The Effect of the Trajectory of Javelin Thrower's Upper Limb on the Muscles, Ligaments, and Reaction Forces at Elbow Joint

A. A. Mohamed, K. T. Mohamed, E.M. Attia, and T.H. Awad

a Department of Mechanical Engineering, Alexandria University, 21544, Egypt
b Department of Mechanical Engineering, Alexandria University, 21544, Egypt
c Department of Mechanical Engineering, Alexandria University, 21544, Egypt
d Department of Mechanical Engineering, Alexandria University, 21544, Egypt

E-Mail address: mielaraby@yahoo.com (E.M. Attia)

Abstract--Our understanding of athletic and sports injuries, and sports medicine has grown immensely as we have become more aware of the importance of exercise and team sports. With the increased number of sports and games played, the risk of injury and the number of people affected have increased. Athletic injuries can occur when an individual is careless, or not fit enough to undertake sports and games. In some cases people become injured during the use of sports equipment. Athletic injuries result from over stress put on bones or muscles. Most common injuries are soft tissue; muscles, tendons, and ligaments injuries. Also, a dislocation occurs when two bones are jolted apart at a joint and is often accompanied by a ligament tear in the joint. In this study, a three-dimensional dynamic model analysis of the human elbow joint during javelin throw has been developed. The model was used to compare between the muscle, ligament, and reaction forces at the human elbow region of two athletes; a professional one and a beginner. The effect of the trajectory of the thrower's upper limb on the distance and on the muscles forces, ligaments forces, and reaction forces was investigated. The javelin throw distance recorded for the professional subject was as twice as that recorded for the beginner subject. The model results showed that the professional subject mainly depended on the upper limb major muscles to achieve his longer throw, while the beginner subject did not, mainly, depend on these muscles. In summary, identification of root causes, either in techniques or training programs, will minimize injury recurrences. The presented model may help in choosing the right techniques or training programs by which injuries, for human elbow joint, can be avoided or at least can be minimized.

Index Term--Elbow joint; Javelin throwing; Muscle forces

INTRODUCTION

Tennis elbow is term used to identify the pain caused by severe stretching of soft tissues, and injuries due to repeated contractions of muscles connected to the elbow joint. Stress on the elbow is inevitable, because some of the force created whenthrowing the javelin automatically passes into the forearm and then to the elbow. Javelin throw is one of the most common sports that can cause tennis elbow. The repeated throw produces trauma to the tissues surrounding the elbow, leading to inflammation and soreness. Unfortunately, continuation of throwing, with inflammation and soreness, worsens the condition, and makes the elbow 'stiff' as a result of a thickening of the synovium, the lubricating membrane which surrounds the elbow joint. So, there is a serious need to understand and investigate, analyze and model the elbow region during javelin throw studies, in two dimensions like the study of Whiting et al. (1) and in three dimensions like the studies of Bartlett and Best (2) and Best et al. (3).

The main goal of these studies was to analyze high performances. However, there is a lack of literature reporting on kinetics data in javelin throwing event (Bartonietz) (4). The main objective of this study is:

1- To compare between the muscle, ligament, and reaction forces at the human elbow region of two athletes using an EMG verified dynamic model introduced by Adel et al. (5).

2- To investigate the effect of the trajectory of the thrower's upper limb on the muscles forces, ligaments forces, and reaction forces and also, on the distance of throw.

METHODS

2.1. Experiment:

Two javelin throwers participated in this analysis, a professional one and a beginner. Two synchronized numerical video cameras (120 fps) were used to collect the kinematic data during javelin throwing. Processing and analysis, by an inverse dynamics approach, were performed using a motion analysis and modeling software (Adel et al. (5)). Surface landmark were used on the right upper limb of each subject to help in acquiring the kinematic data as shown in table.1 and fig. 1 (Zatorsky, V.) (6)
Each of the throwers performed three throws, which were recorded by the two digital video cameras, adjusted to 120 frame per second, to meet the fast arm motion during javelin throw.

### Table I

**Positions of the Surfaces Marks.**

<table>
<thead>
<tr>
<th>MARK NO.</th>
<th>SURFACE MARK POSITION</th>
<th>MARK NO.</th>
<th>SURFACE MARK POSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The hand center of gravity $G_h$</td>
<td>5</td>
<td>The ulno-humeral joint.</td>
</tr>
<tr>
<td>2</td>
<td>The wrist joint.</td>
<td>6</td>
<td>The upper arm center of gravity $G_u$.</td>
</tr>
<tr>
<td>3</td>
<td>The forearm center of gravity $G_f$</td>
<td>7</td>
<td>The center of the humerus head over the skin.</td>
</tr>
<tr>
<td>4</td>
<td>The radio-humeral articulation.</td>
<td>8</td>
<td>The acromion over the skin.</td>
</tr>
</tbody>
</table>

#### 2.2. Design of Experiment:

The experiment was designed as a block factorial experiment. The independent variable was the subject (technique) while...
the dependent variable was the maximum stress in each of the eighteen muscle segments studied Table II.

2.3. Subjects:
Two healthy male subjects (aged 22 and 21 years), with no history of elbow pain, participated in this experiment. To allow comparison between different techniques, one of the subjects is professional in javelin throw and the other is a beginner. The required anthropometric data of each subject was measured and registered.

2.4. Instrumentation:
1- Two digital video cameras, JVC- GR-DVL9800, were used in collecting the required three-dimensional kinematic data for the dynamic biomechanical model as shown in fig. (2).
2- A Dell Pentium-4 pc equipped with the required software to collect and analyze the kinematic data (WINANALZE Software package).

2.5. Equipment Set-up:
1- Two digital video cameras were positioned perpendicular to each other, equidistant from the javelin thrower.
2- Tripod positioning was established with taping to ensure consistency through the recording sessions.
3- Appropriate zoom magnification was maximizing the portion of the motion to be captured.
4- The environment had maximum lighting available and a background that provided good contrast to the surface landmarks color.
5- Shutter speed was set at 120 frames per second to allow enough light for clear definition of the image.
6- Iris settings were set automatically to correspond with the shutter speed so as to provide the brightest and clearest image.
7- Surface landmarks were fixed on the points of interest on subject as shown in table I and fig. (1) and then videotaped to identify the javelin thrower and to allow the software to recognize the position of the surface landmarks in three dimensions. Activity of the two cameras was synchronized.
8- After the placement of the surface landmarks the throwers were asked to perform one trial to ensure the surface landmarks were seen by the two cameras.
9- Once the previous step was completed, each of the two

![Diagram of the Two Digital Video Cameras System Used in Collecting the Three-Dimensional Kinematics data.](image)

3. RESULTS AND DISCUSSION
There are many variables that affect the javelin travel distance, Jose Campos et al. (7). These factors are:
1- The linear velocity of the javelin during the release moment (Hand’s trajectory).
2- The release position of the javelin; the height of the release point, the angle of the release point, and the angle of attack.
3- The angle of the knee for both stopping leg and supporting leg.
4- The rotation of the pelvis and the shoulder in the horizontal plane.
5- The angle of the elbow joint.
6- The acceleration trajectory; the horizontal distance between the hip joint and the center of gravity of the javelin at the start of the release stride.

In this experiment, only the release stage of the javelin throw was considered. This stage is one of the most important stages that affect the javelin throw. Also, it is the most harmful, for the elbow joint, and the main reason for tennis elbow in this
athletic. The professional subject threw the javelin to a
distance almost as twice as that of the beginner subject in a
smaller period.
Fig. 3-15 show the predicted forces for some muscles and
ligaments and also the reaction forces for some joints. These
forces is predicted by using the mathematical model, for both
the professional thrower (A) and the beginner thrower (B). In
these fig., the horizontal axis represents the throw time (s) and
the vertical axis represents the predicted forces in (N).
The trajectory of the thrower’s upper limb affects the distance
of javelin travel. Also, the trajectory of the thrower’s upper
limb affects the predicted muscles, ligaments, and reaction
forces. Muscle stresses as well as ligament forces and reaction
forces become more reasonable and in-harmful as the upper
limb trajectory become closer to the right trajectory. A device
for training the javelin throwing beginners on the right
trajectory of the world champions was designed by Feras (8).
The performance of two groups of javelin throwers was
compared after three months of training. The first group was
trained on the device and the second group was trained, using
the classical training program. The statistical study of the two
groups showed that the first group had a better performance
than the second.
So, in this study the only factor considered, which affects the
throwing technique, is the trajectory of the hand. A
comparison between the predicted muscle force in the Biceps
Branchii (long head - LH) and (short head - SH) muscles is
shown in fig. 3, 4. This is indicated for a professional subject
“A” and the beginner subject “B”.

Also a comparison between the predicted muscles force in the Brachioradialis and Triceps Branchii (LH) Muscles for subject A
and subject B are shown in fig. 5, 6.
Fig. 5. Brachioradialis
Fig. 6. Triceps Branchii (LH)

Fig. 7, 8. shows a comparison between the predicted muscles forces in the Triceps Branchii (medial head -MH) and (lateral head -LAT. H)), for both subject A and subject B.

A comparison between the predicted forces in the Brachialis and Anconeus muscles is shown in fig. 9, 10 for subject A and subject B.
A comparison between the predicted ligament force in the Anterior Ligament (lateral epicondyle-EL) and (medial epicondyle-EM) muscle for subject A and subject B is shown in fig. 11 and 12.

A comparison between the predicted forces in the Brachialis and Anconeus muscles is shown in fig. 9, 10 for subject A and subject B.

Fig. 11. Anterior Ligament (EM)

A comparison between the predicted reaction force at radio–humeral joint and posterior ligament (EM) joint for subject A and subject B.

Fig. 12. Anterior Ligament (EL)
Also a comparison between the predicted reaction forces at elbow joint for subject (A) and (B) is shown in figure 15.

A statistical study for the professional subject “A” and the beginner subject “B” was performed in table II.
### Table II

**The Mean and Standard Deviation for Muscle, Ligament, and Reaction Forces**

<table>
<thead>
<tr>
<th>No</th>
<th>Muscle</th>
<th>Subject A</th>
<th></th>
<th>Subject B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean (N)</td>
<td>SD (N)</td>
<td>Mean (N)</td>
<td>SD (N)</td>
</tr>
<tr>
<td>1</td>
<td>Biceps Branchii (SH)</td>
<td>172.4</td>
<td>94</td>
<td>147.4</td>
<td>100.9</td>
</tr>
<tr>
<td>2</td>
<td>Biceps Branchii (LH)</td>
<td>179.4</td>
<td>94</td>
<td>147.8</td>
<td>104.7</td>
</tr>
<tr>
<td>3</td>
<td>Brachioradialis</td>
<td>91</td>
<td>53.4</td>
<td>84.4</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>Triceps Branchii (LH)</td>
<td>170.1</td>
<td>113.2</td>
<td>139.6</td>
<td>103.6</td>
</tr>
<tr>
<td>5</td>
<td>Triceps Branchii (MH)</td>
<td>173.5</td>
<td>84.2</td>
<td>143.4</td>
<td>105.9</td>
</tr>
<tr>
<td>6</td>
<td>Triceps Branchii (LAT H)</td>
<td>234.4</td>
<td>129.8</td>
<td>208.9</td>
<td>127.5</td>
</tr>
<tr>
<td>7</td>
<td>Brachialis</td>
<td>336</td>
<td>176.5</td>
<td>336.4</td>
<td>200.8</td>
</tr>
<tr>
<td>8</td>
<td>Anconeus</td>
<td>166</td>
<td>98</td>
<td>181.3</td>
<td>90.1</td>
</tr>
<tr>
<td>9</td>
<td>Supinator</td>
<td>114.6</td>
<td>66.7</td>
<td>104.7</td>
<td>59.3</td>
</tr>
<tr>
<td>10</td>
<td>Pronator Teres</td>
<td>157.4</td>
<td>99.2</td>
<td>167.2</td>
<td>87</td>
</tr>
<tr>
<td>11</td>
<td>Extensor Carpi Radialis Long</td>
<td>143.1</td>
<td>96.1</td>
<td>167.2</td>
<td>102.6</td>
</tr>
<tr>
<td>12</td>
<td>Extensor Carpi Radialis Brevis</td>
<td>120</td>
<td>58</td>
<td>107.8</td>
<td>67.6</td>
</tr>
<tr>
<td>13</td>
<td>Extensor Digitorum Communis</td>
<td>236.6</td>
<td>127.7</td>
<td>226.2</td>
<td>124.1</td>
</tr>
<tr>
<td>14</td>
<td>Extensor Carpi Ulnaris</td>
<td>307.2</td>
<td>153</td>
<td>258.2</td>
<td>137.6</td>
</tr>
<tr>
<td>15</td>
<td>Flexor Carpi Ulnaris</td>
<td>226.2</td>
<td>144.7</td>
<td>245.7</td>
<td>140.7</td>
</tr>
<tr>
<td>16</td>
<td>Flexor Carpi Radialis</td>
<td>86.8</td>
<td>63.4</td>
<td>98.2</td>
<td>57.9</td>
</tr>
</tbody>
</table>

**Table II Cont.**

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>Flexor Pollicis Longus</td>
<td>133.7</td>
<td>81.6</td>
<td>145.4</td>
<td>76.1</td>
</tr>
<tr>
<td>18</td>
<td>Flexor Digit Sublimis</td>
<td>542.7</td>
<td>302.4</td>
<td>488.4</td>
<td>301.2</td>
</tr>
<tr>
<td>19</td>
<td>Anterior Ligament (EM)</td>
<td>4967.5</td>
<td>2847.2</td>
<td>4873.6</td>
<td>2886.3</td>
</tr>
<tr>
<td>20</td>
<td>Anterior Ligament (EL)</td>
<td>5034.7</td>
<td>2812.5</td>
<td>4925.9</td>
<td>2882</td>
</tr>
<tr>
<td>21</td>
<td>Posterior Ligament (EM)</td>
<td>5696.4</td>
<td>2706.6</td>
<td>4274.7</td>
<td>2556.1</td>
</tr>
<tr>
<td>22</td>
<td>Posterior Ligament (EL)</td>
<td>4694.8</td>
<td>2908</td>
<td>4318.8</td>
<td>2836.7</td>
</tr>
<tr>
<td>23</td>
<td>Radial Collateral Ligament</td>
<td>3873.2</td>
<td>3040.2</td>
<td>4692.1</td>
<td>3081.9</td>
</tr>
<tr>
<td>24</td>
<td>Ulnar Collateral Ligament</td>
<td>4828.2</td>
<td>3210.4</td>
<td>5649.1</td>
<td>3193</td>
</tr>
<tr>
<td>25</td>
<td>Total Resultant Contact Force</td>
<td>874.1</td>
<td>371.2327</td>
<td>859.014</td>
<td>399.6358</td>
</tr>
<tr>
<td>26</td>
<td>Radio-humeral Contact Force</td>
<td>97.3676</td>
<td>30.356</td>
<td>92.0981</td>
<td>28.0177</td>
</tr>
<tr>
<td>27</td>
<td>Elbow Contact Force</td>
<td>863.4682</td>
<td>354.7289</td>
<td>878.6436</td>
<td>376.3558</td>
</tr>
</tbody>
</table>
The statistical results in table II can be divided into four groups:

In the first group: (Biceps Branchii (SH), Biceps Branchii (LH), Triceps Branchii (MH), Extensor Carpi Radialis Brevis, Anterior ligament (EM), Anterior ligament (EL) and Total resultant contact force), the statistical results show that the mean force is greater for subject “A” than that for subject “B”, but the SD for subject “A” is smaller than that of subject “B”. In the second group: (Brachialis, Extensor Carpi Radialis Long. Radial Collaterl Ligament and Elbow contact force), the statistical results show that the mean force and SD are smaller for subject “A” than that for subject “B”.

In the third group: (Anconeus, Pronator Teres, Flexor Carpi Ulnaris, Flexor Carpi Radialis, Flexor Pollicis Long and Ulnar Collateral Ligament), the statistical results show that the mean force is smaller for subject “A” than that for subject “B”, but the SD for subject “A” is greater than that of subject “B”. The last group: (Brachioradialis, Triceps Branchii (LH), Triceps Branchii (LAT H), Supinator, Extensor Digitorum, Extensor Carpi Ulnaris, Flexor Dgit. Sublimis, Posterior Ligament (EM), Posterior Ligament (EL) and Radio-humeral contact force), the statistical results show that the mean force and the SD are greater for subject “A” than that for subject “B”.

During the release stage of the javelin throw, the motion of the upper arm is almost abduction followed by adduction for a very short period. Each of the abduction and adduction of the upper arm are accompanied with medial rotation at the shoulder joint. Also, the motion of the forearm is extension for most of the time of this stage and flexion for a very short period.

The forearm is in the normal position when it is flexed, and supinated when it is extended. The motion of the hand is extension followed by flexion at the wrist joint. The flexion-extension motion of the hand is accompanied with abduction for the most stage time followed by adduction at the wrist joint.

It was expected, from the arm motion, that the mean muscle, ligament, and reaction forces of the first and last results groups will be greater for subject “A”. This expectation is based on the knowledge that the release stage of the javelin throw is mainly achieved by the muscles included in these groups. Most of these muscles are the major supinators and extensors of the forearm (An et al. (9)). Also, these groups included the extensors and abductors of the hand (Brand et al. (10)).

The javelin throw distance recorded for subject “A” was as twice as the recorded for subject “B” within a shorter time. At the start and the end of this stage, the forearm strongly extends causing high force in the anterior and posterior ligaments leading to higher contact force in the radio-humeral joint and total resultant contact force. Also, the force in the muscles which abducts and extends the hand at the wrist joint is higher for subject “A”. For most of the time of javelin release stage, the hand is strongly extended and abducted causing higher forces in the hand abduction and extension muscles at the wrist joint. The standard deviation (SD) for the first and the second groups of the statistical results is smaller for subject “A” than that for subject “B”. The chance for rupture in the muscles and ligaments included in these groups is smaller for subject “A” than that for subject “B”. On the other hand, the mean muscle, ligament, and reaction forces for the second and the third groups are smaller for subject “A” than that for subject “B”. Two muscles of these groups; Flexor Carpi Ulnaris and Flexor Carpi Radialis are used to flex and abduct hand at wrist joint. The activity of these muscles may have small effect in the release stage of javelin throw, because the activity of these muscles increases only in the last moment of javelin release. The action of Flexor Pollicis Longus muscle is to flex the phalanges of the thumb. The activity of this muscle depends on how much tight the thrower catches the javelin. The Anconeus muscle assists the Triceps in extending the forearm and abducts the ulna during pronation. Therefore, the force produced by this muscle increases either in the case of weakness of the Triceps or at high resistance loads. Since subject “A” gave his upper limb the right trajectory, the second and the third muscle groups had small forces. Also, the force in the ulnar collateral ligament and radial collateral ligament is smaller for subject “A” than that for subject “B”.

For all cases the reaction forces at the radio-humeral articulation, humero-ulnar articulation and the total joint did not exceed the maximum value estimated or measured in previous studies of Aims et al (11, 12, and 13) and Breme et al. (14).

4. CONCLUSIONS

The previous results indicate the effect of the trajectory of the arm during the release stage of the javelin. It was observed that the muscle, ligament, and reaction forces differ with the change of the arm trajectory. This may help us to choose the right trajectory, using the model, which minimizes the injuries. Also, this helps us in the design of instructional devices for better athletics performance. The model results showed that the professional subject mainly depended on the upper limb major muscles to achieve his longer throw, while the beginner subject did not, mainly, depend on these muscles. In summary, identification of root causes, either in techniques or training programs, will minimize injury recurrences. The presented model may help in choosing the right techniques or training programs by which injuries, for human elbow joint, can be avoided or at least can be minimized.

REFERENCES

[6] Zatorsky V., “The mass and inertia characteristics of the main


