields 29 and 34. The points marking the wrist (at handlebars), knee, ankle, 5th metatarsal, front and rear wheel hubs, and crank represent the lower portion of the bike-rider system, and achieved maximum upward velocity between fields 36 and 41 (shortly after the initiation of the airborne phase on field 35).

Angular velocity was determined for the following joint angles: elbow, shoulder, left ankle, left knee, left hip, spine and head. The spine angle was defined as the angle formed by the lines connecting the 12th thoracic to the 7th cervical vertebrae and to the lateral superior iliac crest. The head angle was relative to the horizontal plane using two markings on the bicycle helmet. Just prior (fields 28-32) to take off at field 35, the elbow and knee achieved maximum extension velocity, the ankle achieved maximum plantar flexion velocity and the head was tilting upward at it's maximum extension velocity. These joint movements coincided with the maximum upward velocity of points on the upper system prior to takeoff.

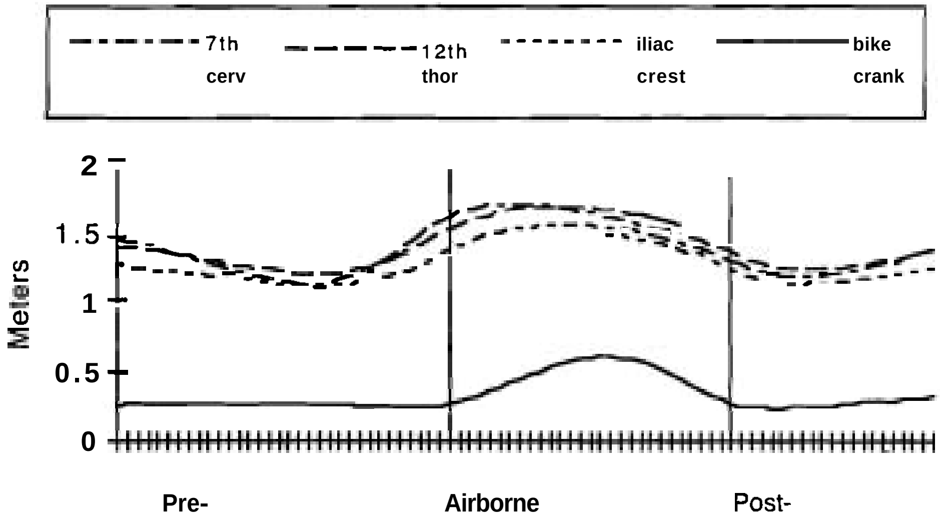

Figure 1. Vertical placements of the 7th cervical vertebrae, 12th thoracic vertebrae, iliac crest and bike crank.

Following obstacle clearance of the bike, all points on the system descended. All points on the bike-rider system achieved maximum downward velocity during the 0.068 seconds prior to landing (fields 58-62). Upon landing, the upper system continued to lower after the wheels struck the ground as part of the shock absorbing process. Just after landing contact (fields 63-64), the shoulder achieved it's maximum extension velocity, the ankle achieved it's maximum dorsi flexion velocity and the head was tilting downward at it's maximum flexion velocity.

DISCUSSION

The results of this study can be compared to that of King (1991). King compared vertical standing jump height with and without arm swing and concluded that arm swing can contribute up to a 25% gain in jump height. A gain in reach height is caused by the lowering of the CG within the body by lowering one arm prior to the peak CG height. Such a move causes a lower part of the system to rise higher thereby elevating the parts above it (the reaching hand) to a greater height. The ground reaction force resulting from the final extension of the supporting hip, knee and ankle joint is used to further increase the projection height and velocity of the already upward-traveling center of gravity (Kreighbaum & Barthels, 1990). The data indicated that a similar maneuver apparently was used in performing the bunny hop. The cyclist needs to have an upward acceleration of a portion of the body mass prior to a deceleration of that portion of body mass just prior to takeoff. Then, during the airborne phase, a downward movement of the upper body causes upward movement of the rest of the bike-rider system. This downward movement must be done prior to the vertical peak of the system's center of gravity to result in lifting of the bicycle relative to the cyclist.

APPLICATIONS

After qualitative and quantitative analyses of the bunny hop, the following instructions describe how to perform a bunny hop. As you approach the obstacle, level your pedals and be sure that you are coasting at an appropriate speed to clear the obstacle (even if you can get both wheels off the ground, a slow forward velocity could result in having the rear wheel come down on top of the obstacle). Approach the obstacle in a crouched position then rapidly stand up (straighten your arms and legs). A final rapid extension of the knees and plantar flexion of the feet will give your body upward momentum. Just prior to the obstacle, pull up on your handle bars and feet to jump (toe clips will keep your feet connected to the pedals). Once airborne, and while the bike-body system is still rising, flex the hips, knees and ankles and assume a crouched position with the head and trunk to pull the bike up closer to you and further from the ground to clear the obstacle. As the bike descends toward the ground, come out of your crouched position and extend the arms and legs so they are in a position to flex to absorb the shock of the landing. Then, absorb the landing shock with the arms and legs flexing.

CONCLUSIONS

This study was based on two assumptions. It was assumed that the movements performed by this subject are similar to the motions taken by other skilled mountain bikers during a bunny hop over an obstacle. However, it is possible that the findings from this single skilled subject are not representative of the common or preferred method of bunny hopping. Analysis of a larger number of skilled subjects would be necessary to reveal commonalties among skilled performers. It was also assumed that the performance of a bunny hop over an obstacle in a laboratory setting would be similar to that of a real outdoors setting.

Another recommendation for further research in this area would be to compare the use of toe clips, clipless pedals (which allow for the cyclist's shoes to be firmly connected to the pedals if there is no pronation or supination of the foot) and ordinary pedals that do not hold the foot to the pedal. This could help to determine the importance of having the feet connected to the pedals in performing a bunny hop. It is possible that an upward elastic force is created within the bicycle. It may also be helpful to compare a bunny hop with a bike with no suspension, front suspension and dual suspension.

A final recommendation for further research in this area would be to use three-dimensional analysis to determine the lateral motions of the arms as well as the center of gravity of the bike-rider system.

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