A Motion Analysis Study Describing the Kinematics of the Curling Delivery

Sam Harms
University of North Dakota

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A MOTION ANALYSIS STUDY DESCRIBING THE KINEMATICS OF THE CURLING DELIVERY

by

Sam Harms
Bachelor of Science in Physical Therapy
University of North Dakota, 1999

An Independent Study
Submitted to the Graduate Faculty of the
Department of Physical Therapy
School of Medicine
University of North Dakota
in partial fulfillment of the requirements
for the degree of
Master of Physical Therapy

Grand Forks, North Dakota
May
2000
This Independent Study, submitted by Samuel P. Harms in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

(Faculty Preceptor)

(Graduate School Advisor)

(Chairperson, Physical Therapy)
PERMISSION

Title A Motion Analysis Study Describing the Kinematics of the Curling Delivery

Department Physical Therapy

Degree Master of Physical Therapy

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Signature

Date 12-17-79
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ACKNOWLEDGMENTS

I would like to extend my extreme thanks to Dave Relling for his participation in this study. Without his willingness to learn and explore new areas of research, this study would never have been completed. In addition, I would like to thank the University of North Dakota Physical Therapy Department faculty and staff for everything they have done for me over the past three years. My classmates and roommates from the “LiteHouse” deserve acknowledgement for their support and companionship throughout my college career. Finally, my greatest appreciation goes out to my parents, who deserve all the credit for my accomplishments. They taught me that through hard work and perseverance anything is possible.
ABSTRACT

**Background and Purpose:** In 1998, curling was awarded medal status in Olympic competition, and since then, the popularity of the sport has dramatically increased. This has led to increased skill level and competition among curlers. However, there is currently limited research analyzing the curling delivery. The purpose of this study is to provide scientific information explaining delivery characteristics of curlers while executing draw and take-out shots. This study concentrated on the force generators within the delivery and the mechanisms used to control and determine weight. **Methods:** Three healthy subjects participated in this motion analysis study. Subjects were video taped completing three successful draw and three successful take-out shots using their normal curling delivery. Eighteen successful deliveries were analyzed in this study. An independent t-test was used for analyzing the means of rock height, subject COG linear velocity, and rock linear velocity. In addition, a visual comparison of angular velocities occurring at the hip, knee and ankle was made between draw and take-out deliveries. **Results:** When comparing the two deliveries, two of three subjects showed significant increases in rock height and rock linear velocity. No subjects showed significant increases in COG linear velocity. Two subjects seemed to show large increases in angular velocities when comparing the deliveries. **Conclusion:** No one consistent method of weight control was used by the three subjects, and weight control seems to be due to individual preference.
CHAPTER I
INTRODUCTION

After four appearances in the winter Olympics as a demonstration sport, the United States Curling Association and curlers around the world were beginning to question if the world’s most dominant teams would ever be awarded medals for their achievements in Olympic competition. Finally, in July 1992 curlers received their wish. Curling was approved to participate in the 1998 winter Olympics as an official medal sport. Gaining medal status did not get the same attention as women's hockey or snowboarding for their debut as a medal sport, but to the estimated 1.5 million people in thirty-three countries who participate in the sport of curling the events were equally important.

Curling described by Brian Carr, CBS SportsLine Senior Editor, as "Take the strategy of chess, the precision of bowling and the finesse of billiards. Add a dash of shuffleboard and put on gloves and a hat." It is generally agreed upon that curling originated in Scotland in the 16th century where Scottish farmers curled on frozen marshes using "channel stones," which were naturally smoothed by the water. Throughout the last 300 years the principles of the game have remained similar however the rules, equipment and skill level have changed tremendously.

Scottish immigrants introduced the game to North America first in Canada in 1759 and later to the United States in 1832. Since the 1850's, curling has thrived in the
northern states including: Wisconsin, Minnesota and North Dakota. In all there are twenty-six states in the nation with active curling clubs and it is estimated there are over 15,000 curlers in the United States and 1.5 million world wide.\textsuperscript{3}

In Nagano Japan the United States finished fourth and fifth in the men's and women's divisions respectively in the eight country field with Switzerland and Canada winning the gold medals.\textsuperscript{4,5} With the popularity of the sport increasing and now possessing medal honors in Olympic competition, research must be done to increase the understanding of the game and the overall skill level of U.S. Olympic curlers. This research will keep U.S. curlers competitive with other countries as the sport enters the new millennium.

The United States Curling Association (USCA) and the United States Olympic Committee (USOC) offer many teaching schools and programs each year to improve performance in an attempt to enable the United States to remain competitive with other countries. It is this effort by the USCA and USOC to improve performance that a biomechanical investigation of the curling delivery was considered important and timely.

**Problem Statement**

Few scientific investigations of the curling delivery have been reported in the literature. Weyman and Watson published the earliest work explaining delivery mechanics.\textsuperscript{7} In 1979 Holt and Alexander attempted to apply biomechanical techniques to the study of the curling delivery, and in 1982 Constance Marie Bothwell-Myers published the most recent study explaining the mechanics of the curling delivery.\textsuperscript{7} However, the fact remains that in 1999 little research has been completed to explain the kinematics of the curling delivery.
Purpose of Study

The purpose of this study is to provide scientific information explaining delivery characteristics of experienced curlers while executing draw and take-out shots. Such information can be used to reaffirm current ideas, beliefs and practices related to the mechanics of the curling delivery, improving the overall skill level of competitors.

Significance of Study

The significance and need for the study was supported by the little research completed and the desire of the researcher to explore questions which have emerged from a review of the literature and the researcher’s active participation in the sport of curling. The intent of this study is to provide a better understanding of the mechanics of the curling delivery. This will allow coaches to make adjustments based on research, optimally improving performance of curlers.

Research Questions

The two research questions most important to the investigator relate to the forces generated during the forward propulsion of the curling delivery.

1. What mechanisms do curlers use to control and determine weight while delivering the stone?
2. Are the mechanics of the curling delivery similar for draw and take-out shots?

Hypotheses

H_0 1: There is no significant difference in the height the rock is lifted off the ice when comparing draw and take-out trials of individual subjects.
$H_a$ 1: There is a significant difference in the height the rock is lifted off the ice when comparing draw and take-out trials of individual subjects.

$H_o$ 2: There is no significant difference in the linear velocity of the center of gravity (COG) of the subject when comparing draw and take-out trials of individual subjects.

$H_a$ 2: There is a significant difference in the linear velocity of the COG of the subject when comparing draw and take-out trials of individual subjects.

$H_o$ 3: There is no significant difference in the rock velocity when comparing draw and take-out deliveries of individual subjects.

$H_a$ 3: There is a significant difference in the rock velocity when comparing draw and take-out deliveries of individual subjects.
CHAPTER II
LITERATURE REVIEW

Almost nothing in the world of sports remains constant. New equipment, techniques and rules are constantly being added to improve the sport as a whole. The sport of curling is no different. Changes in equipment, techniques and facilities have been made to help gain mastery of the game. Throughout this chapter pertinent information regarding the curling delivery and most specifically the source of forward propulsion of the curler from the hack will be discussed.

Curling which began on frozen rivers and lakes, and participants used primitive brooms to clear snow from the path of the sliding stones. To the modern version, which is played on refrigerated ice to assure consistency, and brooms are used to control the weight and direction of the curling stone. However, the most dramatic change the game has seen involves the delivery of the curling stone. The delivery has changed from one of a stationary position to the modern technique of sliding a distance of approximately thirty feet. Bothwell-Myers describes the stationary delivery as, "The curler stood on the plate and delivered the stone from a stationary, crouch position with either a pushing motion or a side arm swing." It was not until the introduction of the hack that the first sliding delivery was noticed. The hack allowed solid footing and the ability for curlers to use a higher arc on their back swing. This increased the velocity of
the downswing, eventually pulling the curler out of the hack; hence, initiating the start of the slide delivery. Curlers soon realized reducing the friction between the ice and the sliding foot would lengthen the slide and bring the curler closer to the target before releasing the stone, improving their overall accuracy.7 Today, the slide delivery predominates and the growing interest in the sport, especially among the young, is often credited to the attraction of the long slide delivery.

The curling delivery is described in four different components: 1) stance, 2) backswing, 3) downswing, and 4) slide and follow-through.8 For this study the backswing and downswing are of particular interest. It is within these two components where curlers' forward propulsion appears to be generated. The question remains, how is this force generated?

In reviewing the literature, there seems to be somewhat of a disagreement as to the method curlers' use to control weight or forward propulsion. As defined by Mark Mulvoy,8 "Weight is the amount of force, or momentum, on the stone as it moves down the ice." One theory claims weight control is determined by the height of the curler's backswing during the delivery. For example, a curler may take a long, high backswing for a take-out shot, or a shorter, lower backswing for a draw shot.8 The higher the backswing the more stored potential energy available to deliver the rock, increasing the overall velocity of the rock. Roy Thiessen, author of Curling Handbook, follows the backswing theory of weight control.9 He states, "The primary function of the backswing is to provide appropriate momentum to successfully complete the forward swing and thus execute the desired shot."
In contrast, Ernie Richardson\textsuperscript{8} uses a different method of weight control. He states, "I prefer to depend on my leg drive as a gauge for weight." This method of using the leg drive for weight control is expressed in \textit{Curling to Win} as well.\textsuperscript{10} However, this literature discusses different methods of weight control for draw and take-out shots. As explained for take-out shots,\textsuperscript{10} "The speed of the slide is direct and forceful with a strong leg drive." Where as for draw shots, "The speed of the delivery is slower with the weight coming more from the stone and less from the leg drive."

A third theory addressing a method to control the momentum or forward propulsion of the curler from the hack involves the use of friction.\textsuperscript{7,10} Ed Werenich uses friction to make adjustments during his delivery. He applies pressure through his trailing leg to slow the velocity of his delivery and rock.\textsuperscript{10} Bothwell-Myers, author of \textit{Kinematic Characteristics of the Curling Delivery}, found the release point of the stone in the delivery as the predominant weight control mechanism. This would seem to support Ed Werenich's method of weight control.\textsuperscript{7} Bothwell-Myers found the release point for a draw shot was 1.66 meters longer than a take-out shot. In other words, curlers use this extra distance to decelerate themselves and the stone allowing execution of proper weight.

In contrast to the theory, which uses the height of the backswing to control weight, Bothwell-Myers found the height of the backswing to be similar for draw and take-out deliveries. She attributes rock and center of mass momentum to a combination of factors: (a) acceleration during the downswing, (b) forward displacement of the center of mass during the downswing, and (c) hack knee extension during the leg drive phase.\textsuperscript{7} In addition, the subjects generated approximately seven times more rock force while
leaving the hack than necessary for a takeout shot and about ten times more force than necessary for a draw shot. Without a doubt, these forces are generated to overcome forces of friction during the glide phase, which in turn, seems to support the theory that weight is controlled or adjusted by varying the release point during the glide phase of the curling delivery.

With the findings that weight control occurs by varying the release point in the glide phase of the delivery, there tends to be no differences in the stance, backswing, and downswing aspects of the curling delivery when comparing take-out and draw shots. These findings concur with Bothwell-Myers in that the pattern of acquisition of momentum is similar for draw and take-out deliveries and differences relate to individual preferences.

In review, there seems to be three predominant methods of weight control: varying the height of backswing, altering the release point, and increasing leg drive to increase forward momentum. Therefore, the researcher performed this study to reaffirm current ideas, beliefs and practices associated with methods to acquire forward momentum in the curling delivery.
CHAPTER III

METHODS

Subjects

Due to the limited number of experienced curlers available, subjects were asked to participate in the study by the researcher. Each subject was informed they were participating on a volunteer basis and information gained from their participation would benefit the sport of curling. Three experienced curlers agreed to participate in this study. In order to participate in the study, each subject was required to deliver the curling stone with a "leg drive and slide" delivery.

The subjects were between the ages of 21 and 40 (Table 1). Prior to data collection subjects completed a prescreening questionnaire (Appendix B). The questionnaire identified previous injuries or complications that would put them at risk or interfere with the results of this study. The subjects were informed of the purpose of this study and their rights as human subjects. All subjects signed a consent form approved by the Institutional Review Board at the University of North Dakota (Appendix B).

Instrumentation

The collection of data involved the use of four PULNix video cameras (Appendix C) with optional 60/120 Hz scanning frequencies. Due to the relatively slow speed of the curling delivery the 60 Hz setting was used in this study. The master camera (camera #1) was placed perpendicular to the sagittal plane approximately twenty feet to the subjects'
left and slightly behind the hack (Figure 1). Camera #2 was placed directly opposite camera #1 (Figure 2). Therefore, viewing the markers placed on the subjects’ right. Cameras #3 (Figure 2) and #4 (Figure 1) were placed near each hog line on adjacent sheets and were directed at approximately 45° to the frontal plane.

Table 1. Subject Characteristics (n=3)

<table>
<thead>
<tr>
<th></th>
<th>AVERAGE</th>
<th>RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGE (years)</td>
<td>29</td>
<td>21-40</td>
</tr>
<tr>
<td>HEIGHT (inches)</td>
<td>69</td>
<td>64-71</td>
</tr>
<tr>
<td>WEIGHT (pounds)</td>
<td>168</td>
<td>130-205</td>
</tr>
<tr>
<td>GAMES/PRACTICES (per week)</td>
<td>6</td>
<td>4-7</td>
</tr>
<tr>
<td>CURLING EXPERIENCE (years)</td>
<td>19</td>
<td>11-30</td>
</tr>
</tbody>
</table>

Video information was subsequently recorded on tape using a JVC Model BR-S378U S-VHS VCR (Appendix C). After recording each individual trial, the video taped data was transferred via a Sanyo Model GVR-S955 SVHS VCR and a Sony Trinitron Color Video Monitor to the PEAK Technologies System. Analyzing the video data was completed using the PEAK Technologies System equipped with the Peak Motus software version # 4.3.1. The PEAK 25 point calibration frame was recorded prior to video data collection giving a reference to position in space for data analysis by the PEAK Technologies System (Figure 2).
Figure 1. Photographic set-up showing cameras 1 and 4

Figure 2. Photographic set-up showing cameras 2, 3 and the PEAK calibration frame
Procedure

Data collection took place at the Grand Forks Curling Club located in Grand Forks, North Dakota. Permission to use this four sheet facility was granted by the club president for March 25, 1999. The experimental protocol for this study required each subject to complete 3 successful out-turn draw shots and 3 successful out-turn take-out shots. In order to be considered a successful draw shot the stone must come to rest inside the house. For take-out deliveries, a target stone was placed on the intersection of the centerline and t-line. In order to be a successful take-out delivery, the curler had to deliver a stone with enough force and accuracy to remove the target stone from play. Subjects were informed to use their normal deliveries and to choose their own line of delivery to complete the shot required. It should be noted that the speed of the ice during data collection was approximately 22 seconds (measured from near hog-line to far t-line).

Subjects were scheduled upon their availability on the day of data collection. Upon arrival subjects were informed of the data collection procedure and asked to read and sign the consent form as explained previously. Subjects were allowed to warm-up until comfortable using their normal curling delivery to complete the shots required.

To improve reliability of marker placement and digital analysis, subjects wore black lycra on their lower extremities. Reflective markers were placed bilaterally on the subjects on the following landmarks (Figure 3): fifth metatarsal head, calcaneous (level to the fifth metatarsal head), lateral malleolus, mid shaft of the tibia, lateral aspect of the knee joint line, greater trochanter, iliac crest (70% of the distance from the S2 vertebral level and the ASIS), and S2 on the sacrum. In addition a marker was placed on the curling stone to allow tracking throughout the delivery.
A total of twenty-one deliveries were recorded for analysis. However, only successful deliveries were of interest in this study meaning that eighteen were used in data analysis. An average of 3.7 and 3.3 deliveries were required to complete the draw and take-out series of shots respectively.
Data Analysis

Analysis of the eighteen deliveries was completed using the Microsoft Excel 2000 Statistical Package. An independent t-test was used for analyzing the means of rock height, subject COG linear velocity, and rock linear velocity.
CHAPTER IV

RESULTS

Due to the small sample size, data for the draw and take-out deliveries are compared within each subject or individually. Results are based on the means for the three successful draw deliveries and three successful take-out deliveries. Independent t-tests were used in determining the results of the study with an alpha level of 0.05.

The maximal height of the backswing was compared between draw and take-out deliveries. Subject #1 shows a mean back swing of 0.18 m for a draw delivery and 0.56 m for a take-out (Table 2). This difference in rock heights between draw and take-out deliveries was found to be significant (P=0.003). Subject #2 shows a mean backswing height of 0.09 m for the draw and 0.09 m for the take-out delivery (Table 3). These results did not prove to be significant (p=0.619). Subject #3 displays a mean backswing of 0.11 m for a draw delivery and 0.22 m for a take-out proving to be significantly different (P=0.008) (Table 4).

Table 2. Subject #1 Rock Height

t-Test: Two-Sample Assuming Equal Variances: SUBJECT #1 Rock Height

<table>
<thead>
<tr>
<th></th>
<th>Draw</th>
<th>Take-Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.18</td>
<td>0.56</td>
</tr>
<tr>
<td>Variance</td>
<td>6.223E-05</td>
<td>0.01</td>
</tr>
<tr>
<td>df</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.003</td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Subject #2 Rock Height

<table>
<thead>
<tr>
<th></th>
<th>Draw</th>
<th>Take-Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>Variance</td>
<td>0.0005</td>
<td>4.34887E-06</td>
</tr>
<tr>
<td>df</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.62</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Subject #3 Rock Height

<table>
<thead>
<tr>
<th></th>
<th>Draw</th>
<th>Take-Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.11</td>
<td>0.22</td>
</tr>
<tr>
<td>Variance</td>
<td>0.0008</td>
<td>0.0007</td>
</tr>
<tr>
<td>df</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.009</td>
<td></td>
</tr>
</tbody>
</table>

The subjects' COG linear velocity, defined as movement of the sacral marker, was analyzed for differences between the two deliveries. Sacral linear velocities were calculated based on the last 10% of the filmed video frames. This is commonly termed as the push-off phase with the end of filming representing the subjects' stance leg leaving the hack and becoming the trailing extremity. Subject #1 displayed a mean sacral velocity of 2.21 m/s for draw deliveries and 2.14 m/s for take-outs (Table 5). This difference in COG velocities was not found to be significant (p=0.824). In fact this particular subject leaves the hack with greater COG velocities for draws when compared to take-outs. In Table 6, Subject #2 shows a mean sacrum velocity of 1.88 m/s for draw deliveries and 2.17 m/s for take-outs, also proving to be insignificant (p=0.061). In addition, subject #3 displays no significant difference in COG velocities when comparing
draw and take-out deliveries (Table 7). Subject #3 shows a mean velocity of 1.18 m/s for
draws and 1.54 m/s for take-outs (p=0.767).

Table 5. Subject #1 COG Linear Velocity

<table>
<thead>
<tr>
<th>Draw</th>
<th>Take-Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.21</td>
</tr>
<tr>
<td>Variance</td>
<td>0.19</td>
</tr>
<tr>
<td>df</td>
<td>4</td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.82</td>
</tr>
</tbody>
</table>

Table 6. Subject #2 COG Linear Velocity

<table>
<thead>
<tr>
<th>Draw</th>
<th>Take Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.88</td>
</tr>
<tr>
<td>Variance</td>
<td>0.002</td>
</tr>
<tr>
<td>df</td>
<td>4</td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Table 7. Subject #3 COG Linear Velocity

<table>
<thead>
<tr>
<th>Draw</th>
<th>Take Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.18</td>
</tr>
<tr>
<td>Variance</td>
<td>1.95</td>
</tr>
<tr>
<td>df</td>
<td>4</td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.77</td>
</tr>
</tbody>
</table>

In addition to analyzing center of gravity linear velocity throughout the different
deliveries, it is also necessary to observe the angular velocities occurring at the hip, knee
and ankle of the stance lower extremity. For reporting this portion of the results,
individual angular velocities were estimated visually from the graphs displayed in the
corresponding figures. Generalities seen within or between subjects will be reported. However, no statistical analysis for numerical comparison can be accurately determined. Also, graphs show some excessive points throughout and are probably due to limitations within the photographic equipment and software used. These points were considered outliers and are not used in determining the results.

In comparing angular velocities of the lower extremity of subject #1 for draw (Figure 4 in Appendix A) and take-out deliveries (Figure 5 in Appendix A) there are slight differences noted. Focusing on the hip angular velocity from a general perspective the subject shows maximal push-off (hip extension) occurring at approximately 90% of the filmed delivery for draw shots. However, maximal hip angular velocity into extension for take-out deliveries occurs around 85% of the filmed delivery. Not only does there seem to be a difference in timing of hip motion, this subject seems to elicit a slight increase in hip angular velocity into extension (~140 degrees/sec) for draw deliveries when compared to take-out deliveries (~100 degrees/sec). Knee angular velocity for subject #1 seems to show an earlier and faster movement into extension for draw deliveries when compared to take-outs. Draw deliveries show maximal knee extension movements occurring at 60% (~200 degrees/sec) and again at 95% (~200 degrees/sec) of the filmed data. Ankle dorsiflexion and plantar flexion angular velocities show no apparent differences when comparing the two deliveries with an increase in plantarflexion moment occurring for both deliveries within the last 10% of the filmed delivery.

Subject #2 shows no distinct differences in angular velocity occurring at the hip between draw (Figure 6 in Appendix A) and take-out (Figure 7 in Appendix A)
deliveries. However there seems to be a large increase in knee angular velocity moving into extension when comparing take-outs to draws. Subject #2 demonstrates angular velocities in excess of ~200 degrees/sec for take-out deliveries and ~100 degrees/sec for draws. In addition, subject #2 shows a large increase in angular velocity moving into plantarflexion (~220 degrees/sec) for take-out deliveries throughout the last 10% of the filmed data when final push-off occurs.

Hip angular velocities for subject #3 do not vary considerably when comparing the two graphs (Figures 8,9 in Appendix A). When analyzing knee angular velocities, subject #3 seems to show an increased and earlier movement into extension for draws (~180 degrees/sec at 30%) when compared to take-outs (~100 degrees/sec at 55%). Ankle plantarflexion and dorsiflexion show no apparent differences with both showing a large increase in plantarflexion angular velocity throughout the push-off phase of the curling delivery.

In comparing rock linear velocity for subject #1 differences are noticed. Subject #1 shows a rock velocity of 2.53 m/s and 3.19 m/s for draw and takeout deliveries respectively (Table 8) showing significance (p=0.009). Subject #2 demonstrates a rock linear velocity of 2.34 m/s for draw deliveries and 2.76 m/s for take-outs (Table 9). This difference shows significance (p=0.004). Table 10 displays the rock velocity for subject #3. This subject shows a rock linear velocity of 2.33 m/s for draws and 2.40 m/s for take-outs showing no significance (p=0.829).
Table 8. Subject #1 Rock Linear Velocity  
t-Test: Two-Sample Assuming Equal Variances: Subject #1 Rock Velocity

<table>
<thead>
<tr>
<th></th>
<th>Draw</th>
<th>Take Out</th>
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<tbody>
<tr>
<td>Mean</td>
<td>2.53</td>
<td>3.19</td>
</tr>
<tr>
<td>Variance</td>
<td>0.01</td>
<td>0.04</td>
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<tr>
<td>df</td>
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<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.009</td>
<td></td>
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Table 9. Subject #2 Rock Linear Velocity  
t-Test: Two-Sample Assuming Equal Variances: Subject #2 Rock Velocity

<table>
<thead>
<tr>
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<th>Draw</th>
<th>Take Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.34</td>
<td>2.76</td>
</tr>
<tr>
<td>Variance</td>
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<td></td>
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<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.004</td>
<td></td>
</tr>
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</table>

Table 10. Subject #3 Rock Linear Velocity  
t-Test: Two-Sample Assuming Equal Variances: Subject #3 Rock Velocity

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<th>Draw</th>
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<td>0.27</td>
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<tr>
<td>df</td>
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<td></td>
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<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.83</td>
<td></td>
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CHAPTER V
DISCUSSION

As mentioned in chapter 2, three theories of weight control seem to predominate. The first method is related to the height of the back swing. The higher the backswing the more potential energy available and subsequent increase in rock velocity. A second theory relates to increased push-off force with the stance leg creating an increase in velocity of the curler and the rock. The third method of weight control addresses the point of release of the curling stone. The earlier the rock is released the more velocity it carries due to the decreased amount of friction to slow the stone and curler. In contrast, the longer the curler delays the release the more friction occurs between the curler, rock and ice causing a decrease in velocity. To determine the method of weight control four aspects of the curling delivery were analyzed: height of the backswing, linear velocity of center of gravity \((S_2)\), angular velocities occurring at the hip, knee, ankle of the stance leg, and the linear velocity of the rock.

When attempting to interpret the results of this study it is difficult to analyze the data due to the limited number of similar studies completed on the curling delivery. However, in looking at the overall results of all subjects there does not seem to be one consistent method of weight control used. Also, many of the results of this study contradict what Bothwell-Myers found in her research. For example, she concluded there
is no significant increase in backswing height when comparing the two deliveries.\textsuperscript{7} This study shows 2 of 3 subjects use a significantly higher backswing when executing take-out shots.

In addition, she found only slight increases in angular velocities occurring at the knee joint between deliveries.\textsuperscript{7} Whereas, 2 of 3 subjects seem to show increases in angular velocities of the lower extremity for take-out deliveries when compared to draws. These results are difficult to compare because Bothwell-Myers analyzed only knee angular velocities, and this study looks at velocities occurring at three joints of the lower extremity.

It is difficult to compare studies and draw conclusions about the curling delivery. When looking at the results individually, conclusions arise referring to individual preference in controlling the weight of the curling stone. The method of weight control for subject #1 differs between types of deliveries. Increasing the height of the backswing predominates as the method for increasing rock velocity for subject #1 during take-outs. This is enforced by the significant increase in rock height when comparing draw and take-out deliveries (Table 2). However, methods of acquiring velocity for draw deliveries differ from take-outs. The results seem to show increases in lower extremity stance angular velocities (push-off) for draws when compared with take-outs. This increase in lower extremity involvement makes sense when analyzing the subjects COG linear velocities of 2.21 m/s for draws and 2.14 m/s for takeouts (Table 5). This subject seems to use a higher backswing to increase rock velocity for take-outs, but acquires velocity or momentum from the stance leg for draw deliveries.
The results of subject #2 agree with Bothwell-Myers in that this subject does not show a significant increase in backswing height (Table 3). However, this subject appears to demonstrate increases in angular velocities (Figures 6,7) occurring at the knee and ankle when comparing the deliveries, but statistically there is no significant increase in COG linear velocity for take-out deliveries. It appears this subject attains forward momentum or velocity primarily from the stance leg during push-off even though the numbers do not prove to be significant.

In analyzing the method of weight control for subject #3 the source of force is difficult to determine. The significant increase in backswing height (Table 4) would make sense if there were a significant increase in rock linear velocity when leaving the hack, but that does not prove to be true. Like the other subjects, there is not an increase in COG velocity, and angular velocities seem to show differences in timing of maximal velocities. The actual velocities themselves do not seem to be different. This is probably not involved with the actual forward propulsion of the subjects, but rather a difference in technique when executing the different shots. Therefore, the method of weight control might be due to the release point during the delivery, but that cannot be proven due to the limitations of this study.

This study attempts to show differences in linear and angular velocities between draw and take-out deliveries through statistical and visual analysis of figures. However, Bothwell-Myers found subjects exert approximately seven to ten times more force than is needed to complete the desired shot. If subjects leave the hack with more force than is already needed to complete the desired shot whether it be a draw or take-out, why is it necessary to increase the force generators within the curling delivery? Subjects can
generate the same velocities and use friction to control the weight of the required shot. If this holds true analyzing the results of this study with statistical analysis would not show distinct differences between deliveries. Because the results of this study are mixed between subjects and no one consistent force generator was found it is probable that subjects controlled the weight of the curling stone by altering the release point, or a combination of the above-examined variables. The only way to prove friction plays a key role in determining force and velocity within the curling delivery is to analyze the release point along with the elements observed in this study.

Limitations

The PEAK system has shown good reliability of angular velocity measurements in comparison with Biodex isokinetic testing. Selfe\textsuperscript{11} completed a study, which showed a mean difference in angular velocity of 0.96° s\textsuperscript{-1} when comparing the PEAK 5 system and Biodex isokinetic dynamometer. In addition, the 95\% confidence interval was 1.5 cm indicating a relatively high reliability of reflective marker placement.

Undoubtedly, the most prominent limitation of this study would be the limited number of subjects analyzed. With only 3 subjects completing 3 successful draw and 3 successful take-out deliveries it is difficult to get an accurate average and compare subjects as a group and not individually. In conjunction with the limited number of subjects, the statistical tests lack reliability and the risk for committing a type I error is quite high.

Recommendations

The following are recommendations offered for future research:

1. Use a greater number of subjects in future investigations of the curling delivery.
2. Record the point of release of the curling stone by either video equipment or manually observing.

3. An analysis of the braking forces existing and how these forces are used to control the weight and momentum of the curling stone.

4. Compare subjects who do not use a backswing in their normal curling delivery to subjects who use the backswing delivery.
CHAPTER VI
CONCLUSION

Within the limitations of this study, in which 3 subjects of a varying skill level took part, the following conclusions seem justified:

1. Motion analysis can be used to quantify some of the important kinematic variables of the curling delivery related to the successful completion of draw and take-out shots.
2. The method of weight control is not consistent between all three subjects.
3. Subjects seem to use their own method or a combination of methods to control the weight of the curling stone when leaving the hack.

As with most biomechanical analysis, this study looked for similarities in the curling delivery optimally leading to improved technique and skill level of curlers. Although no distinct aspect of delivering the curling stone seemed to be consistent between all subjects, this quantitative information can be used for comparative data in future studies. Hopefully, enough studies will be completed leading to an understanding and agreement of the optimal delivery. In such a case, exercise programs can be derived to improve the performance of individual curlers and improve the level of play in the sport of curling. In addition, a better understanding of correct technique will lead to decreased rates of injury and provide better treatment methods leading to a quicker return to sport which all athletes desire.
APPENDIX A
FIGURE 4. Trial averages for subject #1 showing angular velocities occurring at the hip, knee and ankle for draw deliveries.
FIGURE 5: Trial averages for subject #1 showing angular velocities occurring at the hip, knee and ankle for take-out deliveries.
FIGURE 6. Trial averages for subject #2 showing angular velocities occurring at the hip, knee and ankle for draw deliveries.
FIGURE 7. Trial averages for subject #2 showing angular velocities occurring at the hip, knee and ankle for take-out deliveries.
FIGURE 8. Trial averages for subject #3 showing angular velocities occurring at the hip, knee and ankle for draw deliveries.
FIGURE 9. Trial averages for subject #3 showing angular velocities occurring at the hip, knee and ankle for take-out deliveries.
X _EXPERIENCED REVIEW REQUESTED UNDER ITEM (NUMBER(S)) OF HHS REGULATIONS
EXEMPT REVIEW REQUESTED UNDER ITEM (NUMBER(S)) OF HHS REGULATIONS

UNIVERSITY OF NORTH DAKOTA HUMAN SUBJECTS REVIEW FORM FOR NEW PROJECTS OR PROCEDURAL REVISIONS TO APPROVED PROJECTS INVOLVING HUMAN SUBJECTS

PRINCIPAL INVESTIGATOR: Dave Relling, Sam Harms
TELEPHONE: (701) 777-4091
DATE: February 28, 1999
ADDRESS TO WHICH NOTICE OF APPROVAL SHOULD BE SENT: 501 N. Columbia Road, P.O. Box 9037, Grand Forks, ND 58202-9037

PROPOSED PROJECT: Project Dates: March 1999 - May 2000

PROJECT TITLE: Motion Analysis of the Curling Delivery

FUNDING AGENCIES (IF APPLICABLE):

TYPE OF PROJECT (Check ALL that apply):

X NEW PROJECT ___ CONTINUATION ___ RENEWAL ___ THESIS RESEARCH ___ STUDENT RESEARCH PROJECT

___ CHANGE IN PROCEDURE FOR A PREVIOUSLY APPROVED PROJECT

DISSERTATION/THESIS ADVISER, OR STUDENT ADVISER: Dave Relling, MS, PT

PROPOSED PROJECT: ___ INVOLVES NEW DRUGS (IND) ___ USE OF DRUG INVOLVES A COOPERATING INSTITUTION

IF ANY OF YOUR SUBJECTS FALL IN ANY OF THE FOLLOWING CLASSIFICATIONS, PLEASE INDICATE THE CLASSIFICATION(S):

___ MINORS (<18 YEARS) ___ PREGNANT WOMEN ___ MENTALLY DISABLED ___ FETUSES
MENTALLY RETARDED

___ PRISONERS ___ ABORTUSES X UND STUDENTS (>18 YEARS)

IF YOUR PROJECT INVOLVES ANY HUMAN TISSUE, BODY FLUIDS, PATHOLOGICAL SPECIMENS, DONATED ORGANS, FETAL MATERIAL, OR PLACENTAL MATERIALS, CHECK HERE

IF YOUR PROJECT HAS BEEN WILL BE SUBMITTED TO ANOTHER INSTITUTIONAL REVIEW BOARD(S), PLEASE LIST NAME OF BOARD(S):

Status: ___ Submitted; Date _____________ ___ Approved; Date _____________ _____ Pending

1. ABSTRACT: (LIMIT TO 200 WORDS OR LESS AND INCLUDE JUSTIFICATION OR NECESSITY FOR USING HUMAN SUBJECTS.)

According to the United States Curling Association, there are over 15,000 curlers in the United States, and with the sport becoming an official Olympic medal sport in 1998 more people are showing interest in the game. This increase of interest has raised the level of competition placing more emphasis on the technical aspects of the game. For this reason, research analyzing the kinetic and kinematic variables of the curling delivery is essential. However, in reviewing the literature analyzing the curling delivery, it is found that few...
studies of this subject have been completed. The purpose of this study is to analyze and describe the kinetic and kinematic variables of the curling delivery with a 3-D motion analysis system.

The results will attempt to provide objective information associated with the curling delivery, and allow development of training programs to enhance the curling Athlete's performance. This information will be beneficial to physical therapists working with experienced or novice curlers, both for training and rehabilitation if injury occurs. Normal, trained, healthy subjects will be used in this research. Human subjects are needed for this research study in order to analyze the kinetic and kinematic aspects of the curling delivery.

PLEASE NOTE: Only information pertinent to your request to utilize human subjects in your project or activity should be included on this form. Where appropriate attach sections from your proposal (if seeking outside funding).

2. PROTOCOL: (Describe procedures to which humans will be subjected. Use additional pages if necessary.)

Subjects
The sample will consist of 10 curlers of either sex, voluntarily recruited for this study. Subjects must be healthy and without pathology which may lead to injury or limit their curling delivery. Subjects' age will be 18 or older. We will not accept subjects who are pregnant. All participants will sign the appropriate human subject consent forms prior to initiation of the study.

Procedure:
The study will be conducted at the Grand Forks Curling Club. Upon entering the facility, subjects will be given verbal instructions on purpose and procedure of the experiment and then will be asked to sign a consent form. Video analysis will be used to analyze the kinetic variables associated with the curling delivery. Reflective markers will be attached to the trunk and lower extremity bilaterally using double-sided tape. Video cameras will be placed around the subject and will film the subject's lower extremity and trunk movements throughout the delivery. The information collected will be recorded on videotapes and will then be transferred to a computer for analysis.

Subjects will be allowed to warm-up and take practice deliveries with the markers in place to ensure their delivery will not be impeded. Each subject will be asked to perform two successful "draw" and "takeout" shots using their normal delivery. Motion analysis will be recorded for each delivery.

Data collection will consist of motion present at the trunk and lower extremities. The video image will be converted to a stickman-like figure, from which we can determine the kinematics of the curling delivery.

3. BENEFITS: (Describe the benefits to the individual or society.)
The possible benefits of this study will include obtaining information on the curling delivery that may lead to the development of training programs to increase the skill level of participants. By identifying desired kinematics at the joints, a more efficient training program may be developed to train muscles affecting the joints observed. By establishing normative data on trunk and lower extremity motion during the various stages of the curling delivery, we will provide information that could be used in future curling studies.

4. RISKS: (Describe the risks to the subject and precautions that will be taken to minimize them. The concept of risk goes beyond physical risk and includes risks to the subject's dignity and self-respect, as well as psychological, emotional or behavioral risk. If data are collected which could prove harmful or embarrassing to the subject if associated with him or her, then describe the methods to be used to insure the confidentiality of data obtained, including plans for final disposition or
destruction, debriefing procedures, etc.)

Physical risks to the subjects in this study are minimal. Motion analysis equipment poses no risk of injury to the subjects. The possibility of muscle strains and falls due to the ice surface exists. However, these risks are minimal considering the athletes' condition, warm-up period allowed and experience in performing such activities.

Data will be collected in a confidential manner and the collected data will be kept confidential in a locked office in the Physical Therapy department for a minimum of three years. Names will not be used for any reason in this study, and code numbers will be assigned to ensure strict confidentiality. Participation in this study is voluntary and subjects are free to withdraw at any time and for any reason without fear of retribution.

5. CONSENT FORM: A copy of the CONSENT FORM to be signed by the subject (if applicable) and/or any statement to be read to the subject should be attached to this form. If no CONSENT FORM is to be used, document the procedures to be used to assure that infringement upon the subject's rights will not occur.

The signed consent forms will be kept by David Relling in the University of North Dakota Physical Therapy Department for a period of three (3) years. A copy of the consent form is attached.

6. For FULL IRB REVIEW forward a signed original and thirteen (13) copies of this completed form, and where applicable, thirteen (13) copies of the proposed consent form, questionnaires, etc. and any supporting documentation to:

Office of Research & Program Development
University of North Dakota
Grand Forks, North Dakota 58202-7134

On campus, mail to: Office of Research & Program Development, Box 7134, or drop it off at Room 105 Twamley Hall.

For EXEMPT or EXPEDITED REVIEW forward a signed original and a copy of the consent form, questionnaires, etc. and any supporting documentation to one of the addresses above.

The policies and procedures on Use of Human Subjects of the University of North Dakota apply to all activities involving use of Human Subjects performed by personnel conducting such activities under the auspices of the University. No activities are to be initiated without prior review and approval as prescribed by the University's policies and procedures governing the use of human subjects.

SIGNATURES:

Principal Investigator

Project Director or Student Adviser

Training or Center Grant Director

Date

Date

Date

37
STUDENT RESEARCHERS: As of June 4, 1997 (based on the recommendation of UND Legal Counsel) the University of North Dakota IRB is unable to approve your project unless the following "Student Consent to Release of Educational Record" is signed and included with your "Human Subjects Review Form."

STUDENT CONSENT TO RELEASE OF EDUCATIONAL RECORD

Pursuant to the Family Educational Rights and Privacy Act of 1974, I hereby consent to the Institutional Review Board's access to those portions of my educational record which involve research that I wish to conduct under the Board's auspices. I understand that the Board may need to review my study data based on a question from a participant or under a random audit. The study to which this release pertains is.

I understand that such information concerning my educational record will not be released except on the condition that the Institutional Review Board will not permit any other party to have access to such information without my written consent. I also understand that this policy will be explained to those persons requesting any educational information and that this release will be kept with the study documentation.

[Signature]
Date

1Consent required by 20 U.S.C. 1232g.
REPORT OF ACTION: EXEMPT/EXPEDITED REVIEW
University of North Dakota Institutional Review Board

DATE: March 16, 1999  PROJECT NUMBER: IRB-9903-184

NAME: Dave Relling; Sam Harms  DEPARTMENT/COLLEGE: Physical Therapy

PROJECT TITLE: Motion Analysis of the Curling Delivery

The above referenced project was reviewed by a designated member for the University's Institutional Review Board on March 17, 1999 and the following action was taken:

☑ Project approved. EXPEDITED REVIEW NO. 6
☐ Next scheduled review is on March 2000

☐ Project approved. EXEMPT CATEGORY NO. _______________. No periodic review scheduled unless so stated in the Remarks Section.

☐ Project approved PENDING receipt of corrections/additions. These corrections/additions should be submitted to ORPD for review and approval. This study may NOT be started until final IRB approval has been received. (See Remarks Section for further information.)

☐ Project approval deferred. This study may not be started until final IRB approval has been received. (See Remarks Section for further information.)

☐ Project denied. (See Remarks Section for further information.)

REMARKS: Any changes in protocol or adverse occurrences in the course of the research project must be reported immediately to the IRB Chairperson or ORPD.

PLEASE NOTE: Requested revisions for student proposals MUST include adviser's signature.

cc: D. Relling, Adviser  Dean, Medical School

Signature of Designated IRB Member  UND's Institutional Review Board

If the proposed project (clinical medical) is to be part of a research activity funded by a Federal Agency, a special assurance statement or a completed 310 Form may be required. Contact ORPD to obtain the required documents.
Information and Consent Form

Title: Motion Analysis of the Curling Delivery

You are being invited to participate in a study conducted by David Relling, a physical therapy instructor, and Sam Harms, a physical therapy student at the University of North Dakota. The purpose of this study is to analyze joint range of motion and center of gravity throughout the different phases of the curling delivery. The results will attempt to provide information on developing training programs with the purpose of enhancing the athlete's skill level. Only normal, healthy subjects will be asked to participate in this study.

You will be asked to make three successful “draw” and “takeout” shots using your normal curling delivery while being monitored by motion analysis cameras. You will be given a few minutes to warm-up prior to performing the actual trials. You will be given adequate time between trials.

The study will take approximately one hour of your time. You will be asked to report to the Grand Forks Curling Club in Grand Forks, North Dakota at the designated time. We will record your age, height, gender, years of curling experience and level of achievement for data analysis purposes. During the experiment, we will be videotaping the kinematics associated with the curling delivery.

Although the process of physical performance testing always involves some degree of risk, the investigators in this study feel the risk of injury is minimal. In order for us to record range of motion data we will place some reflective markers to certain landmarks on your body for motion analysis cameras. The amount of exercise you will be asked to perform will be minimal.

Your name will not be used in any reports of the results of this study. Any information that is obtained in connection with this study and that can be identified with you will remain confidential and disclosed only with your permission. The data will be identified by a number known only by the investigator. The investigator or participant may stop the experiment at any time if the participant is experiencing discomfort, pain, fatigue, or any other symptoms that may be detrimental to his/her health. Your decision whether or not to participate will not prejudice your future relations with the Physical Therapy Department or the University of North Dakota. If you decide to participate, you are free to discontinue participation at any time without prejudice.

The investigator involved is available to answer any questions you have concerning this study. In addition, you are encouraged to ask any questions concerning this study that you may have in the future. Questions may be addressed to Dave Relling or Sam Harms at (701) 777-2831. A copy of this consent form is available to all participants in this study.
In the event that this research activity (which will be conducted at the Grand Forks Curling Club) results in physical injury, medical treatment will be available, including first aid, emergency treatment and follow up care as it is to any member of the general public in similar circumstances. Payment for any such treatment must be provided by you, and your third party payer if any.

ALL OF MY QUESTIONS HAVE BEEN ANSWERED AND I AM ENCOURAGED TO ASK ANY QUESTIONS THAT I MAY HAVE CONCERNING THIS STUDY IN THE FUTURE. MY SIGNATURE INDICATES THAT, HAVING READ THE ABOVE INFORMATION, I HAVE DECIDED TO PARTICIPATE IN THE RESEARCH PROJECT.

I have read all of the above and willingly agree to participate in this study explained to me by Dave Relling and Sam Harms.

Participant’s Signature __________________________ Date __________________________

Witness (not the scientist) ______________________ Date __________________________
February 26, 1999

To Whom it may Concern:

Sam Harms has our permission to use the Grand Forks Curling Club for his studies.

Sincerely,

Cindy Samson
President, GF Curling Club
Kinetic and Kinematic Characteristics of the Curling Delivery

Research #

Name: _____________________________ Age: __________

Height: ___________ Weight: ___________

Permanent Address:

Phone Number: _______________________

How many years have you been curling?

About how many games or practices do you participate in one week?

What levels of competition have you competed (Club, District, State, National, World)?

Have you had any curling related injuries? If so, what are they and magnitude of involvement?

Have you ever participated in a study related to curling in the past? If so, what was the researcher testing?
APPENDIX C
EQUIPMENT SOURCES

PEAK Analog Module
PEAK PerformanceTechnologies
7388 S. Revere Parkway, Suite 601
Englewood, CO 80112-9765

JVC Model BR-S378U S-VHS VCR
JVC of America
41 Slater Drive
Elmood Park, MF 07407

Sanyo Model GVR-S955 SVHS VCR
Sanyo Fisher (USA) Corporation
1200 W. Artesia Boulevard
Campton, CA 90220

VIDEOTEK Model PVS-6 6X1 Passive Video Switcher
VIDEOTEK, Inc
243 Shoemaker Road
Pottstown, PA 19464-6433

Sony Trinitron Color Video Monitor
Sony Corporation

PEAK Event Synchronization Unit
PEAK PerformanceTechnologies
7388 S. Revere Parkway, Suite 601
Englewood, CO 80112-9765

PULNiX Video Cameras
PULNiX America Inc.
1330 Orleans Drive
Sunnyvale, CA 94089

PEAK Calibration Frame
PEAK PerformanceTechnologies
7388 S. Revere Parkway, Suite 601
Englewood, CO 80112-9765

Horita TG-50 SMPTE Time-Code Play Speed Reader, Generator Window Inserter
Horita
P.O. Box 3993
Mission Viejo, CA 92690
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