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Athens 2004 Olympic 400m hurdles Champion (52.82) Fani Halkia (Greece)

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Louise Mead Tricard

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Estimating the Optimum Angle of Release in the Shot Put Event

Andreas Maistros, Ph.D.

Hays, Kansas USA

Introduction

The objective of shot-putting is to throw a 7.26kg ball as far as possible while following the rules that govern the event. The range of the shot is determined by its conditions at release, that is:
1. velocity
2. height
3. horizontal distance (distance in front or behind the circle), and
4. angle of release.

Changes in the velocity of release will affect the distance thrown more than equal changes in either the angle or height of release (Gregor, McCoy, & Whiting, 1990; Hay, 1985).

Although not so critical as the velocity of release, the angle of release is important (Gregor et al., 1990). Given this property, the estimation of the optimum angle of release to maximize the distance thrown is sought. However, the release of the shot under different angles may affect the:
1. release velocity
2. release height
3. distance of the shot from the front of the board at the moment of release, and ultimately
4. distance thrown

The theoretical optimum angle of release for the shot put event should be between 41° and 43° (Hay, 1985). The estimation of such a theoretical optimum angle is based on mathematical manipulation of the mechanical principles that govern the flight of a projectile. In addition, one basic assumption that is made during the construction of a theoretical model is that there is independence between:
1. angle of release, and
2. velocity of release

As a result, such a model cannot take into account the shot put athletes because they may not be able to produce high velocities at a variety of angles of release.

Presently, analyses of shot put athletes have shown that release angles between 34° and 42° are prevalent (McCoy, 1989, 1990). Given the experimental information that the angle of release athletes use in competition is generally smaller than the theoretical optimum, it is hypothesized that the angle of release influences the velocity of release.

On the other hand, the optimum angle of release could be estimated based on an experimental model that takes into account the relationship at the time of release ("shot distance at release") between the:
1. angle of release and the velocity of release,
2. angle of release and the height of release, and
3. angle of release and the horizontal distance between the shot and the front of the circle

Investigators have examined the kinematic and kinetic variables of the shot put action with no attempt to examine the effect of the release angle on the release velocity. Consequently, the estimation of how throwing at different release angles affects release velocity will aid in further understanding the optimum release conditions of the shot.

It is hypothesized that there is a significant relationship at shot release:
1. between the angle of release and the velocity of release,
2. between the angle of release and the height of release, and
3. between the angle of release and the shot distance.

An experimental model was produced that estimates the optimum angle of release in the shot put event.

Method

The participants were five male collegiate shot putters who used the rotational technique. The characteristics of each participant are shown in Table 1. Participants read and signed a consent form before taking part in the study.

Table 1. Characteristics for each participant.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Height (m)</th>
<th>Mass (kg)</th>
<th>Personal record (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.82</td>
<td>115</td>
<td>17.17</td>
</tr>
<tr>
<td>2</td>
<td>1.84</td>
<td>102</td>
<td>18.24</td>
</tr>
<tr>
<td>3</td>
<td>1.83</td>
<td>105</td>
<td>16.49</td>
</tr>
<tr>
<td>4</td>
<td>1.77</td>
<td>98</td>
<td>15.03</td>
</tr>
<tr>
<td>5</td>
<td>1.80</td>
<td>100</td>
<td>18.08</td>
</tr>
</tbody>
</table>
Filming Procedure. The participant threw from a regulation shot put throwing circle, while being videotaped (120 fps) with a Pulnix high-speed video camera. The camera view was perpendicular to the participant’s throwing arm side when the thrower was facing the direction of the throw. A plumb bob in the background was used during videotaping to identify the vertical axis.

Testing Procedure. For each attempt, the athletes tried to project the shot at an angle within one of the five throwing conditions as follows:
1. At his normal angle
2. Slightly higher than his normal angle
3. Slightly lower than his normal angle
4. Much higher than his normal angle
5. Much lower than his normal angle

Specifically, the athletes were instructed to use angles of release that were approximately five degrees above or below the “normal” angle. However, for the “much lower” and the “much higher” angles the athletes were instructed to throw as low as possible, but never below horizontal, and as high as possible, respectively. From a preliminary investigation it was determined that release angles greater than 60° were extremely unlikely to occur.

The purpose of using the five throwing angle conditions was not to achieve accuracy in the angle of release, but to obtain a wide variety of angles of release. As Bashian, Gavois, & Clark (1982) speculated, it would be naive for anyone to claim that an athlete can purposely throw the shot at a specific angle of release.

Each athlete performed 10 acceptable trials, as suggested by Bates, Dufek & Davis (1992), in each of the five throwing conditions resulting in the filming of a total of 50 throws for each thrower. The throws were “all-out” with the athlete trying to achieve his best performance each time as if he were in a competitive environment.

Since the athletes had to throw a total of 50 throws, testing occurred on five different days (10 throws each day). Only one condition of angle of release was used for each throwing session. For each thrower, the investigator randomly determined the order of each throwing condition beforehand. Foul throws were not analyzed and were repeated. Each throw was measured with a tape to assess the accuracy of the velocity, angle, height and shot distance at release data, obtained from the video records. The throwers practiced the high and low throws in several workouts before the filming session. This took place in an effort to reduce the presumed advantage of throwing near the normal angle as opposed to throwing at the higher and lower angles.

Video Analysis Procedure. To calculate the desired variables, a video analysis system from Peak Performance Corporation was used. The center of the shot was digitized throughout the analysis. The raw coordinate points were smoothed using a zero-lag fourth order recursive Butterworth digital filter with a cutoff frequency set at 6 Hz.

To calculate the velocity and the angle of the shot at release, the horizontal and vertical location of the shot in the air in each of the first eight frames of its path after release was determined. In a method similar to that followed by McDonald and Doppe1 (1991), a straight line was fit to the horizontal position versus time values and a parabola of second derivative equal to \( g = 9.81 \text{ m/s}^2 \) was fit to the vertical position versus time values. Public domain computer subroutines (QR and OVER of the NAPACK package obtained from NETLIB@ORNL.GOV) were used to perform the line and curve fitting procedures. These computer routines estimated the horizontal and vertical velocities at the time of release.

Based on the equations of the line and of the parabola, it was possible to obtain valid estimates of the release variables via the application of basic trigonometry principles.

Statistical Analysis Procedure. To examine whether a significant relationship exists between the angle of release and the velocity of release in the shot put event, the Pearson product moment correlation was used. Correlation techniques were also used to examine the relationships among all the other variables measured in this study.

To obtain the experimental optimum angle of release, simple regression equations of the form, \( Y = bX + a \), were generated, where:
- \( Y \) = the predicted value,
- \( b \) = the regression coefficient,
- \( X \) = the predictor value (here the angle of release), and
- \( a \) = the regression constant.

For each thrower, these equations estimated as a function of the angle of release \( (a) \) the:
- velocity of release \( (v_0) \),
- height of release \( (h) \), and
- shot distance at release \( (d) \)

To estimate the experimental optimum angle of release, a computer routine was used. The routine considered all possible angles of release values, in
decimals of 1/10 of a degree, starting with the value of 45°. For each value of the angle (A), the routine first solved the regression equation for the velocity, the height, and the shot distance at release variables, using the angle as the predictor variable. Subsequently, the routine substituted its values in solving the equation for range (R) as follows (Hay, 1985),

\[ R = \frac{v^2 \sin \alpha \cos \alpha + v \cos \alpha \sqrt{(v \sin \alpha)^2 + 2gh}}{g} \]

where:
- \( v \) = the velocity of release,
- \( h \) = the height of release, and
- \( g \) = the gravitational acceleration.

The value for the distance between the shot and the front of the circle at release was added to (if release took place in front of the circle) or subtracted from (if release took place behind the circle) the value for distance derived from the equation for range. Finally, the routine reported the angle that resulted in the longest range. That angle was assumed to be the experimental optimum angle of release for that particular thrower.

Following, the obtained estimated experimental optimum angles were compared with the angles actually measured and resulted in the longest throw for each thrower.

Simple regression techniques were used to test the agreement between the actual and the experimental optimum angles of release, and also between the actual and the estimated from the experimental model distances. For a perfect agreement between the actual and the predicted values, a correlation of one should be observed with the constant of the regression equation being equal to zero and the regression coefficient being equal to one.

Since it was unlikely for the data to agree perfectly, the regression coefficient was tested against the hypothesis that it was significantly different from one, and the constant was tested against the hypothesis that it was significantly different from zero. To assess the significance of the regression equation itself, the regression coefficient was also tested against the hypothesis that it was significantly different from zero.

Results

Table 2 lists the correlation coefficients among the variables measured in this study based on the data obtained. All release variables were significantly correlated with each other for all participants as follows:

1. There was a significant negative relationship between the velocity and the angle of release. This relationship was essential for this study since it suggests a dependency of the release velocity on the release angle in shot-putting, with higher angles leading to smaller velocities.

2. There was a significant positive relationship between the angle and the height of release. Higher angles lead to higher release heights.

3. There was a significant negative relationship between the distance of the shot at release and the angle of release. Higher angles result in shorter distances between the shot and the front of the circle at release.

4. There was a significant negative relationship between the height of release and the velocity of release. Higher heights of release result in lower release velocities.

5. There was a significant negative association

<table>
<thead>
<tr>
<th>Table 2. Correlations among release variables.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity vs. Angle</td>
</tr>
<tr>
<td>Participant</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

*p<0.01, **p<0.001
between the height of release and the distance of the shot at release. Higher release heights result in shorter distances between the shot and the front of the circle at release.

6. There was a significant positive relationship between the release velocity and the distance of the shot at release. Increased distances between the shot and the front of the circle at release, are associated with higher velocities.

The Regression Equations

Table 3 lists the regression coefficient b and the constant A of the regression equations predicting the release variables from release angle, for each participant. The values of the F statistic and the b coefficient were significant in all equations for all participants.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Velocity</th>
<th>Height</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.35</td>
<td>-0.05</td>
<td>1.64</td>
</tr>
<tr>
<td>2</td>
<td>12.93</td>
<td>-0.05</td>
<td>1.62</td>
</tr>
<tr>
<td>3</td>
<td>13.56</td>
<td>-0.07</td>
<td>1.67</td>
</tr>
<tr>
<td>4</td>
<td>14.02</td>
<td>-0.10</td>
<td>1.59</td>
</tr>
<tr>
<td>5</td>
<td>14.71</td>
<td>-0.08</td>
<td>1.75</td>
</tr>
</tbody>
</table>

The Experimental Optimum Angles of Release

Using the obtained regression equations, the experimental optimum angles of release were generated and are shown in Table 4. The corresponding distances are also shown. The actual angles that resulted in the longest distance thrown along with that longest distance are also shown.

There were no significant differences between the obtained optimum angles and the actually measured ones. The b coefficient was not significantly different from one, t=0.51, P>0.05, and the constant _ was not significantly different from zero, t=0.679, P=0.55. The regression coefficient was significantly different from zero, t=3.71, P=0.034.

The values of the actual distances thrown were similar to those obtained from the experimental data, and no significant statistical differences were observed. The b coefficient was not significantly different from one, t=1.31, P>0.05, and the constant a was not significantly different from zero, t= -1.43, P=0.25. The regression coefficient was significantly different from zero, t=10.49, P=0.0018.

The minimum difference between the actual and the estimated optimum angle was 0.1 of a degree with the maximum difference being 3.1°. In four of the five cases, the optimization models tended to under predict the optimum angle.

Discussion

As expected:

1. a significant relationship was observed between the velocity of release and the angle of release for all the shot-putters tested in this study, indicating a dependency of the velocity of release on the angle of release.

2. Shot-putters experience a decrease in the maximum achievable velocity of release as the angle of release increases.

3. The observed dependency of the velocity of release on the angle of release shows a disagreement between the theoretical optimum angle of release (as

Table 4. Estimated and actual angles of release, estimated and actual distance thrown for each of the participants.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Estimated optimum angle</th>
<th>Actual angle</th>
<th>Estimated distance</th>
<th>Actual distance</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>31.5</td>
<td>33.1</td>
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<td>15.64</td>
</tr>
<tr>
<td>2</td>
<td>33.1</td>
<td>33.0</td>
<td>16.30</td>
<td>16.60</td>
</tr>
<tr>
<td>3</td>
<td>30.1</td>
<td>33.2</td>
<td>15.82</td>
<td>16.14</td>
</tr>
<tr>
<td>4</td>
<td>25.9</td>
<td>28.3</td>
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</tr>
<tr>
<td>5</td>
<td>31.1</td>
<td>32.8</td>
<td>17.04</td>
<td>16.94</td>
</tr>
</tbody>
</table>

Average 30.3 32.1 15.86 16.07 |
derived via the use of mechanical principles) and the actual optimum angle of release (as derived via measurement or the use of experimental models).

4. Consequently, the hypothesis was accepted that the velocity of release is dependent on the angle of release.

If shot-putters were able to project the shot with the same velocity regardless of the release angle, the use of the theoretical optimum angle of release would allow the shot-putter to achieve maximum range. However, biomechanical analyses have suggested that athletes in competition prefer to throw using angles lower or much lower than the theoretical optimum (McCoy, 1989, 1990; Susanka & Stepanek, 1987; Zatsiorsky, 1990).

Generally, shot-putters intuitively choose an angle of release that will maximize loss of velocity while maintaining the angle within "reasonable" levels. Since release velocity is the release variable most dramatically affecting the range of a projectile, it seems wise and logical for the shot-putter to seek an optimum compromise of angle and release velocity.

From a mechanical point of view it may be that as the shot-putter attempts to apply force in an ever-increasing vertical direction, gravity will tend to oppose such an attempt by pulling the shot in the opposite direction. This opposition results in the loss of velocity at the moment of projection.

This biomechanical functional feature is not included in a theoretical model, and the implications of this oversight must be better appreciated. Theoretical models that have been presented (Lichtenberg & Wills, 1978; Maheras, 1994; Shuping & Wangting, 1989), or models suggested for use by athletes (Poole & Bangerter, 1981), are valid only when the velocity of release (Uo) is assumed to be an independent variable and not a function of the angle of release (a). In the shot put event this would be the case if the throwers were able to achieve the same release velocity independent of the release angle.

On the other hand, if the throwers can throw faster at lower angles, as shown in this study, then the optimum release angle can be found using optimization techniques. In this case, the optimum angle of release will be somewhat or considerably smaller than that predicted by a theoretical model based on pure mechanics. The degree to which the angle will be smaller should be thrower specific. Given the above, a theoretical model is not applicable in the shot put event.

Capitalizing on the fact that a theoretical optimum angle of release may not be applicable in shot-putting, this study presented an experimental method to estimate the optimum angle of release in the shot put event, based on data derived from shot put throwing. In four out of the five cases, the optimization technique resulted in values smaller than the actual observed, for both angle and distance data. This difference may be due to the error inherent when employing this type of technique. Also, since the data for the technique was derived using 2D procedures, an error could be introduced if a thrower did not move perpendicularly to the camera.

Except for the significant correlation between the angle of release and the velocity of release, significant correlations were also observed among all the other variables measured in this study (see Table 2):

1. These significant relationships show the interdependency of all release variables during the projection of the shot. The manipulation of one of the release variables will, to a certain degree, affect the other variables too.
2. If the thrower attempts to increase the height of release to be able to project his shot from a more advantageous position, the angle of release will also increase. At the same time, a decrease in velocity will be incurred, along with a decrease in the distance between the shot and the front of the circle.
3. Likewise, a thrower's attempt to increase the velocity of release will be better brought about by a decrease in the release angle which in turn will result in lowering the height of release while there will be an increase in the distance between the shot and the front of the circle.
4. If the thrower attempts to project the shot from a
point as far as possible away from the front of the circle, there will be a decrease in the angle of release with a concomitant decrease in the height of release and an increase in the release velocity.

Since the ultimate concern in shot putting is the distance thrown, success in shot putting will, at least in part, depend upon the successful and optimum compromise of the release variables, particularly the successful compromise between the velocity of release and the angle of release. Likewise, an attempt should be made to examine the potential implications of the effect of release angle on release velocity for the shot-putter, particularly as far as the optimum angle of release is concerned.

In this study, the actually measured angles that resulted in the longest distance thrown were between 28.3° and 33.1° with an average of 32.1°. These angles were considerably smaller than the theoretical optimum angles of 41-43° suggested by Hay (1985). McCoy (1989, 1990) measured release angles that averaged 37.3°. However, all of his participants were elite shot-putters and this may account for the lower range of angles observed in this study where only collegiate shot-putters were used. Indeed, when the subjects were athletes of lower ability (McCoy, 1989), the average measured release angle was 34.6°.

Vigars (1979) stated that during the delivery of the shot the throwing arm is forcefully extended with the shot projected at approximately a 45° angle. Although there was no discussion as to the nature of the approximation, presently, angles of more than 42° should be too great to be suggested as optimum angles of release. Certainly, for the purpose of this study, all shot-putters were able to project the shot at angles greater than 45° but a sacrifice in range was incurred.

Still, a few world-class shot-putters have been reported (Dessureault, 1976; Zatsiorsky, Lanka, & Shalanov, 1981) to have achieved angles of release very close to the theoretical optimum. In this study no association was observed between the athlete's capability, based on his personal record, and his ability to project the shot at higher angles (see also tables 1 and 4). It remains to be seen whether more capable and advanced throwers will be able to consistently achieve higher angles of release.

McWatt (1982) discussed that the observed differences, between theory and practice pertaining to the release angle, should, at least in part, be attributed to the anatomical and physiological character of the shot-putter. He speculated that two techniques might help the shot-putter achieve higher angles of release. He described the first as the shoulder roll. According to this method, the athlete does not push the shot from a purely vertical position, because naturally the trunk bends backwards slightly during the release of the shot, a movement that allows the shoulders to roll into a position that increases the angle of release without changing too greatly the ability of the arm to deliver maximum power.

The second technique described by McWatt (1982) to increase the angle of projection is described as the leg thrust. It is possible that further elevation can occur from a well coordinated forceful upward extension of the legs at the moment of release exactly at the time the arm extends to push the shot. This might add a vertical component to the horizontal component of the arm thrust, thus resulting in the production of a resultant force closer to the theoretical optimum. McWatt (1982) also indicated that it may be that the timing of these two techniques may be critical for further performance enhancement.

Judge (1994) speculated that the shot-putter he analyzed exhibited a lower release angle because there was a difference in bench press strength as opposed to overhead strength. He postulated that more incline bench presses and overhead movements would develop the muscles necessary for a projection close to the theoretical optimum. The same speculation was made by McCoy, Gregor, & Whiting (1989). McWatt (1982) suggested that the angle of the incline bench should be set at approximately 16°.

Conclusions

Given the observations mentioned above and also the results obtained from this study, in shot-putting the velocity of release depends crucially on the angle of release. This phenomenon might be generalized and may lead us to the concept that optimizing release angle and height depends dramatically on how the highest obtainable release velocity is functionally related to these release conditions. The optimum angle of release may be estimated experimentally with the use of applied regression models as shown in this study.

References


Microfiche of typescript, University of Oregon, Eugene, OR.


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Biomechanics Research Team

154 * XVI ITFCA Congress Proceedings