BIOMECHANICAL ANALYSIS OF THE LONG JUMP AT THE VITH WORLD CHAMPIONSHIPS IN ATHLETICS

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INTRODUCTION: The distance (W) was found to have the greatest influence on jump distance (Hay et al. 1986; Lees et al. 1994). The distance (W) can be calculated using the following formula:

$$W = \frac{v^2 \sin 2a}{2g} + v \cos a \sqrt{\frac{2}{g}\left(h + \frac{v^2 \sin^2 a}{2g}\right)} \qquad (1)$$

From the formula it is clear that the distance (W) is dependent on the height of the CM at the end of the take-off phase, and the horizontal and vertical take-off velocities. From this causal dependency various researchers over the past decades (Hay et al. 1986; Koh & Hay 1990; Hay & Nohara 1990; Lees et al. 1993, 1994) have tried to identify which component (horizontal or vertical) of the take-off velocity plays a larger role concerning the jump distance. The results are often controversial and dependent on the performance level of the analyzed jumpers. Koh and Hay (1990) reported that the goal of the take-off is not to minimize the loss of the horizontal CM velocity. This position was supported by the observation that a loss in horizontal velocity often leads to an increase in vertical velocity (Hay et al. 1986; Hay & Nohara 1990; Koh & Hay 1990; Lees et al. 1993, 1994). For both men and women a loss of total energy has been reported (Witters et al. 1992; Lees et al. 1993, 1994). This means that during the transformation of approach energy to jump energy a loss in total energy is to be expected. This also means that a decrease in horizontal CM velocity does not always lead to an increase in vertical CM velocity. The purpose of this study was to examine a group of world class long jumpers to see if they can be divided into groups which have similar initial conditions and different jump characteristics but still achieve similar jump distances. Furthermore, optimal jump parameters will be calculated for given starting conditions for both men and women jumpers at the world class level.

METHODS:
Data collection: Data was recorded from 31 jumps completed by male jumpers and 31 jumps by female jumpers. The jumps were performed by the 12 finalists in both the men's and women's long jump finals at the 1997 track and field world championships. Only legal jumps were analyzed. To capture the data three stationary cameras (50 Hz) were used. Camera 1 was positioned to capture the support phase of the last three strides before take-off. Camera 2 recorded the support phase of the last step and take-off. The third camera recorded the take-off and flight phase until landing. DLTs were used to calculate the spatial coordinates (x, y) of the 19 digitized points per frame.
Data analysis: Equation 1 can be rewritten in the following form:

$$W = \frac{E_{k2} \sin 2a}{g} + \frac{2 \cos a}{g} \sqrt{E_{k2}(E_{p2} + E_{k2} \sin^2 a)} \qquad (2)$$

$$E_{k2} = \frac{E_{kin2}}{m}, \qquad E_{p2} = \frac{E_{pot2}}{m}, \qquad E_{kin2} = \frac{1}{2} m v^2,$$

$$E_{pot2} = mgh$$

A transformation of approach energy to jump energy occurs during the take-off phase a. To quantify this transformation an index was created which shows the relationship of the directional change of the movement during the take-off phase with regard to the energy loss at take-off. The transformation index is defined as the quotient of the take-off angle divided by the energy loss.

$$T_{Index} = \frac{a}{E_{decrease}} \qquad (3)$$

From equations (2) and (3) the distance (W) can be calculated as a function of the starting energy, energy loss, and the transformation index. The potential energy difference among jumps was very small and can therefore be given a constant value for each jumper. The starting energy represents the initial conditions for the jump and the energy loss, and the transformation index represents the jump characteristics. Using a cluster analysis, groups were created on the basis of starting energy, energy loss and the transformation index. For both the men and the women 3 relatively homogeneous groups could be identified. An independent groups T-test was used to measure the differences among the groups.

RESULTS:

Women: Groups 1 and 2 didn’t show a significant difference in the starting energy of the body, while group 2 had the lowest value. During the take-off the energy decrease of group 3 was the highest. In the other two groups no significant difference ($p<0.05$) was found. Although the transformations index in group 3 was the smallest, the take-off angle of this group was significantly ($p<0.05$) larger than that of group 1. The take-off angle of groups 2 and 3 showed no clear difference. The largest values for the jump distance and the effective distance were measured in groups 1 and 3. The horizontal CM touchdown velocity was the lowest in group 2. The horizontal and vertical CM take-off velocities from groups 2 and 3 showed no significant ($p<0.05$) differences. Group 1 produced the highest horizontal CM take-off velocity and the lowest vertical CM take-off velocity of the three groups.

Men: From the men’s competition, groups 1 and 2 had the same beginning energy, and group 3 showed the most beginning energy going into the take-off. Group 3 also had the largest energy loss and the lowest transformation index. Group 2, on the other hand, had the lowest energy loss and the largest transformation index. Group 1 had the lowest end energy, and the other two groups showed no significant difference. The take-off angles of groups 1 and 3 showed no significant ($p<0.05$) difference, while group 2 had the lowest value. The largest values for jump distance and effective distance are found in group 1. Differences among the groups could not be found for angle of projection at touchdown, angle of projection at take-off, hip or knee angles. Group three also demonstrated the highest horizontal CM touch down velocity, as well as the highest vertical CM take-off velocity. A significant ($p<0.05$) difference between groups 1 and 2 was found only for the horizontal cm take-off velocity.

DISCUSSION: From the results it is clear that both the men's and women's groups can be divided into two primary jumping styles which demonstrate the same starting characteristics and achieve the same effective jump distance and jump distance. Groups 1 and 2 from the men and groups 1 and 3 from the women produced the same starting energy. During the take-off the energy loss for group 1 from the men and group 3 from the women was more than that of the other groups. The importance of this observation is that both groups showed less energy and a larger take-off angle at the end of the take-off phase in comparison to groups 2 (men) and 1 (women). The relationship between the horizontal and vertical velocities in groups 1 (men) and 3 (women) also varied. Group 1 from the women produced a higher horizontal and a lower vertical take-off velocity then group 3. Men's groups 1 and 2 differ significantly ($p<0.05$) only in the horizontal take-off velocity, for which group 2 demonstrated the higher value. The touchdown angles of groups 1 and 2 (men) and groups 1 and 3 (women) were the same. From these findings it doesn't seem productive to search through experimental data trying to determine which of the take-off parameters, vertical or horizontal velocity, plays a larger role in jump distance (Lees et al. 1993, 1994). As the group specific data from elite long jumpers indicates, various combinations of the two components can result in the same jump distances. Group 3 from the men had the greatest jump distance, and group 2 from the women had the shortest jump distance. During the take-off phase the relationship between group 3 and the other groups varied. Group 3 had the largest energy loss and the lowest transformation index. Because group 3 produced the highest starting energy as well as the highest energy loss, it was able to achieve a higher end energy than group 1 and a higher take-off angle than group 2. Group 2 of the women demonstrated similar attributes during the take-off phase (similar energy loss and transformation index). But because group 2 produced the lowest starting energy they also showed a lower end energy than group 1. It is clear that at this level of competition the starting energy, which is determined by the horizontal velocity at touch down, plays an important role in jump performance. It can not be concluded that the beginning energy alone determines the jump distance. There is a significant ($p<0.05$) correlation between beginning energy and jump distance, but the correlation coefficients for the women ($r=0.57$) and the men ($r=0.54$) are very low.
The transformation index is the quotient of take-off angle divided by energy loss during the take-off phase. There is a relationship between energy loss and the transformation index. The correlation coefficient of the two parameters is $r=-0.91$, $p<0.000$ for both the men's and women's groups. This means that a higher energy loss can be achieved with a lower transformation index. The transformation index also appears to be dependent on the beginning energy. A significant ($r=-0.67$, $p<0.000$ for the men and $r=0-0.63$, $p<0.000$ for the women) correlation between the two parameters was found. With a multiple regression equation it was possible to calculate the relationship between the transformation index and both the start energy and the energy loss during the take-off phase for both the men's and women's groups. In both cases the multiple correlation coefficients were very high ($r=0.94$ for the women and $r=0.91$ for the men). Formula (2) can be altered so that

the distance (W) can be calculated as a function of initial energy and energy loss. Then it is possible to individually diagnose whether the initial energy is effectively used to create the optimal take-off characteristics (Fig. 1). For example, Drechsler has the highest beginning energy and therefore the possibility to jump the farthest. But in comparison to Galkina her take-off phase is not as effective and therefore the jump distance of Drechsler is less than that of Galkina. If Drechsler had an energy loss of about 5.3-5.8 J/kg she could jump 7.22 m with a take-off angle of 18.6-19 degrees. Galkina, in contrast, demonstrates almost optimal take-off characteristics and effectively uses the beginning energy that she produces.
In the men's group Walder had a starting energy of 69.5 J/kg, which would allow him to jump 8.83 m if his take-off was optimal. An optimal take-off for him would be an energy loss of from 7.7 to 8.3 J/kg (Fig. 1) and a take-off angle of 19.25 to 19.60 degrees. Sosunov demonstrated both too much energy loss (jumps 6 and 2) and too little energy loss (jumps 3 and 5) (Fig.1). On his last jump he produced a starting energy of 67.35 J/kg, which in the best case scenario would produce an energy loss of 7.5- 8.1 J/kg, a take-off angle of 19.32 to 19.80 degrees and a jump distance of 8.57.

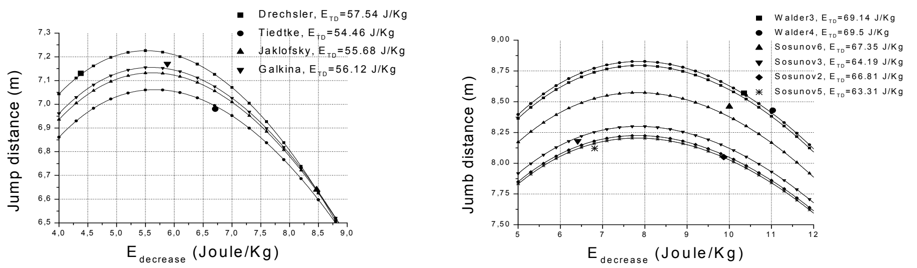

Fig.1: Jump distance as a function of the energy at touch down and energy decrease

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