Diploma in Sport and Exercise Sciences
Biomechanics of Sport & Exercise
Summative 1 Assignment
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1. Introduction

1.1 Objective

The objective of this project is to understand the biomechanics involved in our selected sport of *Archery*. With the Kinovea software, we perform biomechanical analysis of our sports persons and determine how key requirements in physical execution of the sport affects the performance of the athletes.

We will also discuss if the archers observed can make changes in their biomechanics to improve their performances.

1.2 Introduction to Archery

Archery is a shooting sport where the athlete (the archer) shoots a projectile (the arrow) towards a target. All the equipments used by an archer is customised for him/her. Due to the differences in body type and mechanical distances, the same set of equipments used by another archer will achieve different results. Once the equipment for an archer is personalised, the key consideration in executing a good shot is for the archer to be consistent in the execution. This requirement in consistency is similar to other sports such as golf, dart, bowling or rifle shooting - there is no interaction with other players. The sports person controls his/her execution speed, and the target is fixed.

Although we normally talk about having a good aim in archery, an archer's form (body positioning) is more important than the aim. The next diagram (Figure 1) illustrates this point.

Having a good form allows the archer to repeat the shots consistently and get a good "grouping" (i.e. all the shots are very close together). This concept is familiar to a soldier shooting with a rifle, which many Singaporean men has done in national service. The aim can then be corrected towards the bullseye by adjusting the sight aperture.

A bad form is worse. It means the archer is not repeating each shot in a balanced, comfortable way that is less tiring to replicate. This is harder to correct, and causes bad and unpredictable scores, even if the aim is accurate.

To get a good score in archery, we need both good form and good aim. For the purpose of this project, we are focusing on the archers' form.

Figure 1 - Form vs Aim.
© Ian Garner. '10 common mistakes that ruin accuracy, and how to fix them - Understanding Archery', 2017.

1.3 Introduction to Subjects

We have two volunteer archers from the Flaming Arrows Archery Club (FAAC) (www.faac.sg) who will be assisting in this project. Here are their profiles.

	Archer 1	Archer 2
Name	Scott	Shan
Gender	Male	Female
Age		
Archery Experience	6 yrs	6 yrs
Archer Type	Recurve, 32lbs, Right-handed	Recurve, 24lbs, Left-handed
Inter-Club Competitions Participated		
Highest Position Achieved		

We will compare their performances in our biomechanics experiment.

2. Methods

2.1 Temporal Phases

In archery coaching, a beginner archer is taught “9 steps” to take in shooting every arrow, as listed below.

No.	“Step”	Description
1	Stance	Stand across the shooting line. If you place an arrow against the toes of your shoes, it should point towards the target.
2	Nock	Nock (mount) the arrow onto the nock point on the bow string.
3	Set	Place your draw hand fingers on the bow string, and the other (bow) hand on the handle of the bow
4	Pre-draw	Raise your bow up towards the target
5	Draw	Draw the bow in a continuous smooth motion
6	Anchor	Touch the string and/or fingers to a consistent part of your face
7	Aim	Line the sight aperture up with the target
8	Release	Relax the draw hand’s fingers and let the string slip pass
9	Follow-through	The drawing hand should move backward opposite to the arrow’s flight, and the bow arm should still be raised

For the purpose of this project, we are breaking it down into the 2 temporal phases for recording and analysis.

- Temporal phase 1 - Pre-release, steps 6 & 7 - *Anchor* & *Aim*.
- Temporal phase 2 - Post-release, steps 8 & 9 - *Release* & *Follow-through*.

2.2 Muscle Groups

There is no significant muscle movement during the first temporal phase. The body movement in the second temporal phase is a result of the load (tension of the bow & string) going away after the arrow is released.

Muscular contractions are mostly isometric, holding the bow and string in place, and slight adjustments to line the sight-aperture to the target during the aiming process.

The main muscle groups used by archers are the core, upper body, shoulders and arms. The following are diagrams of the key muscle groups. Knowing this allows us to plan for the video capture, as detailed in the next section.

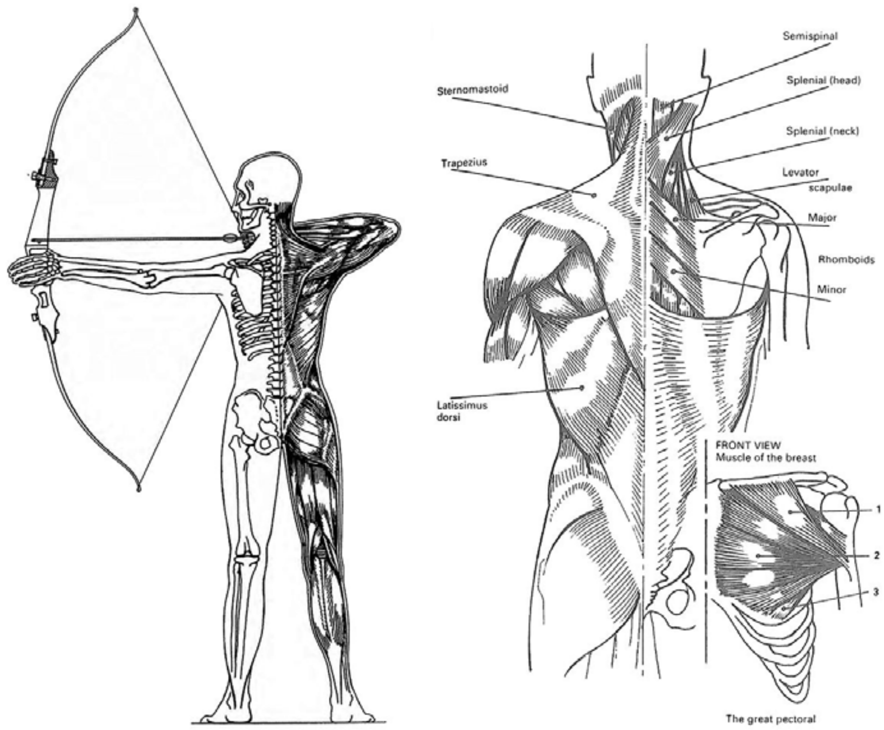

Figure 2 - Archery posture (left) and main engaged muscle groups in the back and front (right). © Axford, Ray. 'Archery Anatomy: An Introduction to Techniques for Improved Performance', Souvenir Press, 1995. pp 77, 35.

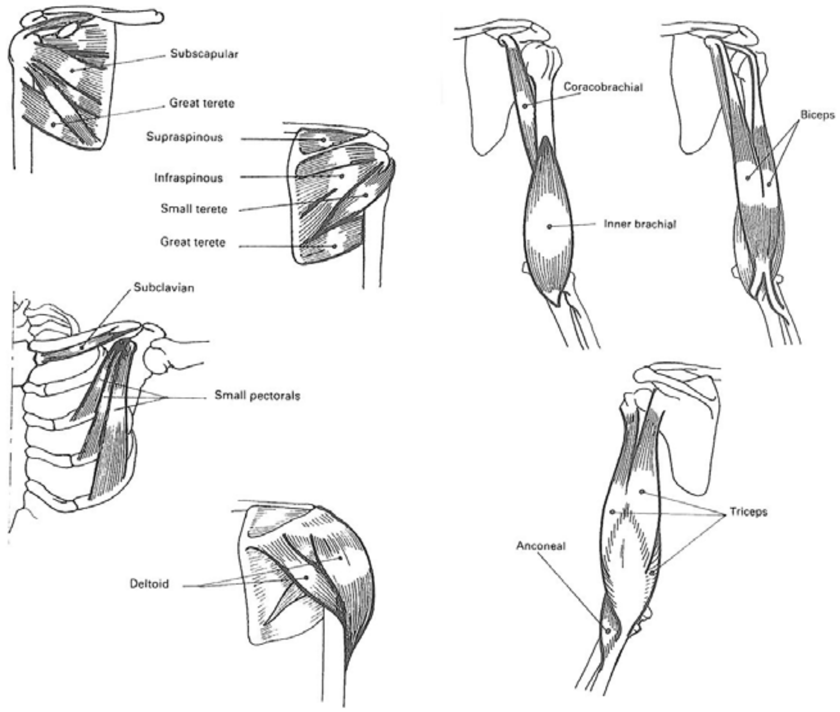

Figure 3 - Specific muscles engaged around the shoulders (left) and the upper arms (right). © Axford, Ray. 'Archery Anatomy: An Introduction to Techniques for Improved Performance', Souvenir Press, 1995. pp 31, 33.

2.3 Equipments & Tools

For the required data collection, we will be performing video recordings of a typical archery session at the FAAC's indoor archery range. The diagram below indicates how the archers will be shooting.

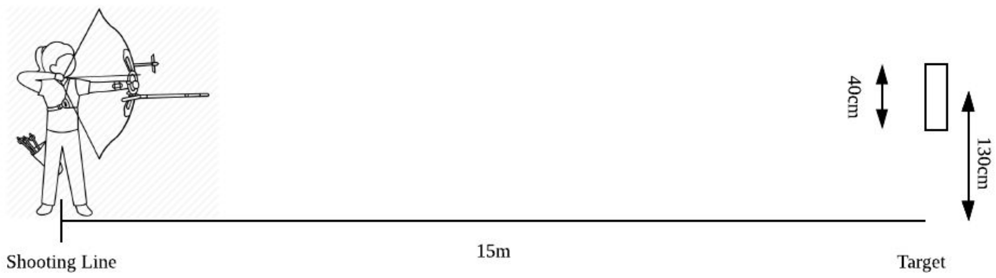

Figure 4 - Archers' shooting setup (top) and the target (above)

The archers shoots at a target at 15m away. The target is a standard 40-cm archery target face, mounted on a board, with the bullseye at a height of 130cm from the ground. Each archer will shoot 6 arrows.

To capture the archers' shooting, we place cameras on both sides of the archer, along the shooting line, perpendicular to the direction of arrow. The cameras will be at a height around the archer's bow arm and the arrow to reduce parallax errors.

After each archer has shot 6 arrows, we will also take note of the scores (between 0 to 10 per arrow) for analysis.

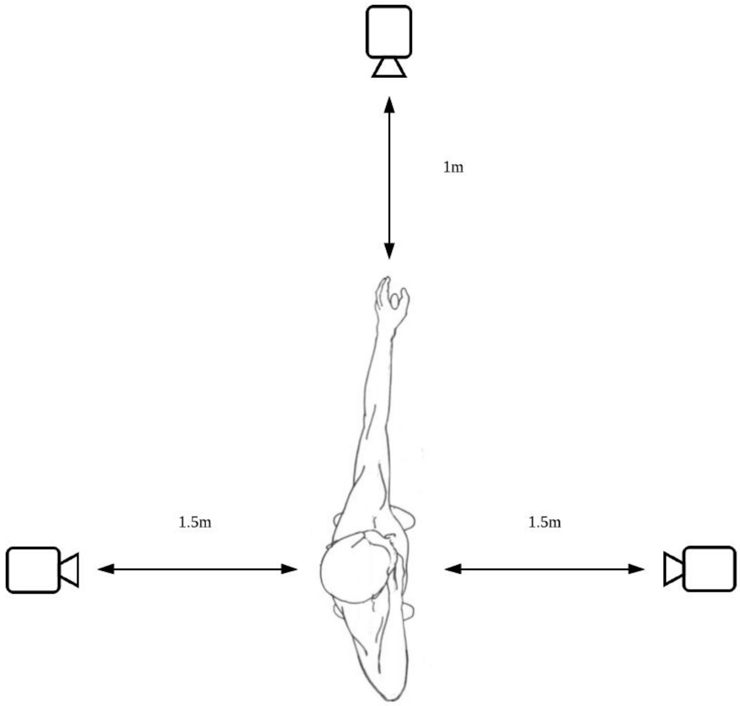

Figure 5 - Camera positions - on both sides of the archer along the shooting line, and in the line-of-sight towards the target

Another angle of interest is the line-of-sight of the archer, between the archer and the target, in the path of the arrow.

However, as this angle is not commonly captured and experimental, due to safety reasons, we will be capturing videos of this angle, at a separate session/recording, without any arrow mounted on the bow. The archer will be asked to draw the string 6 times, to simulate shooting 6 arrows.

2.4 Statistics of Interests

From the 3 directions of video capture, we will be measuring the following.

2.4.1 Direction 1 - Archer's Front (Pre-release)

Figure 6 - Distances and angles to measure on the archer's front at Pre-release phase - distance drawn and the angle of the drawing arm (screenshot from Kinovea software)

In the pre-release phase, we will be measuring:

1. The consistency of the distance of the arrow drawn back. In archery, the "draw-length" is measured from the end of the arrow (at the string) to the arrow-rest on the side of the bow. However, due the point not visible from the camera, we measure an alternative - the distance from the fingers to the inner edge of the bow.

2. The consistency of the angle of the pulling arm. This position allows the back muscles to be engaged, making it easier to consistently hold the string. Beginner archers may drop their elbow, using only their arm muscles to hold the string, which easily tires them out, resulting in inconsistencies.

2.4.2 Direction 1 - Archer’s Front (Post-release)

Figure 7 - Distances and angles to measure on the archer’s front at Post-release phase - drop in bow hand and follow-through distance of drawing arm (screenshot from Kinovea software)

In the post-release phase, we will be measuring:

1. The <u>support (drop) of the bow arm</u>, which should be consistently pushing against the bow, and should not drop too much after release, which indicates a weak hold. However, as this does not matter too long after the arrow is released, we will only be measuring the distance drop after 12 frames, which is 12/60s = 0.2s. Our videos are shot at a frame rate of 60 fps.

2. The <u>follow-through distance of the pulling arm</u>. The pulling arm should consistently be pulling back in the opposite direction of the arrow, and should not be just letting go of the fingers during the release. We are also measuring the distance moved by the elbow after 12 frames (i.e. 0.2s).

2.4.3 Direction 2 - Archer's Back

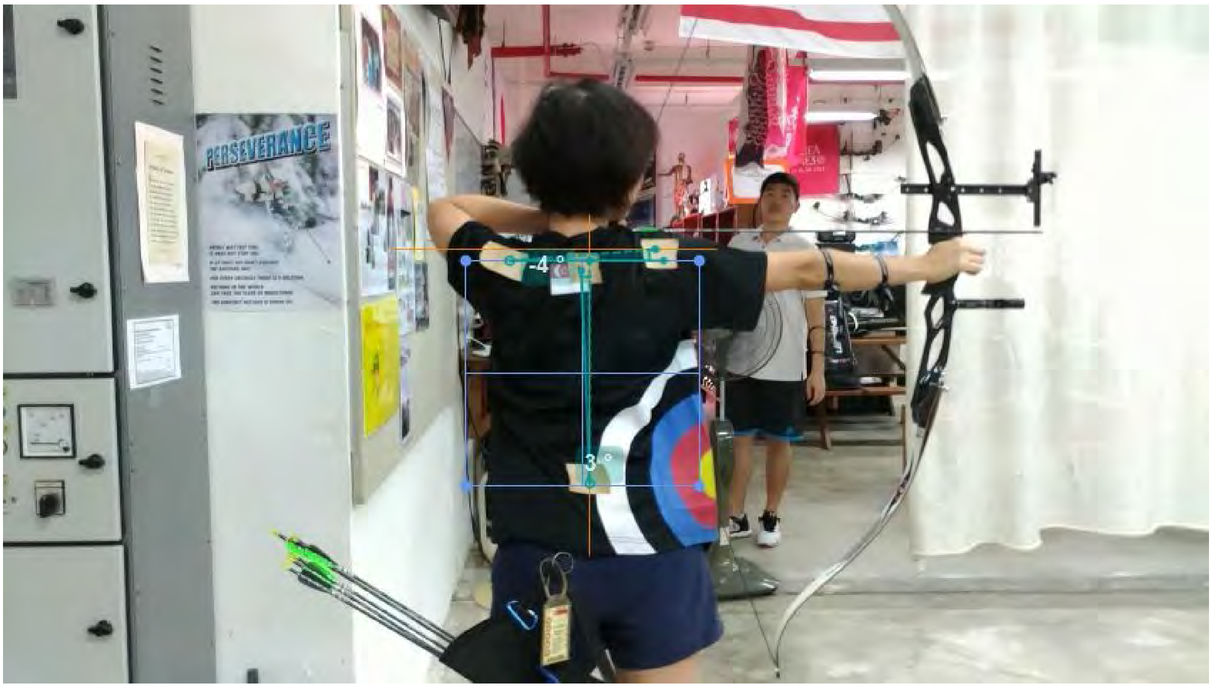

Figure 8 - Angles to measure on the archer's back - vertical and horizontal tilts (screenshot from Kinovea software)

From the back, we will be measuring the following angles in the pre-release phases: (i) vertical tilt and (ii) horizontal tilt of the body in the pre-release phase. We have reference stickers pasted on the subjects' shirts to assist in the measurement.

I. <u>Vertical tilt</u> - the body should be vertically aligned along the sagittal plane. Leaning back often indicates the archer using a bow that is too heavy (i.e. requires more strength to pull), and uses one side of the latissimus dorsi to help pull and hold the bow string.

II. <u>Horizontal tilt</u> - the shoulders should be horizontally aligned to reduce the effort required to sustain the pull-push posture. Fatigue will speed up at the shoulders and arms when this posture is not aligned.

2.4.4 Direction 3 - Archer's Line-of-sight

Figure 9 - Measuring aiming consistency from the archer's line-of-sight (screenshot from Kinovea software)

From the archer's line-of-sight, we want to see if the aim is consistent. The archer will aim by lining up the 3 reference points - aiming eye, sight-aperture and the target. However, there is possible rotation of the bow at the horizontal plane, causing the arrow to be aimed to the left or right without the archer noticing.

To see if this is an issue, with a line-of-sight camera, we measure the horizontal distance gap between the bow and the string, at the height of the nose-tip. This is an approximation to the rotation, although a better way is to measure from the top-view, which we were not able to implement due to higher technical challenges.

This is repeated 6 times to simulate the archers shooting the same 6 arrows as before.

Due to the perspective limitations and differences, we are unable to calibrate the distance in Kinovea. We measure the image pixel distances and normalise them during calculation.

The diagram below illustrates the various planes that we can potentially analyse. Due to time and resources limitation, we will only be measuring those mentioned. This diagram is attached for reference only.

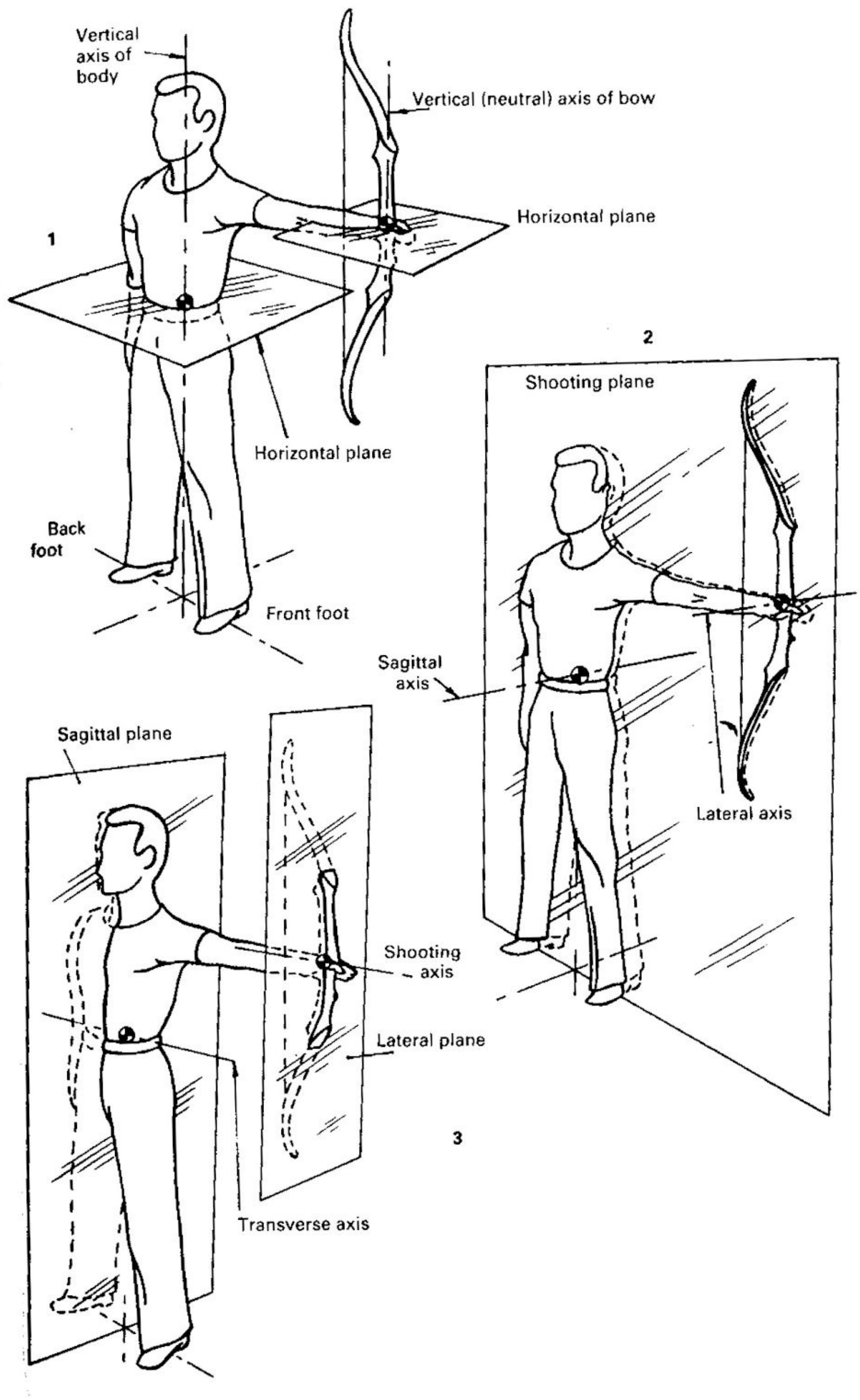

Figure 10 - Planes of an archer.
© Axford, Ray. 'Archery Anatomy: An Introduction to Techniques for Improved Performance', Souvenir Press, 1995. pp 65.

3. Results

3.1 Archers' Score

The scores of the 6 arrows shot for each archers are as follows. As we look at the data from the next 3 sections, we can relate the performance to the biomechanics data observed from Kinovea.

We will also be using a Gold Star (★) to indicate the better performer.

Figure 11 - Scores of each archer's 6 arrows on the target face.
Archer 1 (left) and Archer 2 (right).

Arrow	**Archer 1**	**Archer 2**
1	9	8
2	9	8
3	9	7
4	8	5
5	8	2
6	8	1
Total	51/60	31/60
Mean	8.5	5.2
Standard Deviation	0.548 ★	3.06 ★

3.2 Archers' Front

Before measuring the various distances, we calibrate the measurements in Kinovea based on the length of the arrow. Archer 1's arrow is 80cm. Archer 2's arrow is 79 cm.

Archer 1	**Pre-Release**		**Post-Release**	
Arrow	Reference Draw Distance (cm)	Elbow Angle (°)	Follow-Thru Distance (cm)	Bow Drop (cm)
1	56.57	7	7.19	4.49
2	56.56	8	12.11	1.25
3	56.06	7	9.19	2.99
4	56.07	7	7.60	3.25
5	56.32	8	7.95	2.74
6	55.83	7	11.87	2.79
Mean	56.24	7.33	9.32	2.92
Standard Deviation	0.299 ★	0.516 ★	2.18 ★	1.04 ★
Coefficient of Variation	0.005 ★	0.070 ★	0.234 ★	0.357 ★

Archer 2	**Pre-Release**		**Post-Release**	
Arrow	Reference Draw Distance (cm)	Elbow Angle (°)	Follow-Thru Distance (cm)	Bow Drop (cm)
1	51.99	7	6.60	1.09
2	51.98	7	6.29	0.00
3	50.50	7	5.26	1.49
4	51.54	6	7.41	0.00
5	51.96	7	6.47	0.00
6	49.63	5	6.29	0.85
Mean	51.27	6.50	6.38	0.57
Standard Deviation	0.985 ★	0.837 ★	0.691 ★	0.659 ★
Coefficient of Variation	0.019 ★	0.129 ★	0.108 ★	1.152 ★

3.3 Archers' Back

As we are only measuring the angles from the archers' back, we did not perform any distance calibration in Kinovea for the back view.

	Archer 1		**Archer 2**	
Arrow	Vertical Tilt (°)	Horizontal Tilt (°)	Vertical Tilt (°)	Horizontal Tilt (°)
1	-1	0	-3	-4
2	2	0	0	-3
3	2	0	1	0
4	2	0	1	-4
5	1	0	1	-5
6	2	0	-2	-4
Mean	1.33	0	-0.33	-3.33
Standard Deviation	1.21 ★	0 ★	1.75 ★	1.75 ★

Note: +ve tilt ⇒ lean forward, -ve tilt ⇒ lean backward

3.4 Archers' Line-of-sight

Attempt	**Archer 1 (pixels)**	**Archer 2 (pixels)**
1	25	15
2	22	13
3	25	14
4	24	11
5	24	16
6	26	10
Mean	24.3	13.2
Standard Deviation	1.37	2.32
Coefficient of Variation	**0.056** ★	**0.176** ★

Coefficient of Variation (CV)

The pixel distance ranges are different from the two recordings, due to different equipment, archer anatomy and recording distances. One way to interpret the relative magnitude of the standard deviation is to divide it by the mean, called the coefficient of variation.

4. Analysis & Discussion

4.1 Observations of Subjects' Performance

There is no "right" or "wrong" measurements. For the purpose of determining consistency, we make use of standard deviation. However, due to the anatomical size and length differences, we also use coefficient of variation, which is the standard deviation divided by the mean, which gives a better determination of the variation compared to magnitude of measurements.

Theoretical, the model for the best performance is when the archer can repeat his actions consistently. This is easily measured in an indoor and enclosed space where there is no external elements (e.g. rain, wind) to counter against.

Based on the this model, we observed that Archer 1 has a better consistency compared to Archer 2.

However, there is one measurement which Archer 2 performs better than Archer 1 - the drop of the bow post-release.

From the video, we noticed that Archer 2's bow arm tends to move up post-release, before coming down. This gives better bow-drop measurements compared to Archer 1 within the time span of 12 frames (0.2s). Further video analysis shows that Archer 2's bow arm is pointing above the horizon during aiming. This is due to Archer 2 using a weaker bow, thus required to compensate for the arrows' path of flight by having a higher aim. This vertically upward push is likely to be the cause of her bow arm moving upwards post-release, before dropping.

Archer 2 also has a more significant vertical tilt when shooting. To help reduce this tilt, she can train to strengthen her core muscles, upper back muscles, shoulders and arm muscles. When these muscle groups are stronger, she will be able to draw the bow with less effort, hence less tendencies to tilt her body unnaturally.

4.2 Qualitative Biomechanical Analysis

In the earlier video experiment, we applied the five steps of the qualitative anatomical analysis:

1. We divided the analysis into 2 **temporal phases** that determines the performance (score) of the archer - the pre-release phase which affects the consistency of the aim, and the post-release phase, an indicator of how smooth and consistent the releases are.

2. Other than the core muscles holding the upper body of the archer at a naturally balanced posture, the **joints** from the shoulder to the entire arms (elbows, wrists, fingers) are involved in in the pre-release phase when the archer is aiming at the target. However, there is minimal movements, as movements introduce inconsistencies into the arrows' flight.

3. To keep up the desired posture and balance during shooting, most of these muscles are engaged in **isometric muscle contraction**, i.e. contracting without changing their length. Concentric isotonic contractions also occur with every shot, i.e. length of muscle is shortening while applying force when pulling arrow back. Eccentric isotonic contractions are less common, but occurs when the archer has to ease or release the string-hold without firing the arrow, e.g. when arrow falls off the arrow rest. The concentric and eccentric contractions are outside the scope of our analysis.

4. Due to the limited movements and requirements for the the archers to remain very still before arrow releases, there is no instance with rapid **joint angular acceleration or impact**.

5. Similarly, there is no extremities in the joints' **range of motion**.

5. Conclusion

In this project, we identified archery as a sport, and to analyse key biomechanics involved in the arrow pre- and post-release phases, which are the main phases affecting the outcome (i.e. scores).

We have two volunteer archers and made video recordings from 3 key angles - both sides of the archers along the shooting line, and the front of the archer in the direction of the arrow. Each archer was made to shoot 6 arrows consecutively, and we conducted measurements on the Kinovea sports analysis software, and compare them to the scores achieved.

Measurements include horizontal and vertical tilts of the body, the distance of the arrow drawn, elbow angle, bow arm support and aiming. In general, we look at the consistencies in these statistics, and how well both archers can repeatedly execute the shots with minimal variations in the measurements.

We were able to confirm that the more consistent archer was the one who achieved a better score, confirming the hypothesis that consistency is positively correlated to performance in archery.

6. References

Axford, Ray. ‘Archery Anatomy: An Introduction to Techniques for Improved Performance’, Souvenir Press, 1995. Print.

Ian Garner (2017), 10 common mistakes that ruin accuracy, and how to fix them. Understanding Archery. Available at: https://understandingarchery.wordpress.com/ [Accessed Nov 13, 2018].