

The Importance of Horizontal and Vertical Take-off Velocity for Elite Female Long Jumpers

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ABSTRACT

Although biomechanical research on elite long jumpers has increased knowledge about the event, the analyses conducted to date suffer from certain limitations, including small sample sizes and few studies on women. Among issues that are still open are the statistical reliability of findings about the horizontal and vertical components of take-off velocity and whether findings are equally valid for men and women. This study based on the published findings from six major events to give a larger data set, analysed both take-off velocity components with three different statistical criteria for a total of 42 women who jumped between 6.14 and 7.40m. This allowed comparisons of the impact of both components on the results and the possibility to test five hypotheses. Among the findings are a) better jumpers have more than coincidental advantages over others in both the horizontal and vertical components of take-off velocity, with the vertical being much more distinct, b) the ratio of horizontal to vertical take-off velocity differs in the studied athletes from 2.1 to 3.6 and c) excellent jumps can be achieved with very different combinations of the two components, but overall the ratio of more successful athletes is significantly lower.

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Introduction

Problem

For many years, groups of researchers have conducted biomechanical analyses of the athletics events at Olympic Games and IAAF World Championships in Athletics. From this work our knowledge has been greatly increased. In the long jump, for example, the study of world-class performers has helped to determine the vertical and horizontal components of take-off velocity, the factors that produce the biggest differences in the distance achieved. However, studies on elite women long jumpers are rare, which opens the question as to whether the principles apply equally to both sexes. Moreover, a critical analysis of the existing research leads to the conclusion that the single analyses conducted to date by the different groups have led to contradictory results. For example, almost all research

on world-class long jumpers is based on very small samples, because normally only 12 athletes participate in the finals at the major events and only eight have the possibility to jump in all six rounds. Therefore, the requirements for the significance of differences or connections are very high. This leads to mistakes maintaining the null hypothesis “there is no connection” or “there is no difference”.

In an effort to overcome this problem we have adopted a strategy of combining the published data from different studies. Thus, the statistical results are put on a much wider basis. In addition, a comparison of the results for the different finals is possible. For this study we have collected the data on women long jumpers competing in two Olympic Games, three IAAF World Championships in Athletics and one European Cup 1st League Group B. To our knowledge, the use of all this data has not been looked at to draw inferences until now.

In our review of the existing data we found that almost all analysis so far has been limited to the calculation of linear correlations. This is a one-sided choice and there are good arguments for non-linear correlations. In addition, other existing methods can be used to measure the influence of two cause variables, which is clearly important in the long jump. This can lead to divergent as well as more concrete results. Thus, by taking a different strategy in this area, it could become possible to see how the jump distance changes by a comparable altering of the two components and their relative emphasis in a linear combination could become clear.

Starting point

At the beginning of the flight, the trajectory of the centre of mass (CM) is determined by the horizontal (v_{0x}) and vertical (v_{0z}) take-off velocity. However, this is not necessarily the sole determinate for the distance achieved in jumping events, as flight distance is just a part of the equation. The segmentation of the long jump shown in Figure 1 originates from HAY (1978) and was expended by BALLREICH & BRÜGGEMANN (1986).

Neglecting aerodynamic parameters, the flight distance ($W_2 + W_3$) as a function of the three kinematic parameters horizontal (v_{0x}) and vertical (v_{0z}) take-off velocity as well as difference in position of the CM from take-off (h_0) to beginning of touchdown (h_1) can be calculated as an oblique throw. The horizontal component depends on the velocity during the last stride of the approach (v_{An}) and its reduction by the transformation during take-off (D_{vx}). The vertical component depends on the vertical impulse (G_z) and the mass of the athlete (m).

Current state of research

BALLREICH (1979) compared three groups of male long jumpers with significant differences in jump distance and found that both the vertical and horizontal velocity components contribute to the differences in performance. The deficits of the weaker groups are almost identical for both of the cause variables, which means the relative influence of the vertical component is much higher. This leads to disadvantageous relations for both variables and a much lower flight trajectory for the jumpers of the weaker group.

In a group comparison made by ČOŠ et al. (1997), the advantage of the better jumpers also results from a significant plus in both of the velocity components. In this case, the horizontal component at $\Delta v_{0x} = 0.63$ m/sec is nearly double the value of the vertical of $\Delta v_{0z} = 0.34$ m/sec. A standardisation into differences of means leads to almost identical results of 0.90 sd and 0.85 sd.

Correlative statistics for samples with big variations only exist for male long jumpers. In a research by BRÜGGEMANN et al. (1982), flight distance only shows a common variance of 4% with the horizontal, but of 79% with the vertical component. ČOŠ et al. (1997) show a lower dominance of the vertical component of 35 vs. 19%. NIGG et al. (1973) even found out that particularly long jumps depend only on a high horizontal take-off velocity. The value of this result is questionable though, since the sample only consists of 18 jumps by five athletes.

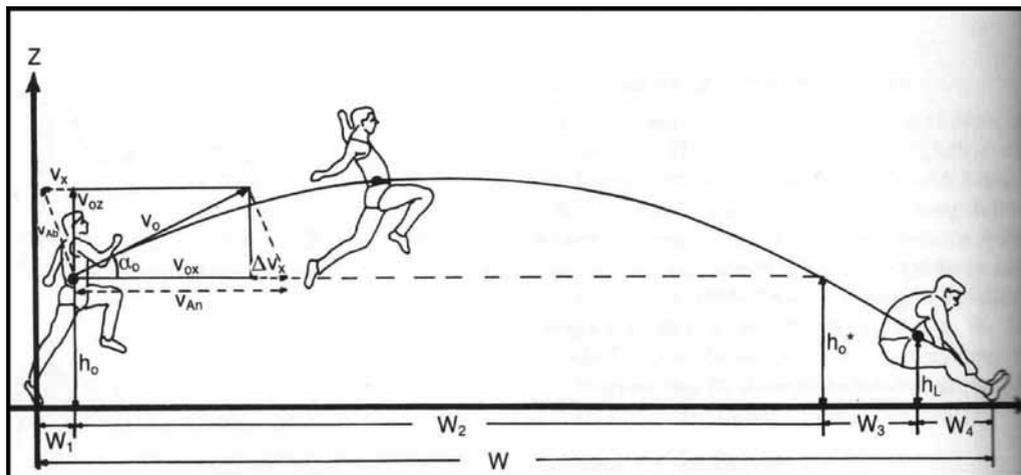


Figure 1: Partial distances of jump distance in the long jump (W): take-off position distance (W_1), symmetric trajectory (W_2), landing flight distance (W_3) and landing position distance (W_4) (BALLREICH & BRÜGGEMANN, 1986)

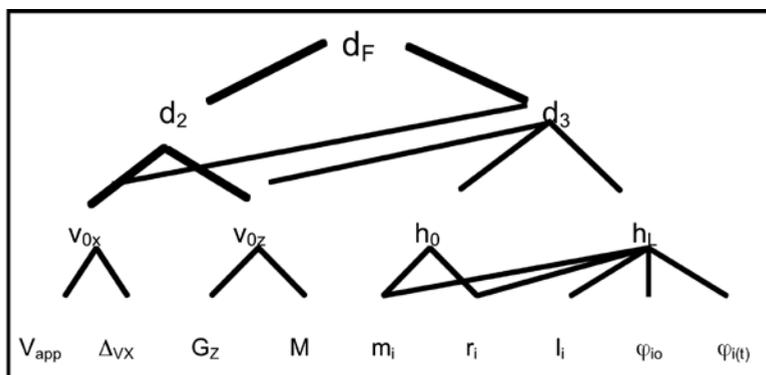


Figure 2: Deductive chain for flight distance as command variable (BURGER, 2000)

KOLLATH (1982) and BALLREICH (1979) have estimated the value of both cause variables with a regression analysis. By variation of parameters with identical absolute values, Kollath has found a higher relevance of vertical take-off velocity in the relation of 1 to 1.4 while Ballreich has altered both independent variables by one standard deviation and found a contradictory relation of 4 to 1. However, his results suffer from the fact that the difference of both standard deviations of ± 0.30 vs. ± 0.04 m/sec is much bigger than in all other studies.

What studies do exist on elite women long jumpers show no evident dominance. Even for $\alpha = 0.10$, all coefficients remain under the random maximum. HAY & MILLER (1994) found relations of $r = 0.3$ and $r = 0.4$ between the two velocity components and effective jump distance for the participants of the 1984 Olympic final ($n = 12$). NIXDORF & BRÜGGEMANN (1988) had $r = 0.55$ and $r = 0.47$ for the top eight of the 1987 IAAF World Championships in Athletics. From these findings it looks like there are great compensational possibilities. In a special analysis, NIXDORF & BRÜGGEMANN (1990) found a wide ratio of both components between 2 to 1 and 3 to 1.

Above average results in both components are very rare or impossible. The more the approach velocity is decelerated at take-off, the more it can be transformed into vertical velocity, which obviously affects the resultant horizontal. In other words, the higher the horizontal take-off velocity, the lower the vertical take-off velocity. TIUPA et al. (1982) present a correlation of $r = -0.66^{**}$.

For elite women long jumpers, many questions remain open. In this article following hypotheses will be statistically reviewed:

- H I:** Horizontal and vertical take-off velocity both are statistically relevant for results.
- H II:** The vertical component is more important than the horizontal.
- H III:** Both components have a negative effect on each other.
- H IV:** The ratio of horizontal and vertical take-off velocity is relevant for results as an optimal trend.
- H V:** There are enormous compensational possibilities. Weaker values in one component can be nullified by higher values in the other.

Methods

Data collection

This documental analysis is based on the data of the long jump finals at the 1984 Olympic Games (HAY & MILLER, 1994), the 1987 IAAF World Championships in Athletics (NIXDORF & BRÜGGEMANN, 1988), the 1988 Olympic Games (NIXDORF & BRÜGGEMANN 1990), the 1997 IAAF World Championships in Athletics (MÜLLER & BRÜGGEMANN, 1998; ARAMPATZIS et al., 1999) and the 2009 IAAF World Championships in Athletics, (MENDOZA et al., 2010), supplemented by the 2006 European Cup 1st League Group B (PANOUTSAKOPOULOS & KOLLIAS, 2007).

By combining these competitions, the size of the whole sample is multiplied by six. For athletes who participated in more than one of these

events, only the best jump is used for the whole sample group ($n = 42$). A mark of 6.00m has been set as the lower limit for consideration. For the variance analysis, the whole group is split up into four performance sub-groups.

Statistics

Because of their functional relation, horizontal and vertical take-off velocities are logically relevant for jump distance. The statistical relevance, indicating that better athletes have significantly higher values, were tested with the following three criteria:

Variance Analysis - A simple variance analysis with subsequent paired comparisons was used. The differences in means were weighed with concrete values and in units of standard deviation. Deviations from the normal distribution were tested with the David method, the homogeneity of variances was tested by the Levene (F_1) method and for dependent samples with the Fergusson t-test. A trend analysis showed if the connection was quadratic, which would be leading to an optimal trend.

Correlation - The connection of both cause variables with the jump distance was first analysed with correlations. These also inform about a higher or lower common variance (r^2). In addition, the linearity of the connection was tested. Since correlation coefficients can't be used to show relations, they are transformed into Fisher's z-values. These were used to test the significance of differences in independent coefficients. The analysis of differences in dependent correlations was done with a special t-test. This was necessary to find out if the connection between horizontal and vertical take-off velocity is significantly different from jumping distance.

Regression Analysis - The regression analysis showed how the jumps change if v_{ox} and v_{oz} are altered by a comparable amount. Usually the standard deviation is comparable. A multiple regression with β -coefficients also produces a weighing of both components. r^2 also informs which ratio of the criteria variance is linked by both cause variables.

Many female long jumpers have also been successful sprinters, for example Heike Drechsler (GER). In these cases we would expect that their horizontal take-off velocity could be very much higher than that of their rivals and that the extreme values would have an enormous influence on small samples. Therefore, every suspected outlier was tested with the Dixon method for $n \leq 25$ and with the Pearson & Hartley method for $n > 25$. Since extreme values are typical for athletics, calculations were made with and without the outliers.

The standards for the significance of statistical measures are very high. A common standard is $\alpha = 0.05$. Since this often leads to unjustified rejections of the null hypothesis, LETZELTER (1986) has suggested that for performance analysis $\alpha = 0.10$ can be used. The statistics textbook by BORTZ (2000) accepts $\alpha = 0.10$. In their analysis HAY & MILLER (1994) have already proceeded along this line. In this report, slightly significant ($p < 0.10$) will be marked with *, significant ($p < 0.05$) with ** and highly significant ($p < 0.01$) with ***.

Results

Comparison of performance groups

The longest jump in the data set was the Olympic record of 7.40m by Jackie Joyner-Kersey

(USA) in the 1988 Olympic Games. The best average for the all the finalists was achieved in the 1987 IAAF World Championships in Athletics. The 10 differences in means differ from $\Delta = 0.04$ to $\Delta_w = 0.22\text{m}$, but all remain under the highest coincidental value ($F = 1.10$). In contrast, the decline in performance was significantly different ($F_L = 4.02^{***}$), with the highest value in the 1988 Olympic Games. The jumps of the 2006 European Cup 1st League Group B, as expected, were significantly shorter than the results in the Olympic Games and IAAF World Championships in Athletics, namely between 0.43 and 0.65m ($t \geq 4.06^{***}$).

The horizontal take-off velocity scatters significantly more than the vertical ($1.79^* \leq t \leq 4.36^{***}$). Therefore, the differences in means, indicated in m/sec, are not comparable. The relative dispersion of $V = \pm 7.0$ to $V = \pm 9.6\%$ for the vertical component is much higher than for the horizontal component of $V = \pm 3.5$ to $V = \pm 5.4\%$. The v_{0x} of 1987 is enormously enlarged by one outlier (Drechsler). However, the six group variances are not significantly heterogeneous ($F_L = 0.93$) and the data does not significantly differ from a normal distribution. The vertical take-off velocities deviate even less ($F_L = 0.43$), with the European Cup Group being much more balanced than all other competitions ($F \geq 4.00^{***}$).

Table 1: Official results of selected groups of elite women long jumpers in major international events

Group	Official Distance (m)			
	min	max	\bar{d}	\pm sd
OG 1984 (n = 8)	6.44	6.96	6.70	0.18
WC 1987 (n = 8)	6.41	7.14	6.92	0.24
OG 1988 (n = 8)	6.47	7.40	6.88	0.36
WC 1997 (n = 8)	6.64	7.05	6.82	0.14
WC 2009 (n = 8)	6.62	7.10	6.80	0.16
ECB 2006 (n = 8)	5.81	6.71	6.27	0.24
all (>6m; n = 42)	6.14	7.40	6.72	0.28

OG 1984 = 1984 Olympic Games, WC 1987 = 1987 IAAF World Championships in Athletics, OG 1988 = 1988 Olympic Games, WC 1997 = 1997 IAAF World Championships in Athletics, WC 2009 = 2009 IAAF World Championships in Athletics, ECB 2006 = 2006 European Cup 1st League Group B

Table 2: Horizontal and vertical velocity at take-off of selected groups of elite women long jumpers in major international events

Group	Horizontal Velocity v_{0x} (m/s)				Vertical Velocity v_{0z} (m/s)			
	min	max	\bar{x}	\pm sd	min	max	\bar{x}	\pm sd
OG 1984 (n = 8)	7.8	8.6	8.20	0.30	2.4	3.1	2.76	0.22
WC 1987 (n = 8)	7.6	9.1	8.15	0.44	2.5	3.2	3.00	0.21
OG 1988 (n = 8)	7.4	8.5	7.85	0.40	2.6	3.5	3.11	0.30
WC 1997 (n = 8)	7.6	8.4	8.09	0.28	2.9	3.5	3.09	0.21
WC 2009 (n = 8)	7.6	8.3	7.91	0.34	2.6	3.5	3.16	0.27
ECB 2006 (n = 8)	7.2	7.9	7.46	0.21	2.3	2.7	2.45	0.11
all (>6m; n = 42)	7.3	8.5	7.89	0.33	2.3	3.5	2.90	0.32

OG 1984 = 1984 Olympic Games, WC 1987 = 1987 IAAF World Championships in Athletics, OG 1988 = 1988 Olympic Games, WC 1997 = 1997 IAAF World Championships in Athletics, WC 2009 = 2009 IAAF World Championships in Athletics, ECB 2006 = 2006 European Cup 1st League Group B

The five means of the horizontal take-off velocity at the Olympic Games and IAAF World Championships in Athletics differ by at most 0.35 m/sec, but because of the big diversion this could be coincidental ($F = 1.31$). The highest value is from the 1984 Olympics, the lowest is from the 1988 Olympics.

In the vertical component, the means differ by up to 0.4 m/sec. This is not coincidental ($F = 2.19^*$). When comparing pairs, only the deficit of 1984 Olympics in contrast to all other groups, except the 1987 world championships is significant. As in the official results, both the means from the 2006 European Cup 1st League are significantly lower than for the five Olympic Games and IAAF World Championships in Athletics ($t \geq 3.7^{***}$).

The means of the results at the Olympic Games and IAAF World Championships in Athletics do not follow the trend “the longer the jump, the higher the take-off velocity”. In fact, the group with the shortest jumps produces the highest average horizontal velocity. For the vertical component, in three cases the ranks are identical, while twice the differences are serious. The rank correlation is illustrated in Figure 3.

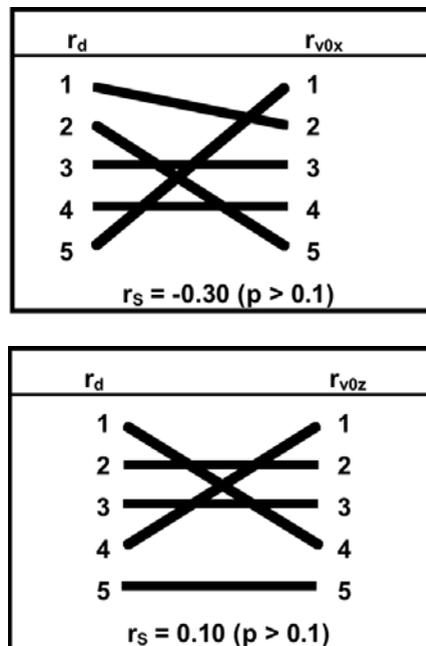


Figure 3: Ranks in official distance (r_d) compared with horizontal (r_{v0x}) and vertical take-off velocity (r_{v0z}) for selected groups of world-class women long jumpers in major international events (1984 Olympic Games, 1987 IAAF World Championships in Athletics, 1988 Olympic Games, 1997 IAAF World Championships in Athletics, 2009 IAAF World Championships in Athletics)

The differences in means for the five finals are relatively small; the results overlap. Between the four performance groups they are much larger. The groups are generated as follows:

**G1: $W < 6.40\text{m}$; G2: $6.40\text{m} \leq W < 6.69\text{m}$;
G3: $6.70\text{m} \leq W < 6.99\text{m}$; G4: $W \geq 7\text{m}$.**

These four groups differ with high significance in vertical take-off velocity ($F = 9.97^{***}$). G1 is more than coincidentally lower than the other three groups. The same is true for G2 being lower than G4. The other two differences are insignificant.

The coherence with jump distance follows a parabolic trend ($F_{\text{quad}} = 3.80$), quantified by $\eta = 0.67^{**}$. The optimum is calculated at 3.17 m/

sec. A higher value must be achieved with too much braking, leading to a disproportionate loss of horizontal velocity. Figure 4 shows the trend curve, which almost perfectly adapts to the four empiric means, as well as the standard deviations. These don't differ significantly ($F_L = 0.72$).

The differences of the four means in horizontal take-off velocity might be coincidental ($F = 2.01$). The paired comparison after the Duncan method shows the deficit of the weakest group to be significant, the more conservative Scheffé method doesn't. The relation with the group at $\eta = 0.38$ is much lower than for the vertical component and also non-linear. There are no heterogeneous variances ($F_L = 0.84$). Because of the missing significance of the differences, the shown parabola is only valid for the sample.

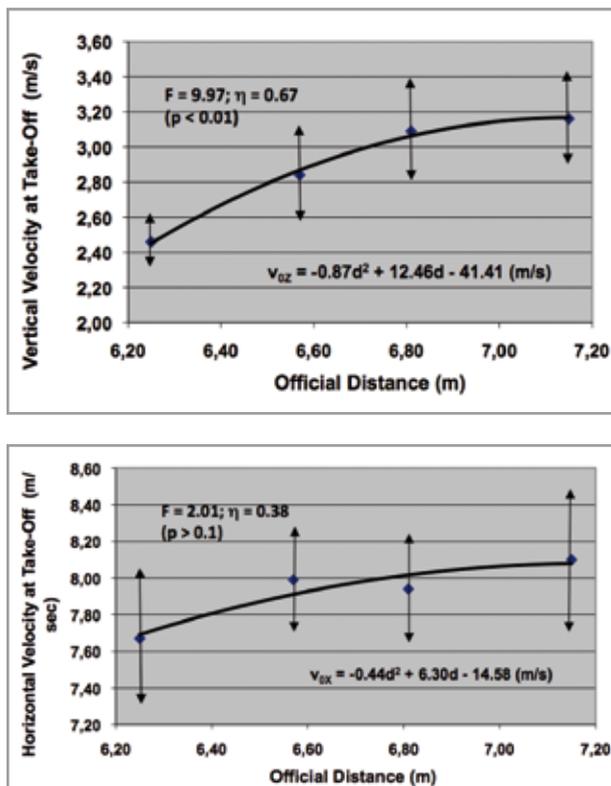


Figure 4: Optimal trend for vertical and horizontal velocity at take-off for four performance groups (G1: $< 6.40\text{m}$; G2: $6.40\text{m} - 6.69\text{m}$; G3: $6.70\text{m} - 6.99\text{m}$; G4: $W \geq 7\text{m}$) for selected groups of elite women long jumpers in major international events (1984 Olympic Games, 1987 IAAF World Championships in Athletics, 1988 Olympic Games, 1997 IAAF World Championships in Athletics, 2009 IAAF World Championships in Athletics, 2006 European Cup 1st League Group B)

Relation of horizontal and vertical take-off velocity and jump distance

Only one of the coefficients for the five Olympic Games and IAAF World Championships in Athletics finals listed in Table 3 is slightly significant. The horizontal component of the 1988 Olympics and the 2009 world championships, as well as the vertical components 1987 and 1997 world championships have no coherence with the jump distance at all if the outlier is included. Without the outlier, the correlation changes considerably. At the 2006 European Cup 1st League, both coefficients exceed the highest coincidental value. We can conclude that the more successful long jumpers take off faster horizontally and vertically.

The results for the complete sample correct the conclusion taken from solitary finals. Forty-seven percent of the differences in jump distance can be explained by those in v_{0z} , but only 10% by those in v_{0x} . The priority of the vertical component is statistically proven, the difference between the two coefficients is not coincidental ($t = 7.0^{***}$). Transformed into Fisher's z'-values this results in impact proportions of 0.83 to 0.32, equalling 2.6 to 1.

If the horizontal take-off velocity increases by 1.0 m/sec, the jump distance is 0.26m

longer. For the vertical component, 1.0m/sec faster means 0.57m longer. The equations for the regression straight lines are: $W = 4.64 + 0.26v_{0x}$ (m) and $W = 5.04 + 0.57v_{0z}$ (m). This also indicates a clear advantage of the vertical component. In contrast to the trend analysis, the connection with the jump distance is linear. The squared approach only leads to a slightly better explanation. A linear combination of both components explains almost two thirds of the criteria variance ($R_{cor}^2 = 0.65^{***}$) with the horizontal and the vertical component contributing $\beta = 0.44$ and $\beta = 0.77$ respectively, making up a relation of 1 to 1.8. In conclusion, all criteria indicate a dominance of the vertical take-off velocity.

As stated above, it is impossible to reach outstanding results in both components. The more of the approach velocity is decelerated, the more can be transformed. The vertical component benefits, the horizontal component suffers. This is statistically confirmed by significant relations. The lowest correlation was found for the 1984 Olympics, but still at $r = -0.60^*$, the highest for the 1997 world championships at $r = -0.76^{**}$. For the whole sample, it was $r = -0.63^{**}$. Long jumpers with 1.0 m/sec more horizontal take-off velocity usually leave the board with a vertical take-off velocity that is 0.5 m/sec lower.

Table 3: Coherence of horizontal and vertical velocity at take-off with official distance for six selected groups of elite women long jumpers in major international events

Group	Horizontal Velocity v_{0x}/d	Vertical Velocity v_{0z}/d
OG 1984	-0.28	0.50
WC 1987	0.49/0.50	-0.01/0.50
OG 1988	0.07	0.62*
WC 1997	0.51	0.06
WC 2009	0.09	0.43
ECB 2006	0.67*	0.73**

OG 1984 = 1984 Olympic Games, WC 1987 = 1987 IAAF World Championships in Athletics, OG 1988 = 1988 Olympic Games, WC 1997 = 1997 IAAF World Championships in Athletics, WC 2009 = 2009 IAAF World Championships in Athletics, ECB 2006 = 2006 European Cup 1st League Group B

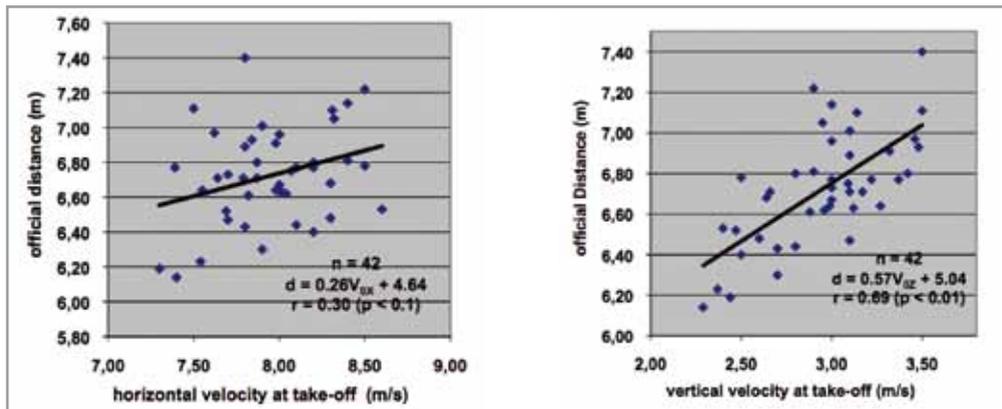


Figure 5: Coherence of horizontal and vertical velocity at take-off with official distance for selected groups of world-class women long jumpers in major international events (1984 Olympic Games, 1987 IAAF World Championships in Athletics, 1988 Olympic Games, 1997 IAAF World Championships in Athletics, 2009 IAAF World Championships in Athletics, 2006 European Cup 1st League Group B)

Regression equations usually produce statistical norms, the residua inform about strengths and weaknesses. In Figure 5, a number of concrete values differ a lot from the straight lines; even some of the best athletes are not compliant. In the 1988 Olympic Games, Joyner-Kersey jumped an Olympic record despite a v_{ox} of 7.6 m/sec. Drechsler placed third in the 1987 IAAF World Championships in Athletics with v_{oz} of 2.50 m/sec. By all means, the standard estimation of error $Se = \pm 0.27$ respectively ± 0.24 (m) has to be taken into account.

Relevance of the horizontal and vertical take-off velocity ratio for performance

For the five Olympic Games and IAAF World Championships in Athletics finals, the means of the ratios differ from $Q; ^- = 2.50$ (2009 world championships) to $Q; ^- = 2.97$ (1984 Olympics). The shortest jump distance goes along with the highest ratio. This is supported by the 2006 European Cup 1st League Group B ratio of $Q; ^- = 3.05$.

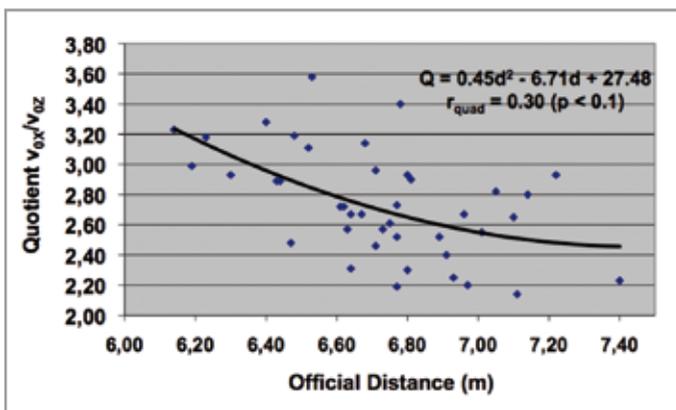


Figure 6: Coherence of ratio and official distance for selected groups of elite women long jumpers in major international events (1984 Olympic Games, 1987 IAAF World Championships in Athletics, 1988 Olympic Games, 1997 IAAF World Championships in Athletics, 2009 IAAF World Championships in Athletics, 2006 European Cup 1st League Group B)

Considering the means of all 42 athletes, for a jump of 6.72m a ratio of 2.73 is the statistical norm. Many female long jumpers vary a lot from that, especially some of the best. Amongst the best jumps of those who jumped over 7m, the span ranges from 2.14 to 2.93, for the best performances of all 42 athletes it ranges from 2.14 to 3.58. Drechsler jumped 7.03m in 1987 with a ratio of 3.64; a year later, a ratio of 2.93 was the foundation of her 7.22m Olympic silver medal performance. With the second lowest overall ratio of 2.17, Joyner-Kersey jumped her Olympic record.

Comparing the four performance groups, the differences are highly significant ($F = 4.8^{***}$). The nonlinear coherence of $\eta = 0.73^{***}$ is very solid. The two better groups are close together, the two weaker ones are significantly inferior.

The results of the group comparison are affirmed by the correlation. With $r_{\text{quad}} = -0.55^{***}$; better female long jumpers by trend have a lower ratio.

Discussion

Discussion of the methods

This report is the result of a documentary analysis. Fortunately, all the CM-velocities used were calculated with the same model. The model is not always indicated, but all authors except HAY & MILLER (1984) originate from the same "school". So the data is comparable although not mistake-free. Possible deficiencies in instrumental consistence might be accompanied by those in performance stability. For example, in two jumps by Carl Lewis (USA) with identical lengths of 8.67m, horizontal take-off velocities of 9.9 and 8.9 m/sec were measured. For a 7.03m leap by Drechsler, a ratio of 3.64 was calculated, while two other jumps of 6.89 and 7.22m both had a ratio of 2.93.

Discussion of the results

The interpretation of the findings is coherent, since various reviews of relevance and priorities have led to similar results.

Better female long jumpers outperform inferior ones mainly because of a higher vertical take-off velocity; not in every single case, but generally speaking. They also have a higher horizontal take-off velocity, but less definite.

In conclusion, **HI** has a higher degree of establishment. The lack of significance in single competitions is a β -mistake, resulting from samples that are too small. A novelty is that the conclusions, unlike in those other studies, are not only based on a single criterion. The importance of the vertical component is affirmed by all three criteria, for the horizontal by all but the variance analysis. Another novelty is that according to the trend analysis, both components follow an optimal trend.

The result confirms $\acute{C}OH$ et al. (1997), who found a difference in both components for two groups of male long jumpers as well as significant coherences and a slight primacy of vertical take-off velocity, although it was not statistically tested.

It also matches the findings of NIXDORF & BRÜGGEMANN (1982) concerning the meaning of the vertical component, but not the horizontal, since the latter is estimated as unimportant by the authors.

Like in the group of male athletes analysed by KOLLATH (1980), in world-class women the variation of the vertical component is more greatly rewarded in performance increase than the horizontal. It does not matter if the variation is shown in absolute values or in standard deviations, since both spreads are almost identical. Thus, **HI** also has a higher degree of establishment.

The advantage of better athletes in the vertical component is significantly larger than in the horizontal.

The findings for the single finals mostly coincide with the overall results, but only in being insignificant. For the 1987 IAAF World Championships in Athletics NIXDORF & BRÜGGE-

MANN (1988) determined $r = 0.55$ and $r = 0.47$. The coefficient for the horizontal component is lower and matches the one published by HAY & MILLER (1986); the coefficient for the vertical is much higher.

H III also passed the confrontation with reality. In the finals, as well as in the whole sample, both components have a negative influence on each other. MENDOZA & NIXDORF (2006) point out the impossibility for men to biomechanically transform such big forces. The coefficients all reside in a very small range and are similar to those found by TIUPA (1982) in a much more heterogeneous group of male athletes.

Outstanding results in both components are impossible. In all analyzed groups the connections are disproportionately negative.

Mostly, better female long jumpers rather have lower ratios. Compared to the horizontal take-off velocity, the vertical is significantly higher. For the resulting quotient, both components produce an optimal trend. In conclusion, **H IV** also has the status of an approved hypothesis. The interval of $2.0 \leq Q \leq 3.0$ mentioned by NIXDORF & BRÜGGEMANN (1990) is not valid for female elite jumpers. It has to be adjusted since even a ratio of 3.5 occurs although in the peak it is an exception.

The extreme individual differences in the ratio of horizontal and vertical take-off velocity as well as the residuals of the values from the regression straight confirm **H V**. Medals can be won with a very high as well as a very low ratio. Athletes with identical values in one or the other component reach different jump distances and vice versa.

Summary

To date, analyses of the horizontal and vertical take-off velocities for female elite long jumpers suffered from very small samples. This problem is solved by combining the data from five Olympic Games/IAAF World Championships in Athletics and one European Cup 1st League Group B. Both components were analysed with three different statistical criteria for a total of 42 athletes who jumped between 6.14 and 7.40m. This also allows comparisons of the impact of both components on the jumps.

Better jumpers have more than coincidental advantages over others in both influencing variables, with the vertical being much more distinct. The ratio of horizontal and vertical take-off velocity differs from 2.1 to 3.6. Excellent jumps can be achieved with very different combinations of both components, but overall the ratio of more successful athletes is significantly lower. It is characterized by an optimal trend.

It is impossible to reach outstanding values in both components since they have a negative influence on each other.

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