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Using an Aerial Drone to Examine Lateral Movement in Sweep Rowers

Joseph S. Munn
The University of Western Ontario

Supervisor
Volker Nolte
The University of Western Ontario

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Abstract

Rowing is a sport that is performed on the water, because of this there are many challenges associated with studying rowing. The primary challenges are an inability to control the environment and limitations with the equipment that can be used to collect data on the water. In order to try and overcome some of these challenges an aerial drone fitted with a high resolution camera was used to examine an understudied element of the rowing stroke, lateral movement in sweep rowers. Oar and shoulder angles and lateral movement of the shoulders and hands were calculated and compared between five different eight person rowing boats. Rowers were found to lean and rotate towards the oar side of the boat. More experienced and larger athletes had longer oar arcs, however, these differences did not necessarily extend to shoulder angle and lateral lean. Individual rowers were also observed to have their own individual styles of movement particularly in the shoulders. Further research needs to be performed to both examine lean and twist in a sweep rowing stroke and to evaluate the utility of drones as data collection tools.

Keywords

Keywords: Rowing, Sweeping, Lateral Movement, Shoulder Angle, Oar Angle, Stroke Rate, Rowing Styles, Aerial Drone

Co-Authorship Statement

Joseph Munn was the first author and Dr. Volker Nolte and Dr. Dan Bechard are co-authors.

All data in this thesis was collected, analyzed and interpreted by Joseph Munn.

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List of Nomenclature

SPM	Strokes per minute
TKE	Total Kinetic Energy (J)
HWM	Heavyweight Men
HWW	Heavyweight Women
LWM	Lightweight Men
LWW	Lightweight Women
NVM	Novice Men
SFOC	Special Flight Operation Certificate
ATC	Air Traffic Control
X-Y	Two-dimensional Cartesian coordinate system

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Chapter 1

1 Introduction

Rowing is a sport that is performed on the water where the primary objective is to cover a 2000m distance in as little time as possible. Like in many sports rowing athletes and coaches are constantly looking for any competitive edge that will allow them to outpace and outperform their opponents. New technology is a huge part of providing this edge for athletes. From the development of lighter and more aerodynamic materials to high speed cameras and 3D analysis systems that allow for more in depth analysis of movement, technology is constantly reshaping the landscape of athletic competition. Some examples of technological improvements from the sport of rowing are: heavy and inefficient wooden boats and oars being replaced by superiorly designed streamlined racing shells made from light composite materials. Along with improvements to rowing equipment, methods for gathering information on the rowing stroke have also improved. Portable cameras have allowed the stroke to be analyzed on the water. Force transducers, potentiometers and impellers have allowed coaches, researchers and athletes to collect greater information on force production, oar angles and boat speed. The improvement in data collection tools has led to a better understanding of the rowing stroke and rowing technique.

Despite the improvements in data collection tools and techniques, researching rowing on the water is still limited by an inability to control the environment and the difficulty in bringing equipment on to the water. Current rowing research has been shaped by these challenges with on water studies primarily examining the stroke by either taking a two-dimensional video of the rower in the sagittal plane or by using measurement equipment that can be attached to a rowing boat. This research looks to overcome some of these challenges by making use of an aerial drone in order to examine the rowing stroke from the perspective of directly above the boat. This study will also evaluate the effectiveness of aerial drones as data collection tools for rowing research. Presently, no research has been found that has made use of a drone as a rowing biomechanics research tool or examined the kinematics of the on water rowing stroke in the transverse plane. Examining the stroke from this perspective as well as using a drone will allow the effectiveness of the drone to be evaluated and allow lateral lean and rotation to be quantified and new information about the rowing stroke to be provided to both researchers and coaches.

1.1 Purpose and Hypotheses

1.1.1 Purpose

The purpose of this study had two components.

- The first is to determine if aerial drones can be effective rowing biomechanics research tools and to determine the strengths and limitations of drones in a research and coaching capacity.
- The second is to quantify shoulder angle, oar angle and lateral displacement of the shoulders and hands during the drive phase of a sweep rowing stroke.

1.1.2 Hypotheses

- The aerial drone will prove to be an effective method of data collection that will provide kinematic information that will be useful both from a coaching and data analysis standpoint.
- Rowers will move their hands and shoulders laterally towards their oar at the catch.
- Shoulder angle will follow oar angle through the complete stroke.
- Rowers will have individual rowing styles and differences in the patterns of lateral lean and shoulder angle will be observed.
- Differences in oar angle, lateral lean and shoulder angle between rowing classes and skill levels will be observed.
- There will be no significant differences in lateral movement of the hands, shoulders and oar angles at different stroke rates.

Chapter 2

2 Rowing background information

2.1 Rowing

There are two types of rowing: sweeping (Figure 2.) and sculling (Figure 1.). Sweeping is an asymmetrical motion where the rower operates one oar on one side of the boat and substantial movement occurs in the sagittal, frontal and transverse plane. Sculling is a much more symmetrical motion where the rower operates two oars with one in each hand and movement primarily occurs in the sagittal plane. Some sweep boats include space for a coxswain. A coxswain is in charge of steering the boat, calling out technical feedback and the race strategy. There are three different types of boats in sweep rowing: the pair (a two person boat), the four (a four person boat which can, but does not always include a coxswain) and the eight (an eight person boat with space for a coxswain). There are three types of sculling boats: the single (a single person boat), the double (a two person boat) and a quad (a four person boat). The following research was performed using eights and unless otherwise specified will refer to eight person boats.

Figure 1. Rowers sculling (Quarrell, 2008).

Figure 2. Rowers sweeping (Peterson, 2012)

2.2 Rowing weight classes and skill levels

Male and female rowers are split up into two categories: heavyweight and lightweight. Lightweight male rowers are defined as weighing less than 72.5kg and lightweight female rowers are defined as weighing less than 59kg. The body weight is open in the heavyweight category. The skill classes for Canadian university rowers are divided into novice, junior varsity and varsity. Novice athletes are defined as athletes who have no or minimal previous rowing experience and have never participated in an official rowing competition prior to their first university rowing season. Junior varsity athletes are experienced rowers, that do not meet varsity level and act as second crew or spares for the Varsity team. Varsity athletes are typically the most experienced athletes who meet the standards for the first boat. This study will examine varsity and novice level crews.

2.3 The stroke

The rowing stroke is comprised of four components; two positions, the catch and finish; and two phases, the drive and recovery (Figure 3.). A position is a single moment in time whereas a phase occurs over a span of time within a stroke. The catch is defined as the position of the rower where the hands are closest to the stern of the boat, whereas the finish is the position where the hands are closest to the bow of the boat. The drive phase starts at the catch and ends at the finish and is the portion of the stroke where the blade is placed into the water and moved, mainly horizontally, through the water to propel the boat forwards. The Recovery phase begins at the finish and ends at the catch. During the recovery the blade is travelling towards the bow of the boat and the rower's body is moving towards the stern to the next catch position (Nolte, 2013). One stroke is defined as being from catch to catch position.

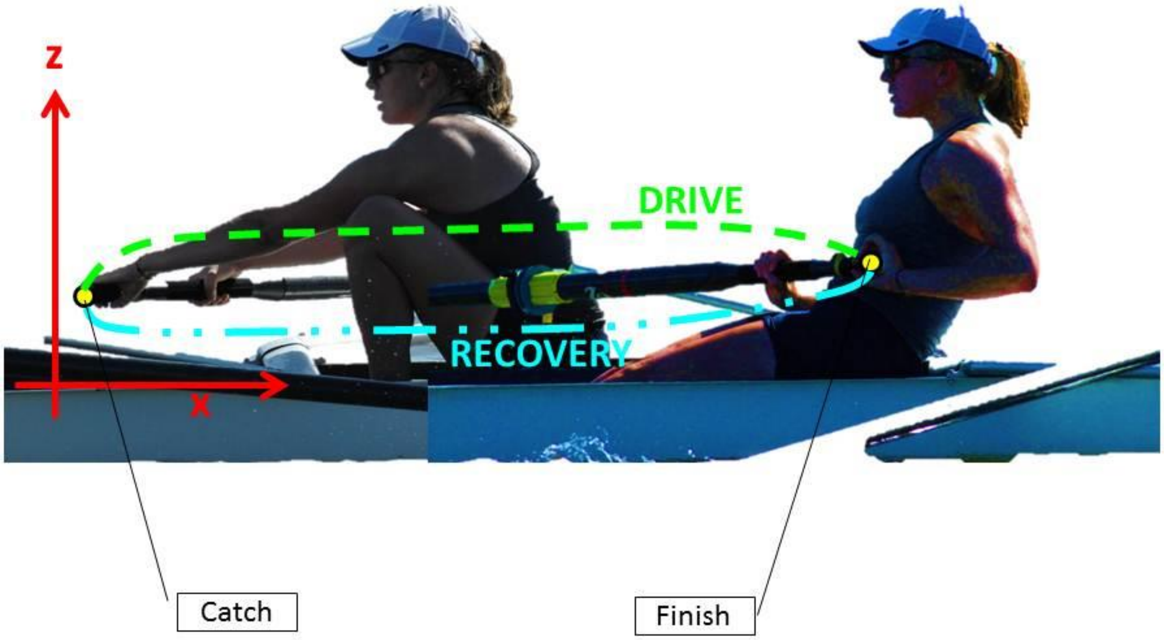


Figure 3. The positions and phases of the rowing stroke (Nolte, 2016)

During a sweep stroke the athlete rotates the oar around the pin. The rower needs to rotate his upper body with the oar and lean to the oar side of the boat to reach for the catch. The athlete then moves back to the center of the boat and straightens their body out during the drive, but may rotate and lean again towards the finish.

When defining oar angles during the stroke 0° represents the point at which the oar is perpendicular with the boat. The oar angle at the catch is negative and the finish angle is positive.

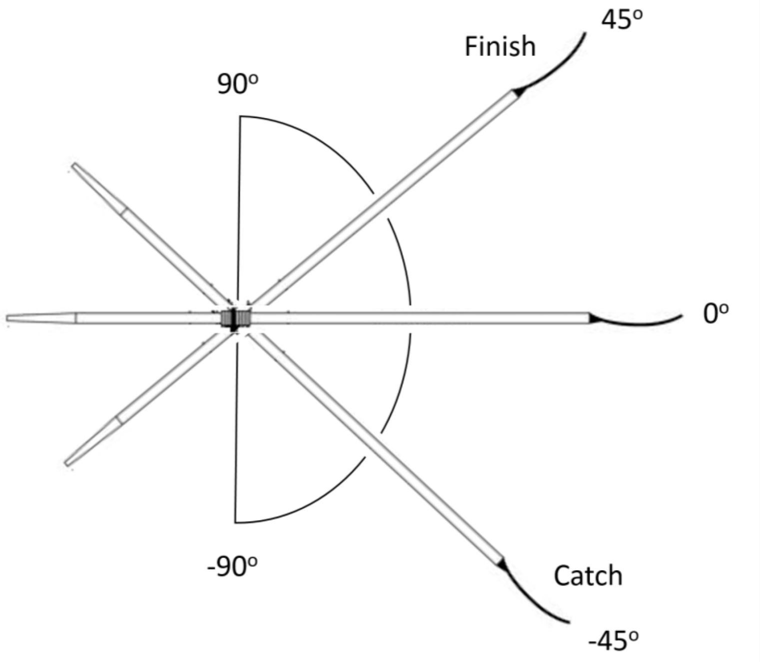


Figure 4. Oar angles with 0^o being set at the point perpendicular to the boat and negative angles being found towards the catch and positive angles towards the finish.

2.4 The boat

In the sport of rowing the following terms are used to describe the parts and orientation of the boat: bow, stern, port and starboard. The bow is the forward end of the boat. The stern is opposite of the bow and the part of the boat that is the furthest back. When facing the bow, the right side of the boat is called the starboard side and the left side is called the port side. Seat numbers are used to describe rowers sitting in different positions in the boat with the number 1 being assigned to the rower in the seat closest to the bow and counting up towards the stern. The rower sitting in the seat furthest to the stern is also referred to as the stroke as they set the pace and all the other rowers must follow his or her lead. For example, in an eight-person boat seat 8 would be the stroke rower (Figure 5).

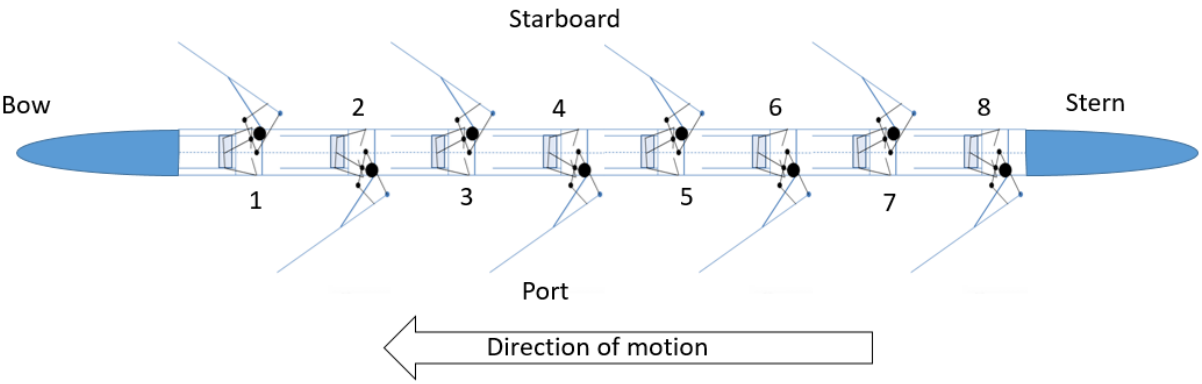


Figure 5. The bow, stern, port and starboard orientations and seat numbers of an 8 person rowing boat.

2.5 Rigging

The rigging of a boat refers to the configuration of the equipment that is attached to the boat. Rowing equipment can be adjusted in order to better suit the physical characteristics of the rowers in the boat. The rigger is a piece of equipment that is attached and extends from the side of the boat. The rigger holds the oarlock or the piece of equipment in which the oar is placed which allows the rower to move the oar. Distances that are often adjusted are the spread, the inboard and the outboard. The spread is the distance from the pin, or the point that the oarlock rotates around, to the midline of the boat. See the oar section for the definition of the inboard and the outboard (Figure 6).

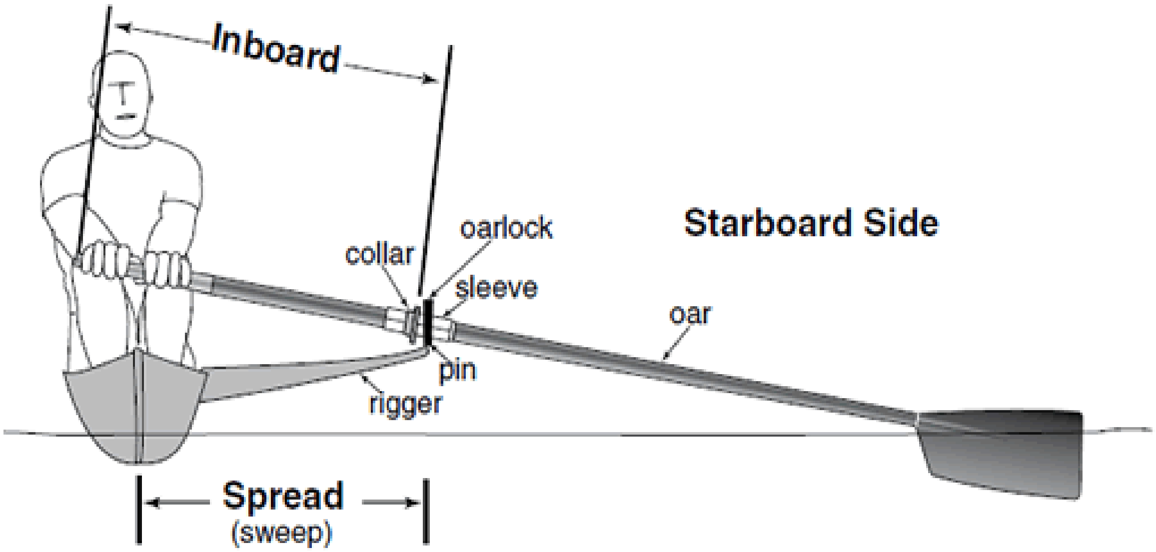


Figure 6. Sweep rowing equipment and parts of the boat (Setting Inboard, n.d.)

2.6 The oar

The oar is made up of five components: the handle, the shaft, the collar, the sleeve and the blade (Figure 7). The handle is the portion of the oar that is gripped by the rower. The blade is the specially shaped, large flat portion at the end of the oar, which is moved through the water to propel the boat forward. The shaft is a long tube that travels the length of the oar from the blade to the handle. The sleeve is an expanded section of the oar shaft that is placed in the oarlock to provide a fixed point to the boat. The collar is attached to the sleeve and its function is to prevent the oar from sliding through the oarlock so that the oar will stay at a fixed lever position during every stroke. The part of the oar from the collar to the end of the handle is called inboard and the part of the oar from the sleeve to the tip of the blade is called the outboard.

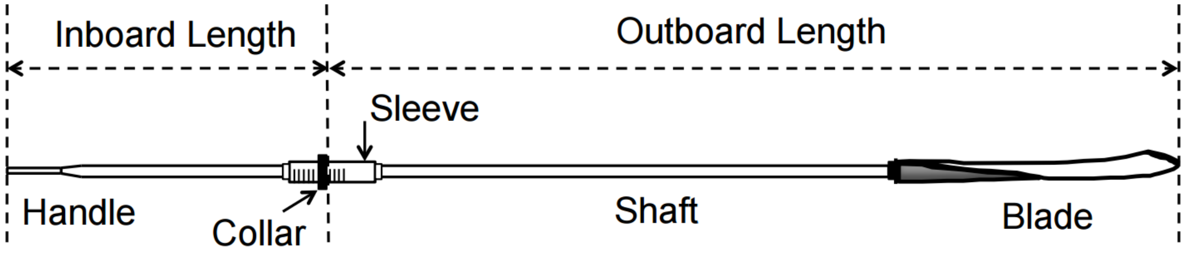


Figure 7. The components of the oar (Laschowski, 2014)

Chapter 3

3 Literature Review

3.1 Overview

The rowing stroke is a complex movement that has been examined in the literature from a number of different perspectives. The following will present a review of the available rowing literature with a focus on rowing kinematics and will also briefly examine previous research that makes use of aerial drones.

3.2 Research methods

Because rowing is performed on the water, there are certain difficulties that are associated with studying the sport of rowing. The primary difficulty is an inability to control the environment, for example, the weather or the calmness of the water. Along with environmental concerns there are also limitations with equipment that can be used on the water. The methods that are most commonly used to study the sport of rowing have been shaped by these challenges. Hand held cameras, potentiometers and strain gauges are frequently used to examine the rowing stroke on the water. These methods are common as they make use of equipment that can be placed on a rowing boat or be brought on to the water in a coach boat.

Rowing ergometers are often chosen as the preferred method of study as they can be used in laboratories which means that the environment can be controlled and more measurement equipment can be used, for example, 3D motion capture systems. This increased level of control removes many of the challenges that are associated with researching rowing on the water.

3.3 Ergometer compared to on the water rowing

There are several types of ergometers: stationary and dynamic ergometers, as well as sweep and sculling simulators. As the name suggests, stationary ergometers are designed to stay motionless relative to the ground. The breaking system and the feet are fixed to the overall apparatus, while the seat is able to move along a rail system (Kleshnev, 2005; Fleming, Donne & Mahony, 2014). A popular example of a stationary ergometer is the Concept 2 rowing machine (Concept 2 Inc., Vermont, USA; see Figure 8.). Dynamic ergometers employ a system where the feet are free to move relative to the ground and are not fixed in place. These types of ergometers were developed in an attempt to more accurately simulate the movement of the rower's center of gravity in a rowing boat (Fleming, Donne & Mahony, 2014; Kleshnev, 2005). A popular example of a stationary ergometer is the so-called Rowperfect (Rowperfect LTD, Duffield, Derbyshire, UK ; see Figure 9.). There are also several other versions of more specialized ergometers that are set up specifically to simulate the sweeping and sculling motions, with the most popular being the Stanford rowing ergometer (no information on the company could be found) (Nelson & Widule, 1983; Strahan, Burnett, Caneiro, Doyle, O'Sullivan & Goodman, 2011). There are other sweep rowing simulators, however, they have not been studied in the literature (example, see Figure 10.).

Figure 8. A standard Concept 2 rowing ergometer (Model D, n.d.).

Figure 9. A Rowperfect ergometer (No Author, 2010, December 12)

Figure 10. Oartec sweep and scull rowing simulator (Oartec Rowing & Sculling Simulator, n.d.).

Due to the popularity of ergometers as training tools, a number of studies have compared ergometers to on the water rowing and demonstrated both similarities and differences. Understanding how comparable ergometers are to on the water rowing and where they differ is essential to interpreting rowing research.

Lamb (1989) compared the kinematics of sweep rowing with a Stanford sweep rowing ergometer in the sagittal plane. He found similar movement patterns and velocities between the trunk and lower limbs. However, he found significant differences in the velocities of the upper arm, lower arm and hand with much greater velocities in the upper limbs being found in on water rowing when compared with the ergometer. Velocities in the upper arm, lower arm and hand were not uniform throughout the entire stroke and the greatest differences in velocity were noted at the beginning and the end of the stroke, especially for the hand and the lower arm. Lamb (1989) attributed the differences to slippage of the oar during the beginning and end of the drive phase. However, Kleshnev (2005), who also noted greater handle velocity using a Concept 2 and Rowperfect ergometer, attributed the differences to the fact that the hands must travel a greater total distance and take a curvilinear trajectory as opposed to the ergometer where the hands moved in a straight line. Martindale & Robertson (1986) using a Gjessing ergometer (no information on the company could be found) found similar results with displacement of the handle in the X direction being equal for ergometers and on water rowing, but a greater total hand movement for on water rowing. Despite the differences in velocity and total movement of the upper limbs, Lamb (1989) concluded that the ergometer is a good approximation of the rowing stroke as he determined that the differences in the hands represented a minor part of the complete rowing stroke when compared to the trunk and lower limbs. This is in agreement with Elliot, Lyttle and Birkett (2002) who found similar body angles for the lower limbs, trunk and hands when examining sculling on the water and ergometer rowing at multiple stroke rates using a dynamic Rowperfect ergometer.

Despite the similarities observed between on water and ergometer rowing, Fleming et al (2014) found that there were greater drive times and drive to recovery ratios for on water rowing when compared to both the stationary Concept 2 and dynamic Rowperfect ergometers. It was also found that these differences in drive time and drive to recovery ratios increased at higher intensities. When comparing the two ergometers, the stationary ergometer had a greater drive time and drive to recovery ratio compared to the dynamic ergometer. Kleshnev (2005), in comparing on water rowing to, stationary Concept 2 and dynamic Rowperfect ergometers, found similar results to Fleming et al (2014). Both the dynamic and stationary ergometers had faster drive times than on water rowing, with the dynamic ergometer having the shortest drive times. Kleshnev (2005) also found shorter horizontal distances of the seat traveling in X direction for both ergometers when compared to on water rowing. Contrary to Lamb (1989) and Elliot et al (2002), Kleshnev (2005) concluded that rowers with stronger upper bodies performed better on ergometers and that the differences were great enough between on water rowing and ergometer rowing that the two should be considered two different types of exercises.

The primary differences between on water and ergometer rowing have been observed in the upper limbs, specifically with greater total movement and velocities occurring in the lower arms and hands for on water rowing. Along with these differences there are still many rowing questions that need to be answered and the differences observed between on water and ergometer rowing point to the position that examining the on water stroke is of greater benefit than a simulated stroke in the laboratory. This is especially the case for sweep rowing as there is no movement in the transverse plane on the two most popularly used and studied ergometers, the Concept 2 and the Rowperfect.

3.4 Technique and sequencing

The rowing stroke is a full body movement in which the majority of power is generated by the legs and the trunk. Rowing styles and techniques can vary greatly from rower to rower. Kleshnev (2011) has identified four main different rowing styles. He describes two types of sequencing: simultaneous, in which the rower extends the trunk and the legs at the same time and consequential, in which the legs or the trunk are extended first and then followed by the remaining body segment. Both simultaneous and consequential sequencing are then characterized by either a trunk or leg emphasis. A trunk emphasis is defined by greater trunk flexion at the catch and extension at the finish. A leg emphasis is characterized by a longer leg drive with very little trunk flexion at the catch and extension at the finish. It is not stated if one style is preferable, however, styles that involve greater trunk activation were noted as producing more power during the drive phase. This is in agreement with Buckeridge, Bull & McGregor (2015) who found that greater degrees of hip flexion or lean towards the stern at both the catch and midway through the drive contributed to greater foot forces during the entirety of the drive phase. Greater extension at the finish has also been found to produce greater power (Bell, Bennett, Reynolds, Syrotuik, & Gervais, 2013). Despite individual styles, there have been a number of studies that have examined the sequencing of the stroke.

Despite differences in rowing technique it appears that there is a specific movement pattern to maximize handle velocity. Nelson & Widule (1983) examined trunk, hip and knee angles over the duration of a rowing stroke using a Stanford sweep rowing ergometer at 30 strokes per minute (SPM). It was found that angular velocity of knee extension was the quickest at the beginning of the drive followed by extension of the trunk nearing the end of the drive phase. Lamb (1989) found that the lower legs accounted for 76% of linear velocity of the seat on the water and 68% on the ergometer in the X direction. Nelson & Widule (1983) determined that the most effective sequence for maximizing handle velocity is knee extension followed by the trunk extension. It was also determined that more skilled rowers time their peak knee and trunk angular velocities so that they are as close together as possible. It appeared that close peak knee and trunk angular velocities lead to higher total linear handle velocity, with the greatest handle velocities being observed when knee and trunk extension angular velocities both peaked with the oar angle at 0^o.

Pollock, Jones, Jenkyn, Ivanova & Garland (2012) have also examined the sequencing of the stroke. Pollock et al (2012) made use of a Concept 2 stationary ergometer and primarily examined sequencing in the sagittal plane. A 2000m maximal effort ergometer test was used and Pollock et al (2012) found similar results when examining angular velocities of knee and trunk extension. However, the researchers did find some differences and noted that during the first 3% of the stroke the oar handle did not move. This indicates that the knees begin by extending without moving the handle. During the drive phase, the arms stayed mostly straight and did not begin to bend until approximately 35% of the way into the drive. A key observation by Pollock et al (2012) was that the kinematics of the drive changed as rowers fatigued. Trunk extension and flexion of the arms began to occur later in the drive. The arms also began to contribute less power along with poorer coordination of knee and trunk extension. With less coordination, the trunk began producing a greater amount of power relative to the legs. It was also observed that some rowers began to increase trunk flexion at the catch by as much as 10^o. The deterioration of the synchronization of knee and hip extension indicates that rowers' technique changes and becomes less efficient as they fatigue (Pollock et al, 2012; Soper & Hume 2005).

As Kleshnev (2011) outlined, there are a number of different rowing techniques. However, based on the findings of Nelson et al (1983) and Pollock et al (2012) there are some indications that there are rowing techniques to maximize X velocity of the handle, which is determined by the timing of the extension of the knees and the hips. The research evaluating sequencing has focused on the sagittal plane, and there is currently a gap in the literature with regards to technique and sequencing in the transverse or frontal plane.

3.5 Lateral Movement

There is very limited research available on lateral movement in rowers and there is no kinematic information that tracks the movement of the hands and shoulders in the transvers plane. Bechard, Nolte, Kedgley & Jenkyn (2009) examined total kinetic energy (TKE) (J) in the frontal plane using a hydraulic ergometer that mimicked sweep rowing. It was found that the lateral movement was responsible for 17.8%±1% of the TKE of a stroke and was consistent during both the drive and recovery. This represents a significant amount of TKE and merits further investigation. Strahan et al (2011) examined axial rotation and lateral bend of the spine by using a Stanford sweep rowing ergometer and placing sensors on the spine at stroke rates of 18, 22 and 26 SPM. It was found that at the catch, there was approximately 15^o of axial rotation in the spine towards the side on which the oar was located. This axial rotation occurred at the pelvis with the majority of the rotation occurring at the catch and very little at the finish. Approximately 10^o of lateral bend towards the oar side at the catch was also observed. This bend occurred at the level of the upper lumbar and lower thoracic spine with the greatest amount of bend observed at the catch and very little at the finish. The axial rotation was only observed through the initial 50% and lateral bend through the majority of the drive phase. This indicates a substantial degree of lean and twist over the duration of a sweep rowing stroke.

There have been several studies that evaluated asymmetry in rowers and indirectly evaluated some aspects of lateral movement. Buckeridge et al (2012) found asymmetries in muscle activation using EMG in the legs of sweep rowers, however, there was not enough evidence to detect a relationship between the side that the sweep rower rowed on and leg dominance (Buckeridge et al, 2012; Buckeridge, Bull, & McGregor, 2014). However, Parkin, Nowicky, Rutherford & McGregor (2001) did find differences in EMG readings on the erector spinae that correlated with the side that the rower rowed on, indicating that lateral movement appears to have an effect on muscle activation.

The lateral aspect of the stroke is of particular importance to sweep rowing and has not been explored very thoroughly. There are still a number of questions surrounding lateral movement and much more study is required to develop a clearer understanding of this component of the rowing stroke.

3.6 Trunk and spine

The movement of the trunk plays an extremely important role in rowing technique. The lower back is also an area that is at risk for chronic injury amongst rowers. In a survey of 1632 collegiate rowers over a 20-year period, 32% experienced back pain at some point during their intercollegiate rowing careers (Teitz, O’Kane, Lind & Hannafin 2002). For 26.5% of athletes, the pain was severe enough to prevent them from participating for one month and for 15.8% of athletes, the injury was severe enough to end their participation in the sport (Teitz et al, 2002). Holt, Bull, Cashman & McGregor (2003), in examining experienced rowers, found that 20% had experienced a chronic overuse injury of some variety at some point in their rowing career, with back pain being a common complaint. Because of the high rates of lower back pain and injury, examining the trunk and spinal kinematics is a popular topic in rowing research. The nature of the rowing stroke requires that the trunk be continuously flexed and extended, which has been associated with disc herniation, putting rowers at risk of back injury (McGill, 1997).

There have been several studies that have examined the kinematics of the spine over the duration of a rowing stroke. In terms of changes in spinal kinematics, fatigue appears to be the most important factor, with increased flexion being observed in the spine over the duration of the rowing session (Bull & McGregor, 2000; Caldwell, McNair, & Williams, 2003; Holt et al, 2003; Mackenzie, 2008; Pollock et al, 2009; Pollock et al, 2012; Wilson, Gissane, Gormley & Simms, 2013). Technique can also have an effect as it has been found that quick loading at the beginning of the drive puts rowers at particular risk of injury (O’Sullivan, O’Sullivan, Bull & McGregor, 2003). Caldwell et al (2003) found that there was a reduced ability to control movement of the lumbar spine as rowers fatigued and suggested that fatigue impaired the proprioception of the rower. It was also suggested that anterior rotation of the pelvis could be a possible strategy to reduce flexion in the lower back and reduce the risk of injury (Caldwell et al, 2003; McGregor, Patankar & Bull, 2008). Pollock et al (2012), using a stationary Concept 2 ergometer, also suggested that maintaining coordination of the extensors of the spine and the pelvis after the catch may be an effective method to protect the spine. When examining the differences between sweeping and sculling using a specialized ergometer, Strahan et al (2011) found very little difference between flexion and extension. A difference between axial rotation and lateral bend was observed (see lateral movement section).

There appear to be several factors that affect the movement of the trunk, with fatigue being the most extensively researched. Further research is required to properly evaluate all the contributing factors to movement of the trunk during the rowing stroke. There is very limited information about how lateral movement affects the spine, although this is an area that merits further exploration.

3.7 Stroke rate

Stroke rate is defined as the number of strokes that a crew or individual rower will take in one minute. Stroke rate at race pace will vary based on the boat and class of rower. Race pace is usually around 30-40 SPM (Soper & Hume, 2004). The average stroke rates for heavyweight men and heavyweight women’s eights for a 2000m race for Olympic crews were 39.9 and 37.9 SPM respectively. The average for Olympic lightweight men’s fours was approximately 40 SPM. There is no information about lightweight women’s sweeping stroke rates as lightweight women only scull at the Olympic level (Kleshnev, 2014). Training paces are typically much lower and will range anywhere from approximately 18-40+ SPM depending on the training goals of the session (Soper & Hume, 2004).

There have been some differences in movement patterns observed at different stroke rates using stationary ergometers. McGregor (2004) observed in less experienced rowers that as stroke rate increased thoracic flexion and shoulder protraction increased in order to maintain longer strokes. This is potentially dangerous as it puts the rower at greater risk of injury. A faster leg drive was also observed along with poorer consistency in the sequencing of body segments over the duration of a stroke as stroke rate increased (Mcgregor, Bull & Byng-Maddick, 2004). Kleshnev (1986) also observed decreased efficiency of the stroke at increasing stroke rates. Athletes are also less efficient when achieving greater linear velocity of the oar handle at higher stroke rates (Hofmijster, Van Soest & De Koning, 2009; Hofmijster, Landman, Smith & Van Soest, 2007). In examining the upper limbs using more experienced rowers, it was observed that males increased total energy expenditure as stroke rate increased, whereas female rowers decreased energy expenditure in the upper body (Attenborough, Smith, & Sinclair, 2012).

3.8 Oar arc

Oar arc is defined as the angular displacement between the angles of the midline of the shaft at the catch and the finish in the transverse plane. Oar angle is typically measured by placing a potentiometer on the oarlock with 0^o defined as the position where the oar is perpendicular to the boat (Bettinelli, Placido, Susmel & Toyo, 2010; Kleshnev, 2015). The direction of the oar angle is defined through negative sign of the angle towards the catch and positive angles towards the finish. The angular velocity during the drive is then positive using this definition. The length of the stroke of an athlete can be affected by many components: the anthropometry, the rigging, the stroke rate and the experience level of the athlete (Barrett & Manning, 2004, Baudouin, & Hawkins, 2002).

The average oar arc for Olympic caliber heavyweight men sweep rowers is 92^{o}, with a catch angle of -59 ^{o} and a finish angle of 33^{o} (Bettinelli et al, 2010; Kleshnev, 2015). For Olympic heavyweight women sweep rowers the average oar arc is 90^{o} with a catch angle of -58^{o} and a finish angle of 32^{o}. Olympic level lightweight men have the same average oar angles as heavyweight women. More experienced and larger rowers will have longer strokes and it can be expected that lower level rowers, at the club or collegiate level, will have 3-5^{o} shorter oar arcs.

Stroke rate also has an effect on stroke length. The longest stroke lengths have been observed at approximately 24 SPM (Kleshnev, 2011). Using stroke length measured as the distance of the handle in the X direction, stroke rates less than 24 SPM have been observed to have handle distances that are approximately 2-3cm shorter than at a stroke rate of 24 SPM. At a stroke rate of 40 SPM in 8 person sweep rowing boats, stroke length has been observed to be as much as 10-11 cm shorter than at a stroke rate of 24 SPM. This reduction in length typically occurs at the catch with very little shortening at the finish (Kleshnev, 2011).

3.9 Differences between men and women

There are several differences between male and female rowing athletes. The key differences are anthropometric in nature. Female rowers are typically smaller than men, with lower fat free mass (Schranz, Tomkinson, Olds & Daniell, 2010; Yoshiga & Higuchi, 2003). Yoshiga et al (2003), when examining men and women it was found that the size of the rower was directly related to performance; however, when men and women were matched for height, weight, aerobic capacity and lean body mass, it was found that men performed a 2000m ergometer test approximately 4% faster than women (Yoshiga & Higuchi, 2003). When solely matched by size and weight, the difference rose to 10%. This result is in agreement with Smith & Spinks (1994) who found that the main differences between men and women was that women produced less power per kg of body mass along with a shorter oar arc. When examining the upper limbs in ergometer rowing, it was found that men produce more power with their upper body as stroke rate increased whereas women produce less (Attenborough, Smith & Sinclair, 2012). Along with differences in power, different rowing kinematics have been observed between women and men. When analyzing the movements of the pelvis using a stationary Concept 2 ergometer, it was noted that women had much greater anterior pelvic rotation at the catch than men, although the difference was smaller at higher intensities (McGregor et al 2008). This greater anterior rotation allowed women to achieve greater hip flexion at the catch and extension at the finish, lengthening their stroke. McGregor et al (2008) concluded that female rowers were better able to optimize their stroke length than their male counterparts. These findings are in disagreement with Strahan et al (2011) who found no differences between men and women when examining spinal kinematics.

The key differences between women and men appear to be related to size and power output. Women and men also appear to exhibit some differences in their rowing technique, although due to contradictions in literature, it is difficult to definitively state where these differences lie.

3.10 Differences between experienced and novice rowers

Experience is a significant factor in achieving speed on the water and one can find several differences between experienced and novice rowers. The key difference appears to be that novice rowers are less efficient at achieving their desired oar handle velocity and are less coordinated in the movement of their body segments. The sequencing of body parts is much poorer than with experienced rowers, especially at higher stroke rates. At 30 SPM experienced athletes were found to be 11% more efficient with a hand velocity in the X direction 19% greater than less experienced rowers (Nelson, & Widule, 1983). When tested on a Concept 2 stationary ergometer, poorer control over the spine was also observed with novice rowers experiencing an increase of 4-5^{o} of flexion in the spine as opposed to 1.6^{o} in experienced rowers at the catch as they fatigued (Wilson et al, 2013). Despite the differences in kinematics, Smith & Spinks (1995) found that the most noticeable difference between novice, intermediate and elite rowers was power production per kg with power production increasing with experience level.

3.11 Drones

Aerial drones have been in use in a research capacity since the 1950s (Howe, 1957). Historically, drones have been used for military surveillance or as a cost effective and accurate way to perform ecological surveys (Koh & Wich, 2012; Quilter & Anderson, 2000). The price of operating a drone, relative to a plane or a helicopter, along with greater control and ability to fly at slower speeds, has made drones a desirable tool for survey research. These drones were typically modeled after airplanes, although more recently, popular drones have been formatted after helicopters and use four or more propellers. This set up allows the drone more mobility and versatility. Although drones are primarily still used as ecological, surveillance and agriculture tools in a research capacity, more recently, the use of drones has begun to branch out into a wider variety of fields.

Figure 11. A DJI Phantom 3 Professional, the drone that was used for this study (DJI Phantom 3 Professional, n.d.).

The DJI Phantom, an off-the-shelf drone using a four propeller design, has been used to survey and develop 3D models of archaeological and historical sites (Uysal, Toprak, & Polat, 2013). It has also been used to evaluate CO_2 soil levels, map 3D landscapes and weather patterns, as well as capture news stories (Alexander & Harvey,2014; Irizarry, Gheisari, & Walker, 2012; Kreimer, & Waite, n.d.; Rekittke, & Ninsalam, 2014; Uysal, Toprak, & Polat, 2013). The Parrot AR, also an off the shelf drone using a four propeller system, was tested as a safety inspection tool for building sites. Researchers found that the drone was an effective tool, however, inspectors were limited by the drone’s short flight time of approximately 13 min.

Only one attempt to use a drone as a tool to analyze human motion was found. Higuchi, Shimada & Rekimoto (2011) made use of a Parrot AR drone to provide immediate feedback to athletes performing discrete motions. The drone recorded a video of the athlete and would play their movements back to them in real time via a head mounted display. This was found to be ineffective and primarily a distractor for the athletes. The main problems that were experienced were again short flight times and also a delay in the video feed that was too great to be useful to the athletes (Higuchi et al, 2011). Although not for research purposes, drones have been used in both by amateurs and professionals to observe sporting events, including both the summer and winter Olympics (Feltman, 2014, February 18). There are also a number of videos posted on Youtube that have made use of a drone to capture rowing, however, none of these videos have examined the stroke in any detail (Nye, 2015; Schad, 2014; Trummer, 2012). No research has been found that has made use of a drone as a rowing or biomechanics research tool.

With increased affordability and availability, drones have become very popular. With this increase in popularity, Transport Canada has begun to introduce greater restrictions and regulations for the use of drones in all capacities and requires that special permissions be received and a series of regulations be followed for flights (No Author, 2016, June 10). It is also anticipated that stricter regulations surrounding the use of drones will continue to be introduced in the future. Despite legal restrictions and the limitations of the drones themselves, their use as research tools should be further investigated.

3.12 Conclusion

This review presented a cross section of the available rowing research that relates to the current study. Rowing kinematic research has almost entirely focused on movement in the sagittal plane. While there is some research that has examined movement in the frontal and transverse planes, it is very limited. Lateral movement is an important part of the rowing stroke and has been studied very little. It is possible that the lateral aspect of the stroke has been ignored due to the challenges of collecting data on the water. The use of drones presents an opportunity to examine the rowing stroke from a new perspective and could potentially answer many rowing related questions. However, drones have been demonstrated to have their own limitations and it is currently unclear how effectively they can be used as data collection tools.

Chapter 4

4 Methods

4.1 Participants

Forty athletes from The University of Western Ontario's rowing team participated in the study. Twenty-four men and sixteen women were recruited: eight heavyweight men (HWM), eight heavyweight women (HWW), eight lightweight men (LWM), eight lightweight women (LWW) and eight novice men (NVM). Thirty-two of the athletes were varsity rowers. The remaining eight rowers were novice rowers. Only rowers who were sweep rowers and rowed in eight person boats were recruited. The experiment and the procedure was explained to the rowers and all participants were afforded opportunities to ask questions. All participants signed letters of information and provided their consent to the protocol that was approved by the institutional research ethics board.

4.2 Data collection

Before data collection began the drone operator was familiarized with the rules, regulations and safety procedures surrounding the use of drones using the drone manuals provided by the company and regulations outlined by Transport Canada. A special flight operation certificate (SFOC) was obtained from Transport Canada, which gave permission to fly the drone at the Fanshawe Lake rowing facility that is used by The University of Western Ontario rowing team as home base. A notice to airmen (NOTAM) was filed with the London Air Traffic Control Tower (ATC) before each flight. The ATC was also notified immediately before any flights began and after they were completed. The drone was not flown unless permission was received from the ATC. The drone was only flown on days where there was minimal wind and cloud cover in compliance with regulations outlined in the SFOC and in keeping with Transport Canada’s regulations.

Measurements were obtained at The University of Western Ontario rowing training facility at Lake Fanshawe. Data was collected during the University rowing season on September 20th and 27th and October 10th and 24th, 2015.

Only eight-person rowing boats were recorded and each group used their own shell. The entire eight-person boat was captured in every frame, mainly due to concerns about the drone’s limited flight time. The drone that was used to record the rowers was a DJI Phantom 3 Professional (DJI Technology Co. Ltd, Global Headquarters Nanshan District, Shenzen, China). The camera that was used to collect all the video records was the Phantom 3 – 4k (DJI Technology Co. Ltd, Global Headquarters Nanshan District, Shenzen, China). Subjects were recorded at 30Hz at a shutter speed of 1/1000s and a resolution of 3840x2160 pixels. The drone was flown over the boat at an altitude of 12m and as close to the center of the boat as possible. Altitude was measured using the output from the GPS and barometer mounted on the drone (no technical information was made available on these components by DJI Technology Co. LTD). All boats were recorded in sunny conditions with minimal wind and cloud cover between the hours of 8am and 12pm. Flights only occurred if visibility was greater than 4.8km, wind speeds were below 30 km/hr, the cloud ceiling was greater than 168m and the temperature was above 5°C. Weather was verified using local weather forecasts. Each trial was recorded during regular rowing training sessions. This ensured adequate natural light for the drone and minimized the impact of the trials on rowing training activities. Each trial consisted of ten strokes at three different stroke rates for a total of 30 strokes. The stroke rates that were chosen were 20, 26 and 30 SPM. Stroke rates were capped at 30 SPM as it was considered unlikely that the novice rowers would be able to reach higher stroke rates. Each trial at the various stroke rates was recorded continuously. The spread and inboard were measured for each boat and they did not differ between athletes within each respective boat. Table 1 shows the spread and inboard measurements for each boat. Measurements were also performed on the boat for later reference. Distances between the distinct markers on the stern and bow of the boat as well as between each of the pins were measured for each boat for calibration purposes.

Table 1. Inboard and spread measurements in cm for each boat.

Boat	Inboard (cm)	Spread (cm)
HWM	113	83
HWW	114	84
LWM	113	84
LWW	113	83
HWW	114	84

4.3 Data analysis

The raw video footage of the whole 20-stroke rowing piece was cut into discrete clips of single strokes using Adobe Premier Pro CC 2015 (Adobe Systems Incorporated, San Jose, California, USA). Five frames before the catch at the beginning of the stroke and after the catch at the end of the stroke were included. Strokes were then numbered and the duration of the stroke was noted to calculate stroke rate for the respective trial. Of the 10 recorded strokes at each stroke rate, the best three strokes were analyzed. These strokes were chosen based on the quality of the recording and consistency regarding the position of the boat with respect to the center of the frame. The individual clips were then loaded into a motion analysis software, Kinovea version 0.8.15 (2011-05-15). Using Kinovea, four points were visually landmarked and tracked on each rower using skin artifacts:

- The metacarpal-phalangeal joint of the first digit on the right hand
- The metacarpal-phalangeal joint of the first digit on the left hand
- The acromion process on the left shoulder
- The acromion process on the right shoulder

The left and right metacarpal-phalangeal joint and acromion process were named inside hand and inside shoulder if they were on the oar side and were named outside hand and outside shoulder if they were not on the oar side.

Figure 12. An image of an individual rower taken by the drone with the tracked points marked in blue.

Ten points were tracked on each boat:

- The marker at the bow of the boat

- The marker at the stern of the boat
- The pin for seat 8
- The pin for seat 7
- The pin for seat 6
- The pin for seat 5
- The pin for seat 4
- The pin for seat 3
- The pin for seat 2
- The pin for seat 1

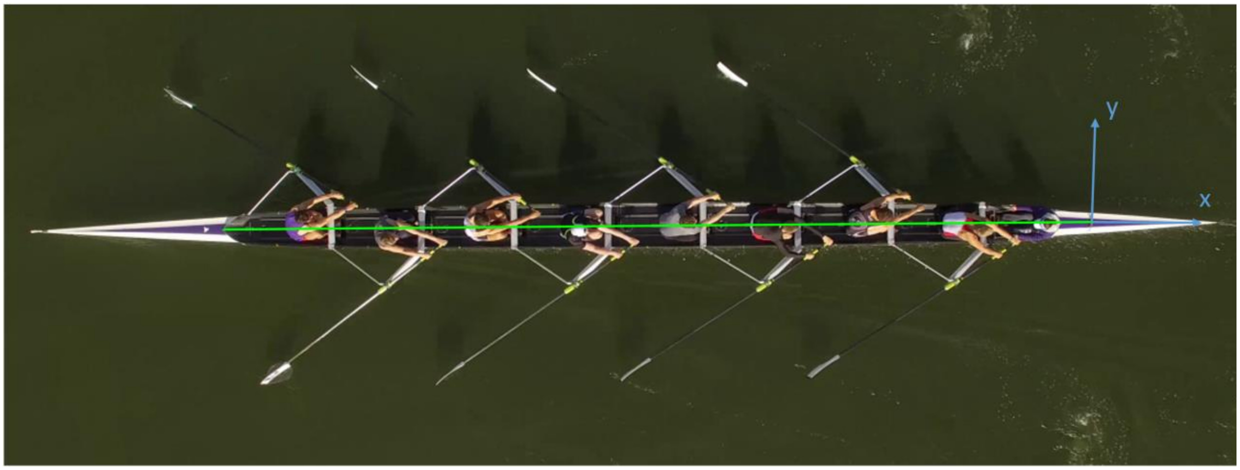


Figure 13. An image from a video of the entire rowing boat taken by the drone. The relative coordinate system is shown in blue, with the origin set at the stern. The distance of known length between the distinct points on the bow and stern of the boat is the green line.

An object of known length using the distance between the 6th and 5th pins was calculated to quantify for any measurement error. An Excel (Microsoft, San Jose, California, USA) spreadsheet with the data was generated for each combination of boat and stroke condition.

The origin of the X-Y coordinate system in Kinovea was set in the middle of the frame for the original digitized data. Because the boat did not stay in the same position on the screen for the duration of a stroke, a relative coordinate system was the calculated with the origin being set at the stern marker. Since the boat did not always stay parallel to the video frame, the X axis was rotated to line up with the center of the boat. The angle of the boat was calculated using the formula:

$$\theta_{boat} = tan^{-1}\left(\frac{y_{stern}-y_{bow}}{x_{stern}-x_{bow}}\right) \tag{1}$$

The formulas that were used to rotate the coordinates systems were

$$x = xcos\theta_{boat} - ysin\theta_{boat} \text{ and } y = xsin\theta_{boat} + xcos\theta_{boat} \tag{2}$$

for counter clockwise rotation and

$$x = xcos\theta_{boat} + ysin\theta_{boat} \text{ and } y = -xsin\theta_{boat} + xcos\theta_{boat} \tag{3}$$

for clockwise rotation. Depending on the rotation of the boat, one set of these formulas were used for each of the tracked points on each rower and on the boat, excluding the tracked points at the stern. A Savitzky-Gola filter (Appendix C) that passed through nine points equidistant from the original value was used on all adjusted points (Zurmühl, 1965, 336). Five frames before catch and after the second catch were included for smoothing purposes.

A scale factor (SF) was calculated using the known distance between the bow and stern marker for the first frame of each analyzed clip and then adjusted for each of the following frames to account for fluctuations in the drones' flight height. The measured length (ML) represents the object of known length's measured length in Kinovea and the actual length (AL) represents the object of known length’s measured length on the boat. The SF was the ratio between ML and AL. Each data point was then adjusted with the SF.

4.4 Data reduction and Measures

All measures were calculated using Microsoft Excel. The video frame numbers of the catch position and finish position of each of the segments were noted and six quantities were calculated for each rower from the catch to finish (Figure 14.) of the drive phase of the stroke:

- Shoulder angle
- Oar angle
- Lateral movement of the left metacarpal-phalangeal joint of the first digit
- Lateral movement of the right metacarpal-phalangeal joint of the first digit
- Lateral movement of the left acromion process
- Lateral movement of the right acromion process.

Oar angle is an absolute angle that was calculated using two points on the oar shaft with the pin as the axis of rotation. Oar angle was calculated using the formula:

$$\theta_{oar} = tan^{-1}\left(\frac{x_{pin} - x_{outsidehand}}{y_{pin} - y_{outsidehand}}\right) \tag{4}$$

Shoulder angle was calculated as an absolute angle, with the inside shoulder being set as the center of rotation. Shoulder angle was calculated using the formula:

$$\theta_{shoulders} = tan^{-1}\left(\frac{x_{insideshoulder} - x_{outsideshoulder}}{y_{insideshoulder} - y_{outsideshoulder}}\right) \tag{5}$$

Lateral movement for each of the tracked points on the rowers was calculated by taking the difference in lateral movement from the catch to the finish.

- Right metacarpal-phalangeal joint of the first digit: $\Delta y_{righthand} = y_{finish} - y_{catch}$ (6)
- Left metacarpal-phalangeal joint of the first digit: $\Delta y_{lefthand} = y_{finish} - y_{catch}$ (7)
- Right acromion process: $\Delta y_{rightshoulder} = y_{finish} - y_{catch}$ (8)
- Left acromion process: $\Delta y_{leftshoulder} = y_{finish} - y_{catch}$ (9)

The Y axis for all starboard data was flipped so that port and starboard rowers could be compared.

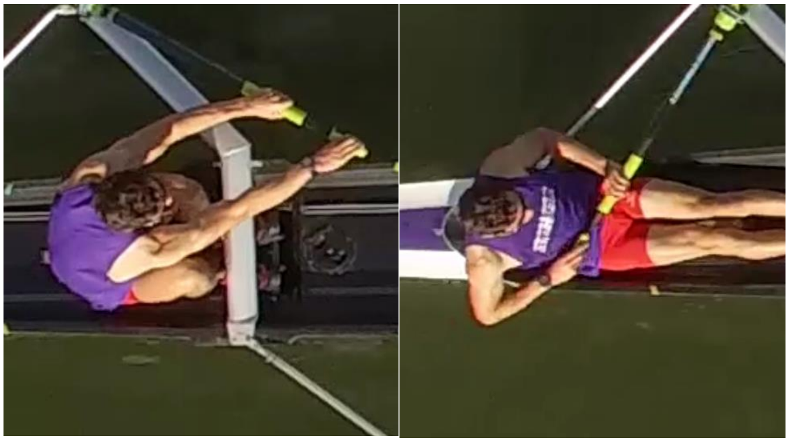


Figure 14. Catch (image on the left) and finish (image on the right) position for a HWM rower.

4.5 Measurement error

Two forms of error were analyzed: digitizing error and camera error.

Digitizing error was measured in two ways. The first was by examining the change in object of known length after the scale factor had been applied. The second method was by digitizing a randomly selected stroke twice and considering the difference between the measured outcomes of the two trials digitizing error.

Camera error was analyzed in a separate trial. A grid of five meters by ten meters was created with cones placed one meter apart creating 50 quadrants on a flat surface. The drone was then flown over top of the grid at an altitude of 12m with the center of the camera being focused on the cone in the bottom right corner of the grid (Figure 15.). The drone was flown to the center cone of the grid to calculate and object of known length was set as a 10m distance that passed through the center of the focal point of the camera. Kinovea was then used to digitize each cone, so that all one-meter segments between cones could be calculated for one frame of the video. The length of each measured segment was then subtracted by one meter to determine total measurement error for each segment in X and Y. Average error for each quadrant was determined for X and Y by taking the average of the two one meter segments that formed the borders quadrant in X and the two one meter segments that formed the borders of the quadrant in Y.

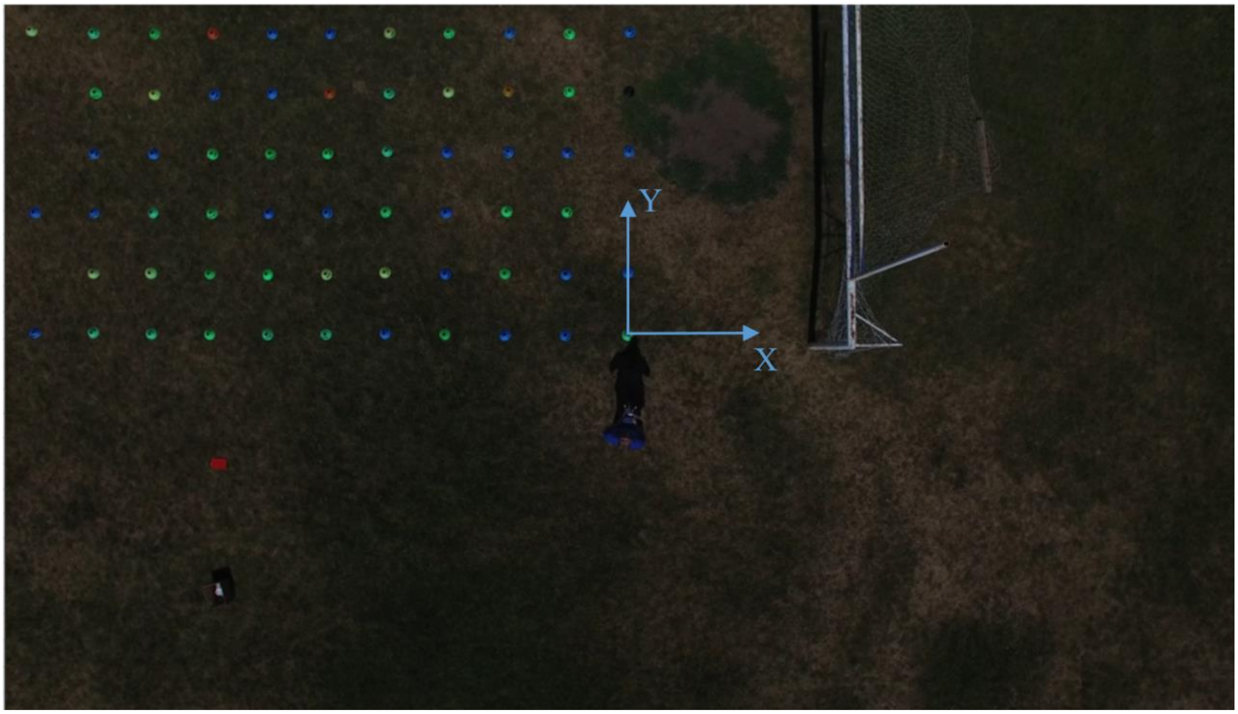


Figure 15. The measurement grid that was used to measure camera error. The distance between each cone is 1m. The X-Y coordinate system was set up at the focal point of the camera.

4.6 Statistical analysis

The repeated measures were aggregated for each stroke condition for each rower. A split plot analysis of variance (ANOVA) was employed for each of the displacement measurements as well as the catch and finish positions. For the split plot ANOVA the dependent observation was stroke rate and the independent observation was the boat or classification of rower (bodyweight, class and sex). The total displacement of each of the tracked points, catch position and finish position were analyzed. Descriptive statistics were calculated for each boat at each stroke rate. A split plot ANOVA was then run to determine if there was a main effect of boat or stroke rate as well as an interaction between the boat and stroke rate. Pairwise t-tests with a Holm Bonferroni correction were used as post-hoc tests when evaluating main effect. When an interaction was detected, an ANOVA was run at each level of the independent variable for each stroke rate with a pairwise t-tests using a Holm Bonferroni correction used as the post-hoc test. All data analysis was done using R statistical analysis software version 3.2.3 (2015-12-10).

Chapter 5

5 Results

5.1 Error

5.1.1 Digitizing Error

An object of known length was calculated by using the distance between two pins. After the scale factor was applied a mean measurement error of 0.8±0.6cm was found. When examining the difference in the stroke that was digitized twice, different degrees of error were observed for different measurements. Table 2 includes the mean and standard deviation of error for each of the calculated variables for each stroke. It was found that the greatest measurement error occurred for the shoulder angle ($2.3^o \pm 1.9^o$) and the inside shoulder (1.6cm±1.2cm).

Table 2. Mean (MN) (and Standard deviation (SD)) of the difference between re-digitized points.

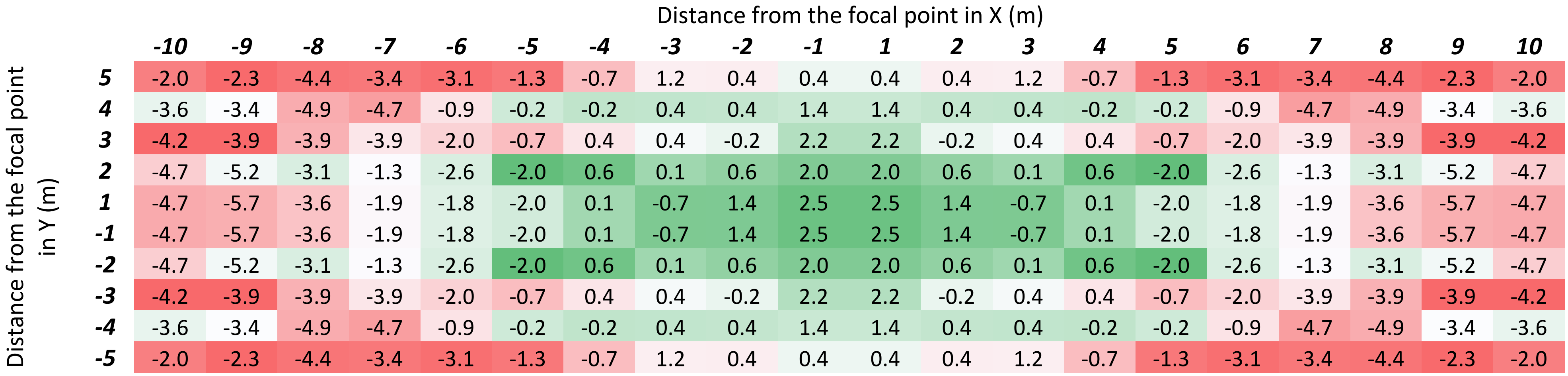
Oar angle (^{o})		Shoulder angle (^{o})		Outside shoulder (cm)		Outside hand		Inside shoulder (cm)		Inside hand(cm)	
MN	SD	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD
0.9	0.9	2.3	1.9	0.8	0.6	1.1	0.7	1.6	1.2	0.7	0.5

5.1.2 Camera Error

There was some distortion of measurement observed when examining the video pictures. Error was found to be greater further away from the center of the frame, Figure 16 illustrates the average distortion per quadrant in the X direction and Figure 17 indicates the average distortion per quadrant in the Y direction. Positive error was observed at the center of the frame and greater negative error was observed the further the measurement point was away from the focal point of the camera. Due to the nature of rowing, the boat does not move at a steady rate and will accelerate and decelerate with each stroke. The sliding mechanism that the rowers' seat is placed on lets the rowers move a significant distance in the X direction relative to the boat. The movement of the boat compounded with the movement of the rowers means that the rowers' total movement in X is likely to be substantial. This means that camera error observed will not be constant for each rower. Digitized points in the X direction were in reality approximately -9 to 9m away from the focal point of the camera while the majority of points were found between 7 to -7m away from the focal point. In the Y direction the majority of points were found between -1.5 to 1.5m away from the focal point of the camera.

5.1.3 Total Error

It is difficult to determine total error as the direction of digitizing error is not known. It is possible that digitizing error and camera error compounded or cancelled each other out. Error would also not be uniform for each rower in each seat of the boat.

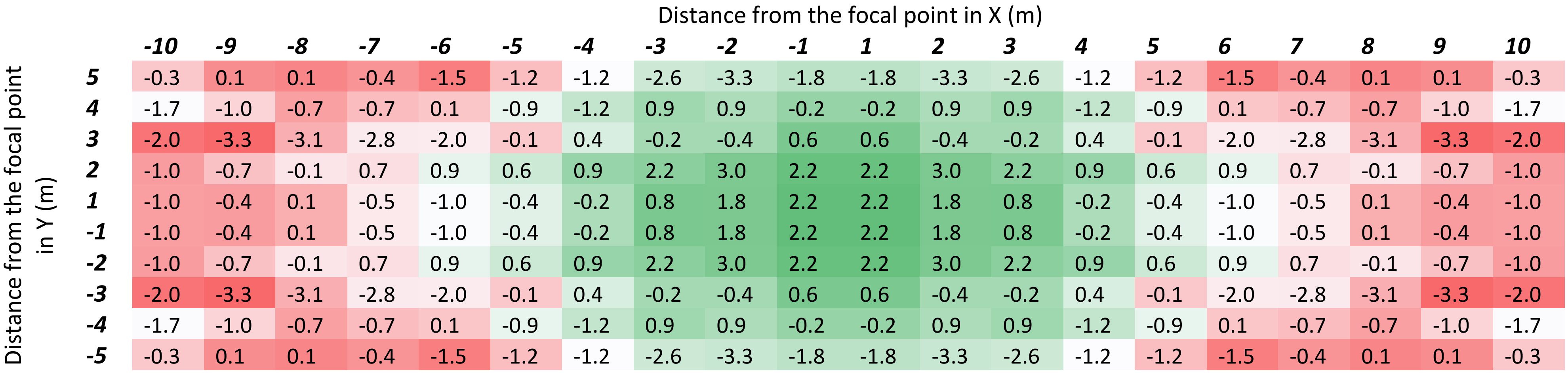


Distance from the focal point in X (m)

Distance from the focal point in Y (m)

	-10	**-9**	**-8**	**-7**	**-6**	**-5**	**-4**	**-3**	**-2**	**-1**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
5	-2.0	-2.3	-4.4	-3.4	-3.1	-1.3	-0.7	1.2	0.4	0.4	0.4	0.4	1.2	-0.7	-1.3	-3.1	-3.4	-4.4	-2.3	-2.0
4	-3.6	-3.4	-4.9	-4.7	-0.9	-0.2	-0.2	0.4	0.4	1.4	1.4	0.4	0.4	-0.2	-0.2	-0.9	-4.7	-4.9	-3.4	-3.6
3	-4.2	-3.9	-3.9	-3.9	-2.0	-0.7	0.4	0.4	-0.2	2.2	2.2	-0.2	0.4	0.4	-0.7	-2.0	-3.9	-3.9	-3.9	-4.2
2	-4.7	-5.2	-3.1	-1.3	-2.6	-2.0	0.6	0.1	0.6	2.0	2.0	0.6	0.1	0.6	-2.0	-2.6	-1.3	-3.1	-5.2	-4.7
1	-4.7	-5.7	-3.6	-1.9	-1.8	-2.0	0.1	-0.7	1.4	2.5	2.5	1.4	-0.7	0.1	-2.0	-1.8	-1.9	-3.6	-5.7	-4.7
-1	-4.7	-5.7	-3.6	-1.9	-1.8	-2.0	0.1	-0.7	1.4	2.5	2.5	1.4	-0.7	0.1	-2.0	-1.8	-1.9	-3.6	-5.7	-4.7
-2	-4.7	-5.2	-3.1	-1.3	-2.6	-2.0	0.6	0.1	0.6	2.0	2.0	0.6	0.1	0.6	-2.0	-2.6	-1.3	-3.1	-5.2	-4.7
-3	-4.2	-3.9	-3.9	-3.9	-2.0	-0.7	0.4	0.4	-0.2	2.2	2.2	-0.2	0.4	0.4	-0.7	-2.0	-3.9	-3.9	-3.9	-4.2
-4	-3.6	-3.4	-4.9	-4.7	-0.9	-0.2	-0.2	0.4	0.4	1.4	1.4	0.4	0.4	-0.2	-0.2	-0.9	-4.7	-4.9	-3.4	-3.6
-5	-2.0	-2.3	-4.4	-3.4	-3.1	-1.3	-0.7	1.2	0.4	0.4	0.4	0.4	1.2	-0.7	-1.3	-3.1	-3.4	-4.4	-2.3	-2.0

Figure 16. Average camera error per quadrant in the X direction in cm. The numbers represent the differences between the measured length and the actual length. A negative number indicates how much smaller the measurement for that quadrant was than 1m and a positive number indicates how much larger the measurement for that quadrant was than 1m. The quadrants that are relatively more positive are coloured in green and quadrants that are relatively more negative are coloured in red with darker and lighter colours indicating lesser and greater positive or negative numbers respectively.



Distance from the focal point in X (m)

Distance from the focal point in Y (m)

	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	7	8	9	10
5	-0.3	0.1	0.1	-0.4	-1.5	-1.2	-1.2	-2.6	-3.3	-1.8	-1.8	-3.3	-2.6	-1.2	-1.2	-1.5	-0.4	0.1	0.1	-0.3
4	-1.7	-1.0	-0.7	-0.7	0.1	-0.9	-1.2	0.9	0.9	-0.2	-0.2	0.9	0.9	-1.2	-0.9	0.1	-0.7	-0.7	-1.0	-1.7
3	-2.0	-3.3	-3.1	-2.8	-2.0	-0.1	0.4	-0.2	-0.4	0.6	0.6	-0.4	-0.2	0.4	-0.1	-2.0	-2.8	-3.1	-3.3	-2.0
2	-1.0	-0.7	-0.1	0.7	0.9	0.6	0.9	2.2	3.0	2.2	2.2	3.0	2.2	0.9	0.6	0.9	0.7	-0.1	-0.7	-1.0
1	-1.0	-0.4	0.1	-0.5	-1.0	-0.4	-0.2	0.8	1.8	2.2	2.2	1.8	0.8	-0.2	-0.4	-1.0	-0.5	0.1	-0.4	-1.0
-1	-1.0	-0.4	0.1	-0.5	-1.0	-0.4	-0.2	0.8	1.8	2.2	2.2	1.8	0.8	-0.2	-0.4	-1.0	-0.5	0.1	-0.4	-1.0
-2	-1.0	-0.7	-0.1	0.7	0.9	0.6	0.9	2.2	3.0	2.2	2.2	3.0	2.2	0.9	0.6	0.9	0.7	-0.1	-0.7	-1.0
-3	-2.0	-3.3	-3.1	-2.8	-2.0	-0.1	0.4	-0.2	-0.4	0.6	0.6	-0.4	-0.2	0.4	-0.1	-2.0	-2.8	-3.1	-3.3	-2.0
-4	-1.7	-1.0	-0.7	-0.7	0.1	-0.9	-1.2	0.9	0.9	-0.2	-0.2	0.9	0.9	-1.2	-0.9	0.1	-0.7	-0.7	-1.0	-1.7
-5	-0.3	0.1	0.1	-0.4	-1.5	-1.2	-1.2	-2.6	-3.3	-1.8	-1.8	-3.3	-2.6	-1.2	-1.2	-1.5	-0.4	0.1	0.1	-0.3

Figure 17. Average camera error per quadrant in the Y direction in cm. The numbers represent the differences between the measured length and the actual length. A negative number indicates how much smaller the measurement for that quadrant was than 1m and a positive number indicates how much larger the measurement for that quadrant was than 1m. The quadrants that are relatively more positive are coloured in green and quadrants that are relatively more negative are coloured in red with darker and lighter colours indicating lesser and greater positive or negative numbers respectively.

5.2 Individual and Crew Data

Three trials at stroke rates of 20, 26 and 30 SPM were analyzed for a total of nine strokes per rower. After analysis certain strokes were found to have too much error and were not used. At 20 SPM for the NVM, LWM and HWM only two strokes could be analyzed. At 26 SPM the LWM only had two analyzed strokes used. At 30 SPM the HWM only had two analyzed strokes used.

Due to the volume of data only significant differences will be reported and only graphical examples will be included in the results section.

5.2.1 Statistics

5.2.1.1 Angles

5.2.1.1.1 Oar Angle

The mean and standard deviation of oar arc, catch and finish angles for each stroke rate can be found in Table 3. For total range of the oar arc a significant main effect of the boat ($p<0.05$) and a significant interaction between boat and stroke rate was found ($p<0.05$). When examining the main effect of boat (mean of all the analyzed strokes) HWM (88.7^{o}±4.2^{o}), HWW (88.8^{o} ±4.5^{o}) and LWM (89.7^{o} ±3.0^{o}) all had significantly greater oar arcs than LWW (84.8^{o} ±4.2^{o}) and NVM (83.2^{o} ±4.7^{o}) ($p<0.05$). When examining the interaction between stroke rate and boat at a stroke rate of 20 SPM, it was found that HWM (91.0^{o}±3.0^{o}) had significantly longer oar arcs than LWW (84.7^{o}±3.7^{o}) and NVM (83.8^{o}±5.2^{o}) ($p<0.05$) and LWM (90.0^{o}±3.2^{o}) had significantly longer oar arcs than NVM ($p<0.05$). LWM (90.8±2.8) were found to have had a significantly longer oar arc than NVM (82.8^{o}±4.4^{o}) at a stroke rate of 30 SPM ($p<0.05$).

When examining the catch position, a significant main effect of the boat was detected ($p<0.05$). HWM (-57.2^{o}±2.5^{o}), HWW (-56.6^{o}±4.11^{o}) and LWM (-58.5^{o} ±3.0^{o}) had significantly greater catch angles than NVM (-51.0^{o}±3.9^{o}) and LWW (-52.6^{o}±3.9^{o}) ($p<0.05$).

There were no significance differences detected between angles at the finish.

Table 3. Oar angle mean (MN) (and standard deviation (SD)) for catch and finish positions and total displacement from the catch to the finish for each boat and stroke rate in degrees.

	Stroke rate 20						Stroke rate 26					
Boat	Catch		Finish		Displacement		Catch		Finish		Displacement	
	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD
HWM	-58.7	2.5	32.3	1.3	91.0	3.0	-56.4	2.4	31.8	1.0	88.2	3.0
HWW	-56.8	4.4	32.2	2.1	89.1	4.9	-56.5	4.5	32.0	2.0	88.4	5.1
LWM	-58.2	3.4	31.8	1.4	90.0	3.2	-58.7	3.1	29.8	1.8	88.4	2.7
LWW	-51.8	4.1	32.9	1.9	84.7	3.7	-53.1	3.7	32.7	2.1	85.7	4.5
NVM	-51.4	3.9	32.4	3.2	83.8	5.2	-50.8	3.6	32.3	2.5	83.1	5.0

	Stroke rate 30						Average					
Boat	Catch		Finish		Displacement		Catch		Finish		Displacement	
	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD
HWM	-56.4	2.1	29.4	4.4	86.8	5.5	-57.2	2.5	31.1	2.9	88.7	4.2
HWW	-56.5	3.9	32.0	2.0	88.8	4.0	-56.6	4.1	32.1	2.0	88.8	4.5
LWM	-58.7	2.9	31.6	1.5	90.8	2.8	-58.5	3.0	31.0	1.8	89.7	3.0
LWW	-53.1	4.2	31.6	4.0	83.9	4.6	-52.6	3.9	32.4	2.8	84.8	4.2
NVM	-50.8	4.4	32.8	2.1	82.8	4.4	-51.0	3.9	32.5	2.5	83.2	4.7

5.2.1.1.2 Shoulder angle

The mean and standard deviation of shoulder arc, catch and finish angles for each stroke rate can be found in Table 4. A significant main effect of both boat ($p<0.05$) and stroke rate ($p<0.05$) were found as well as a significant interaction between boat and stroke rate ($p<0.05$). When examining main effect of boat LWM (40.5° ±6.6°) were found to have significantly greater shoulder arc then, HWW (35.7°±11.1°), LWW (38.0°±6.5°) and NVM (36.7°±6.8°) ($p<0.05$). when examining the interaction between boat and stroke at a stroke rate of 26 LWM (47.9°±9.9°), were found to have significantly greater shoulder arcs than HWW (25.0°±12.9°) ($p<0.05$). No significant differences were detected in post hoc tests for the main effect of stroke rate.

When examining the catch position, a significant main effect of boat ($p<0.05$), stroke rate ($p<0.05$) and interaction between boat and stroke rate was found ($p<0.05$). When examining the main effect of boat, it was found that HWM (-32.0°±8.0°), HWW (-30.0°±9.2°), LWW (-29.6°±5.6°) and NVM (-31.7°±4.6°) all had significantly smaller shoulder angles at the catch then LWM (-39.4° ±7.3°) ($p<0.05$). When examining the interaction between boat and stroke rate at a stroke rate of 26 SPM LWM (-40.9°±8.2°) were found to have significantly greater shoulder angles then HWW (-21.2°±10.7°) ($p<0.05$).

There were no significant differences detected at the finish.

Table 4. Shoulder angle mean (MN) (and standard deviation (SD)) for catch and finish positions and total displacement from the catch to the finish for each boat and stroke rate in degrees.

	Stroke rate 20						Stroke rate 26					
Boat	Catch		Finish		Displacement		Catch		Finish		Displacement	
	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD
HWM	-34.6	5.7	8.4	2.1	43.0	7.1	-28.5	11.0	9.9	7.3	38.4	5.1
HWW	-34.4	3.4	6.7	2.7	41.0	4.7	-21.2	10.7	3.8	3.5	25.0	12.9
LWM	-37.0	6.4	7.3	2.1	44.3	7.2	-40.9	8.2	7.0	2.4	47.9	9.9
LWW	-28.4	6.4	9.0	2.8	37.4	6.3	-30.7	5.5	9.2	5.2	39.8	7.2
NVM	-33.7	5.2	6.3	4.3	39.9	7.1	-31.9	4.2	4.2	5.1	36.1	5.3

	Stroke rate 30						Average					
Boat	Catch		Finish		Displacement		Catch		Finish		Displacement	
	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD
HWM	-32.8	6.0	7.4	3.1	40.1	7.3	-32.0	8.0	8.5	4.7	40.5	6.6
HWW	-34.5	4.5	6.5	4.7	41.0	5.2	-30.0	9.2	5.7	3.8	35.7	11.1
LWM	-40.2	7.5	6.2	3.7	46.4	9.3	-39.4	7.3	6.8	2.7	46.2	8.6
LWW	-29.8	5.6	6.9	4.3	36.7	6.4	-29.6	5.6	8.3	4.1	38.0	6.5
NVM	-29.6	3.9	4.4	5.2	34.0	7.3	-31.7	4.6	5.0	4.8	36.7	6.8

5.2.1.2 Lateral movement

All values describe lateral movement in the Y direction.

5.2.1.2.1 Outside hand

The mean and standard deviation of outside hand displacement and catch and finish positions in Y for each stroke rate can be found in Table 5. For displacement of the outside hand a significant main effect of the boat ($p<0.05$) and a significant interaction between boat and stroke rate were found ($p<0.05$). It was found that the assumptions of homogeneity of variance, sphericity and normality were violated, however, N sizes were equal. After conducting a post hoc test it was found that for each boat HWM (40.6cm±4.3cm), HWW (39.4cm±7.5cm) and LWM (43.4cm±6.1cm) all had significantly greater displacement of the outside hand than LWW (31.2cm±6.0cm) and NVM (28.9cm±6.5cm) ($p<0.05$). When examining the interaction between boat and stroke rate it was found that at a stroke rate of 20 SPM HWM (41.4cm±5.5cm) had significantly greater displacement of the outside hand than LWW (29.9cm±5.9cm) ($p<0.05$) and LWM (41.7cm±6.5cm) had significantly greater displacement than NVM (30.9cm±6.0cm) ($p<0.05$). At a stroke rate of 26 HWM (40.1cm±3.9cm) and LWM (44.7cm±6.3cm) were found to have significantly greater displacement of the outside hand than LWW (32.0cm±7.3cm) and NVM (27.5cm±7.7cm) ($p<0.05$). At a stroke rate of 30 HWM (40.5cm±3.8cm) and LWM (43.8cm±5.8cm) had significantly greater displacement of the outside hand then NVM (27.5cm±7.7cm) ($p<0.05$).

When examining the catch positions, a significant main effect of the boat ($p<0.05$) and a significant interaction between boat and stroke rate was found ($p<0.05$). When examining the main effect of boat, a HWM (-29.6cm±5.0cm), HWW (-29.7cm±7.3cm) and LWM (-31.5cm±5.2cm) all had catch positions significantly closer to the oar side than LWW (-21.7cm±5.8cm) and NVM (-20.6cm±8.6cm) ($p<0.05$). When examining the interaction between boat and stroke rate at 20 SPM it was found that HWM (-32.0cm±4.7cm) have catch positions significantly closer to the oar side than LWW (-20.1cm±5.5cm) ($p<0.05$). At a stroke rate of 30 LWM (-33.3±5.5) were found to have catch positions significantly closer to the oar side than NVM (-19.8cm±8.7cm) ($p<0.05$).

When examining the finish position, a significant main effect of boat ($p<0.05$) and a significant interaction between boat and stroke rate was detected ($p<0.05$). When examining the main effect of boat HWM (11.1cm±3.4cm) were found to have finish positions significantly further away from the oar side than NVM (8.3cm±3.2cm) ($p<0.05$). LWM (11.9cm±3.0cm) were found to have finish positions significantly further away from the oar side than LWW (9.5±1.8) and NVM (8.3cm±3.2cm) ($p<0.05$). When examining the interaction between boat and stroke rate at a stroke rate of 26, LWM (14.6cm±1.1cm) were found to have finish positions significantly further away from the oar side than LWW (8.8cm±1.7cm) ($p<0.05$).

Table 5. Outside hand mean (MN) (and standard deviation (SD)) for catch and finish positions and total displacement from the catch to the finish for each boat and stroke rate in cm.

	Stroke rate 20						Stroke rate 26					
Boat	Catch		Finish		Displacement		Catch		Finish		Displacement	
	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD
HWM	-32.0	4.7	9.4	4.1	41.4	5.5	-27.9	4.7	12.2	1.8	40.1	3.9
HWW	-30.0	8.1	10.1	4.0	40.1	8.4	-29.6	8.2	9.5	3.5	39.0	8.2
LWM	-31.2	4.6	10.6	3.6	41.7	6.5	-30.1	5.7	14.6	1.1	44.7	6.3
LWW	-20.1	5.5	9.8	1.2	29.9	5.9	-22.9	4.8	8.8	1.7	31.7	5.1
NVM	-22.6	8.6	8.3	3.4	30.9	6.0	-19.4	9.2	8.9	4.1	28.3	6.0

	Stroke rate 30						Average					
Boat	Catch		Finish		Displacement		Catch		Finish		Displacement	
	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD
HWM	-28.9	5.2	11.6	3.6	40.5	3.8	-29.6	5.0	11.1	3.4	40.6	4.3
HWW	-29.7	6.3	9.2	2.1	39.0	6.6	-29.7	7.3	9.6	3.2	39.4	7.5
LWM	-33.3	5.5	10.5	1.6	43.8	5.8	-31.5	5.2	11.9	3.0	43.4	6.1
LWW	-22.1	7.3	9.8	2.4	32.0	7.3	-21.7	5.8	9.5	1.8	31.2	6.0
NVM	-19.8	8.8	7.7	2.2	27.5	7.7	-20.6	8.6	8.3	3.2	28.9	6.5

5.2.1.2.2 Outside shoulder

The mean and standard deviation of outside shoulder displacement, catch and finish positions for each stroke rate can be found in Table 6. There were no significant differences for displacement of the outside shoulder.

A significant main effect of boat was found for the catch position ($p<0.05$). HWM (4.1cm±5.7cm), HWW (3.4cm±5.4cm), LWM (1.7cm±6.7cm) and LWW (3.5cm±4.1cm) all had values significantly closer to the oar side at the catch then NVM (11.4 cm±5.4cm) ($p<0.05$).

There were no statistically significant differences at the finish.

Table 6. Outside shoulder mean (MN) (and standard deviation (SD)) for catch and finish positions and total displacement from the catch to the finish for each boat and stroke rate in cm.

Boat	Stroke rate 20						Stroke rate 26					
	Catch		Finish		Displacement		Catch		Finish		Displacement	
	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD
HWM	1.7	4.4	15.2	6.4	13.5	4.8	5.1	4.6	16.4	3.2	11.4	4.9
HWW	3.4	5.2	14.6	5.3	11.2	2.0	3.2	7.2	14.1	5.6	10.9	3.1
LWM	2.9	2.7	13.1	2.6	10.2	6.7	1.1	7.9	12.4	4.9	11.3	6.2
LWW	4.5	3.3	12.6	5.3	8.1	3.4	2.5	5.9	11.2	8.1	8.6	4.0
NVM	9.9	5.3	17.8	4.4	7.9	4.6	12.2	6.5	18.0	4.9	5.9	5.4

Boat	Stroke rate 30						Average					
	Catch		Finish		Displacement		Catch		Finish		Displacement	
	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD
HWM	5.5	7.5	16.2	5.9	10.7	6.1	4.1	5.7	15.9	5.1	11.8	5.2
HWW	3.7	4.1	15.5	4.6	11.9	2.9	3.4	5.4	14.7	5.0	11.3	2.6
LWM	1.0	7.0	11.0	7.1	10.0	6.2	1.7	6.7	12.1	5.1	10.5	6.1
LWW	3.5	2.8	12.8	4.6	9.4	3.5	3.5	4.1	12.2	6.0	8.7	3.5
NVM	12.0	4.7	18.6	2.7	6.6	4.3	11.4	5.4	18.2	3.9	6.8	4.7

5.2.1.2.3 Inside hand

The mean and standard deviation of inside hand displacement, catch and finish positions for each stroke rate can be found in Table 7. For displacement of the inside hand a significant main effect of the boat ($p<0.05$) and a significant interaction between boat and stroke rate was found ($p<0.05$). The assumption of homogeneity of variance was violated, however, N sizes were equal. When examining the main effect of the boat it was found that HWM (32.4cm±3.5cm), HWW (33.5cm±6.5cm) and LWM (32.9cm±4.0cm) all had significantly greater displacement of the inside hand than LWW (25.5cm±4.8cm) and NVM (23.5cm±4.9cm) ($p<0.05$). When examining the interaction between boat and stroke rate. At a stroke rate of 20 HWM (34.2cm±4.2cm) were found to have significantly greater shoulder displacement than LWW (24.4cm±4.8cm) and NVM (24.7cm±4.7m) ($p<0.05$). At stroke rates of 26 and 30 HWM (31.4cm±3.1cm;31.8cm±2.8cm) and LWM (33.3cm±3.9cm;33.4cm±4.1cm) had significantly greater hand displacement then NVM (22.9cm±4.8cm;22.9cm±5.5cm) ($p<0.05$).

When examining the differences in catch position of the inside hand, a significant main effect of the boat ($p<0.05$) and a significant interaction between boat and stroke rate was found ($p<0.05$). When evaluating the main effect of the boat it was found that LWM (-51.5cm±5.3cm) had catch positions significantly closer to the oar side then HWM (-46.8cm±4.7cm), HWW (-44.5cm±6.1cm), NVM (-38.1cm±7.0cm) and LWW (-37.4cm±5.1cm) ($p<0.05$). HWM and HWW were also found to have catch positions significantly closer to the oar side then NVM and LWW ($p<0.05$). When examining the interaction between boat and stroke rate at a stroke rate of 20, HWM (-48.8cm±4.6cm) had catch positions significantly closer to the oar side then LWW (-

36.2cm±5.4cm) and NVM (-39.6cm±6.8cm) ($p<0.05$). At stroke rates of 26 and 30 LWM (-54.1cm±5.5cm; -51.6cm±5.3cm) had catch positions significantly closer to the oar side for the inside hand then HWM (-45.1cm±3.9cm; -46.3cm±5.4cm), LWW (-38.2cm±4.3cm; -37.8cm±6.0cm) and NVM (-37.5cm±7.6cm; -37.1cm±7.4cm) ($p<0.05$).

At the finish a significant difference in the main effect of boat was found ($p<0.05$). HWM (-14.3cm±2.9cm), LWM (-18.6cm±3.7cm) and NVM (-14.6cm±2.7cm) all had finish positions significantly closer to the oar side than HWW (-11.0cm±3.6cm) and LWW (-11.9cm±2.6cm) ($p<0.05$). LWM also had finish positions significantly closer to the oar side than HWM and NVM ($p<0.05$).

Table 7. Inside hand mean (MN) (and standard deviation (SD)) for catch and finish positions and total displacement from the catch to the finish for each boat and stroke rate in cm.

Boat	Stroke rate 20						Stroke rate 26					
	Catch		Finish		Displacement		Catch		Finish		Displacement	
	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD
HWM	-48.8	4.6	-14.7	3.3	34.2	4.2	-45.1	3.9	-13.7	2.0	31.4	3.1
HWW	-44.2	7.0	-10.9	4.7	33.4	6.7	-45.1	7.3	-10.5	2.5	34.6	7.7
LWM	-48.8	4.3	-16.7	2.5	32.0	4.2	-54.1	5.5	-20.8	4.1	33.3	3.9
LWW	-36.2	5.4	-11.8	2.5	24.4	4.8	-38.2	4.3	-12.6	3.5	25.6	4.3
NVM	-39.6	6.8	-14.9	2.5	24.7	4.7	-37.5	7.6	-14.7	3.2	22.9	4.8

Boat	Stroke rate 30						Average					
	Catch		Finish		Displacement		Catch		Finish		Displacement	
	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD
HWM	-46.3	5.4	-14.5	3.5	31.8	2.8	-46.7	4.7	-14.3	2.9	32.4	3.5
HWW	-44.1	4.4	-11.5	3.7	32.6	5.8	-44.5	6.1	-11.0	3.6	33.5	6.5
LWM	-51.6	5.3	-18.2	3.5	33.4	4.1	-51.5	5.3	-18.6	3.7	32.9	4.0
LWW	-37.8	6.0	-11.2	1.9	26.6	5.5	-37.4	5.1	-11.9	2.6	25.5	4.8
NVM	-37.1	7.4	-14.3	2.8	22.9	5.5	-38.1	7.0	-14.6	2.7	23.5	4.9

5.2.1.2.4 Inside shoulder

The mean and standard deviation of inside shoulder displacement, catch and finish positions for each stroke rate can be found in Table 8. When examining lateral shoulder displacement, main effect of boat was found to be significant ($p<0.05$). The assumption of homogeneity of variance was violated for this data set, however N sizes were equal. HWM (2.5cm±5.1cm), HWW (2.7cm±2.6cm) and LWW (3.5cm±2.9cm) were found to have significantly greater lateral lean towards the oar side than NVM (-2.3cm±4.3cm) ($p<0.05$).

When examining the catch position, a main effect of boat was found ($p<0.05$). HWM (-25.7cm±6.1cm), HWW (-23.6cm±5.3cm) and LWM (-24.9cm±5.2cm) were found to have catch position closer to the oar side than NVM (-18.0cm±5.1cm) ($p<0.05$). HWM were also found to have a catch position significantly closer then LWW (-21.5cm±3.1cm) ($p<0.05$).

For the finish position a significant main effect of boat was detected ($p<0.05$). HWM (-23.2cm±3.9cm) and LWM (-24.4cm±4.2cm) had finish positions significantly closer to the oar side then LWW (-18.0cm±4.5cm) ($p<0.05$). LWM (-24.4cm±4.2cm) were also found to have a significantly closer finish position than NVM (-20.2cm±4.7cm) ($p<0.05$)

Table 8. Inside shoulder mean (MN) (and standard deviation (SD)) for catch and finish positions and total displacement from the catch to the finish for each boat and stroke rate in cm.

	Stroke rate 20						Stroke rate 26					
Boat	Catch		Finish		Displacement		Catch		Finish		Displacement	
	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD
HWM	-27.6	3.6	-24.6	4.2	3.0	4.2	-26.1	5.9	-22.6	2.3	3.6	6.3
HWW	-23.3	6.2	-21.3	5.6	2.0	1.9	-24.6	5.9	-21.0	5.2	3.6	3.6
LWM	-24.1	4.6	-23.7	3.2	0.4	6.0	-25.4	6.1	-25.2	3.7	0.2	5.2
LWW	-22.2	3.1	-19.3	5.2	2.9	2.7	-20.6	3.8	-16.6	3.9	4.0	3.7
NVM	-18.6	5.2	-21.0	3.0	-2.4	5.6	-17.4	6.5	-19.6	6.1	-2.2	4.2

	Stroke rate 30						Average					
Boat	Catch		Finish		Displacement		Catch		Finish		Displacement	
	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD
HWM	-23.5	7.9	-22.4	4.8	1.1	4.8	-25.7	6.1	-23.2	3.9	2.5	5.1
HWW	-23.0	4.1	-20.6	3.8	2.4	2.1	-23.6	5.3	-21.0	4.7	2.7	2.6
LWM	-25.2	5.5	-24.4	5.6	0.7	5.4	-24.9	5.2	-24.4	4.2	0.5	5.3
LWW	-21.6	2.6	-18.1	4.5	3.5	2.5	-21.5	3.1	-18.0	4.5	3.5	2.9
NVM	-17.9	3.9	-20.1	4.9	-2.1	3.3	-18.0	5.1	-20.2	4.7	-2.2	4.3

5.3 Stroke styles

5.3.1 Shoulder angle

When examining lateral movement and shoulder angle, it was found that shoulder angle follows oar angle for the duration of the stroke (Figure 18. However, not every rower moved their shoulder in the same fashion, different styles between rowers were observed (Figure 19, Figure 20 and Figure 21). These differences were primarily observed in the recovery portion of the stroke, although differences of timing of peak shoulder angle at the finish were observed, there appeared to be consistency in stroke styles amongst rowers. There is also much greater variability observed in both the tracked points on the shoulders and shoulder angle. As the shoulder angle is calculated using the tracked points on the shoulder these measures are connected. The greater variability is partially attributed to greater digitizing error.

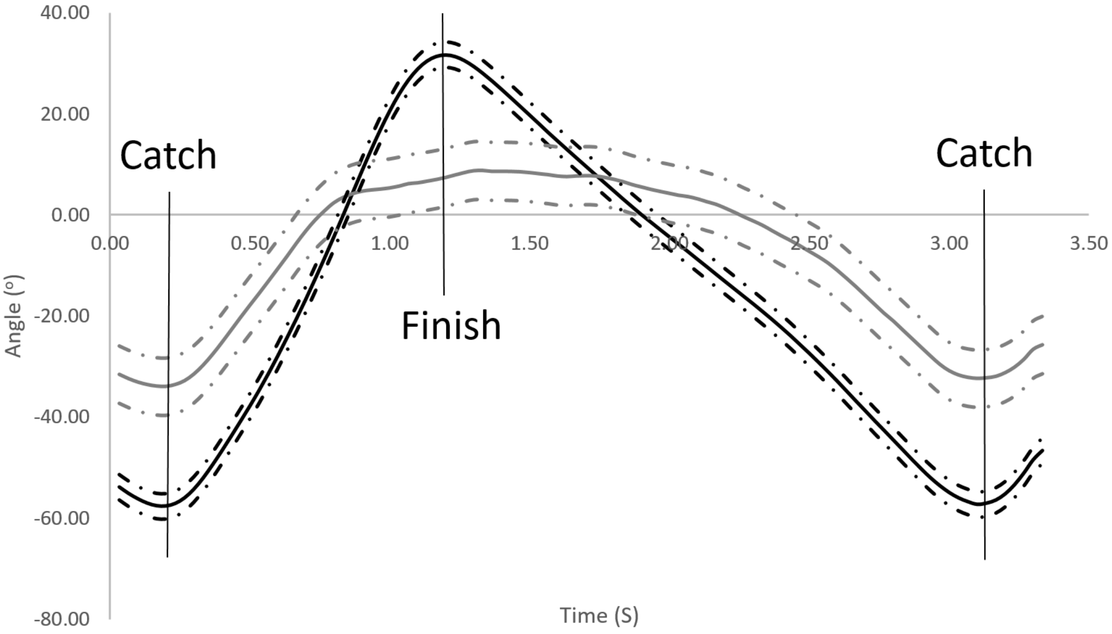


Figure 18. Average oar (black line) and shoulder angle (grey line) at a stroke rate of 20 for the HWM's 8. Solid lines represent the average and dotted lines represent standard deviation.

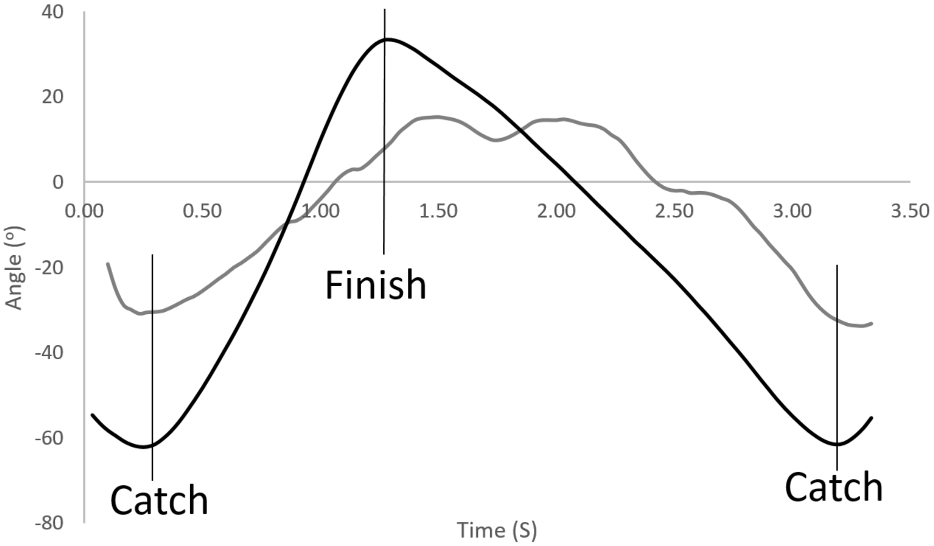


Figure 19. Oar arc (black line) and shoulder arc (grey line) for HWM's eight at a stroke rate of 20 for seat 6.

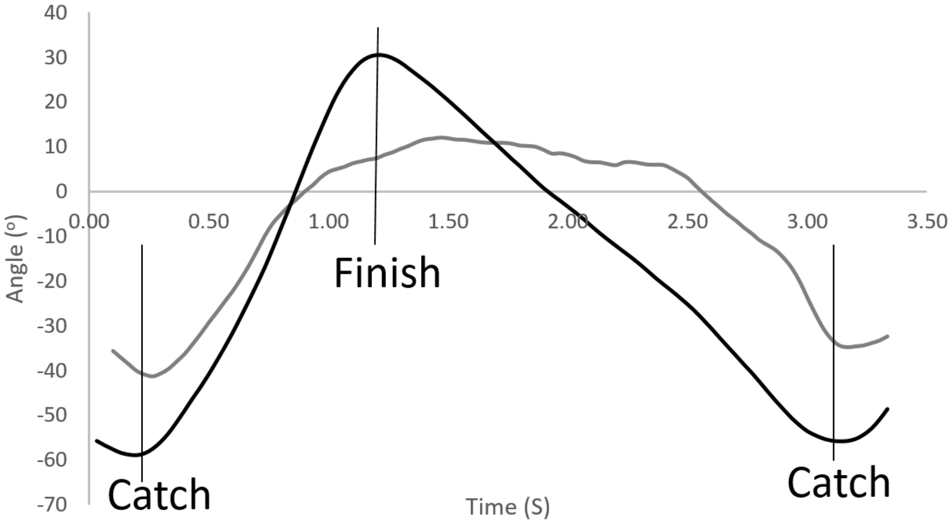


Figure 20. Oar arc (black line) and shoulder arc (grey line) for HWM's eight at a stroke rate of 20 for seat 5.

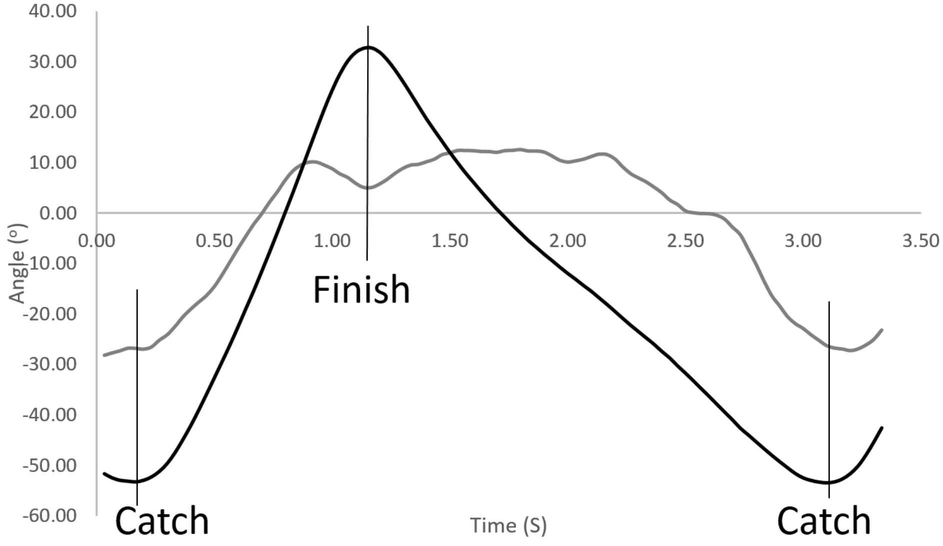


Figure 21. Oar arc (black line) and shoulder arc (grey line) for HWM's eight at a stroke rate of 20 for seat 2.

5.3.2 Lateral movement

There were also different styles of lateral movement observed when examining lateral lean in the Y direction as well as patterns of the shoulders in the X-Y coordinate system. however, these patterns were not observed to be necessarily related to shoulder angle.

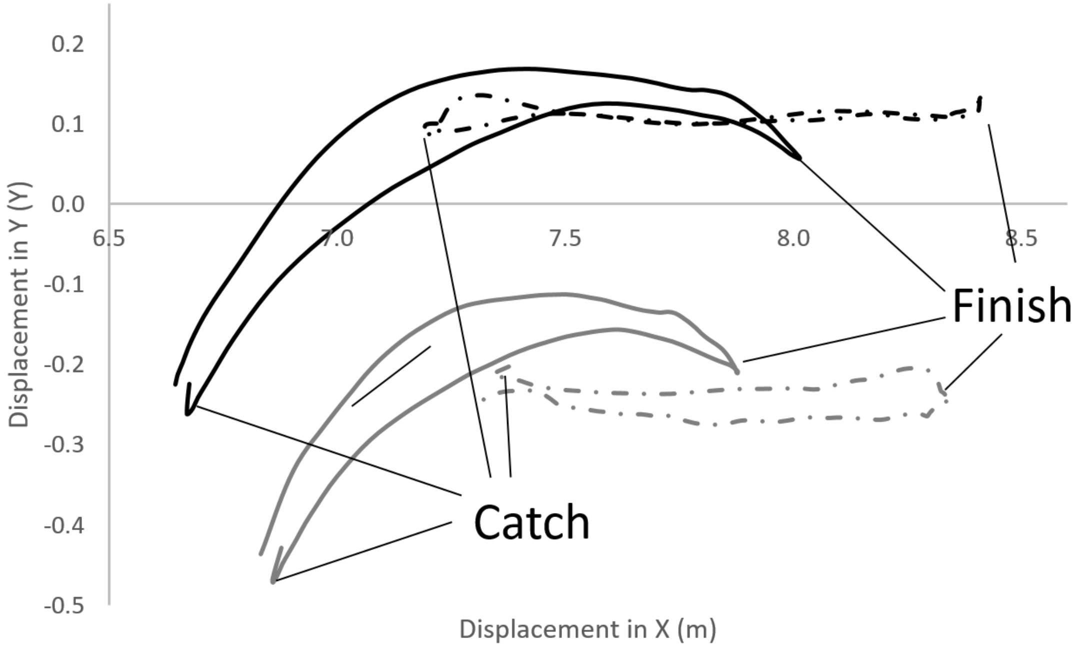


Figure 22. Movement of the hands and shoulder in the X and Y coordinate system for the outside hand (solid black line) outside shoulder (dashed black line) inside hand (solid grey line) and inside shoulder (dashed grey line) for the NVM's 8 seat 4 at a stroke rate of 20.

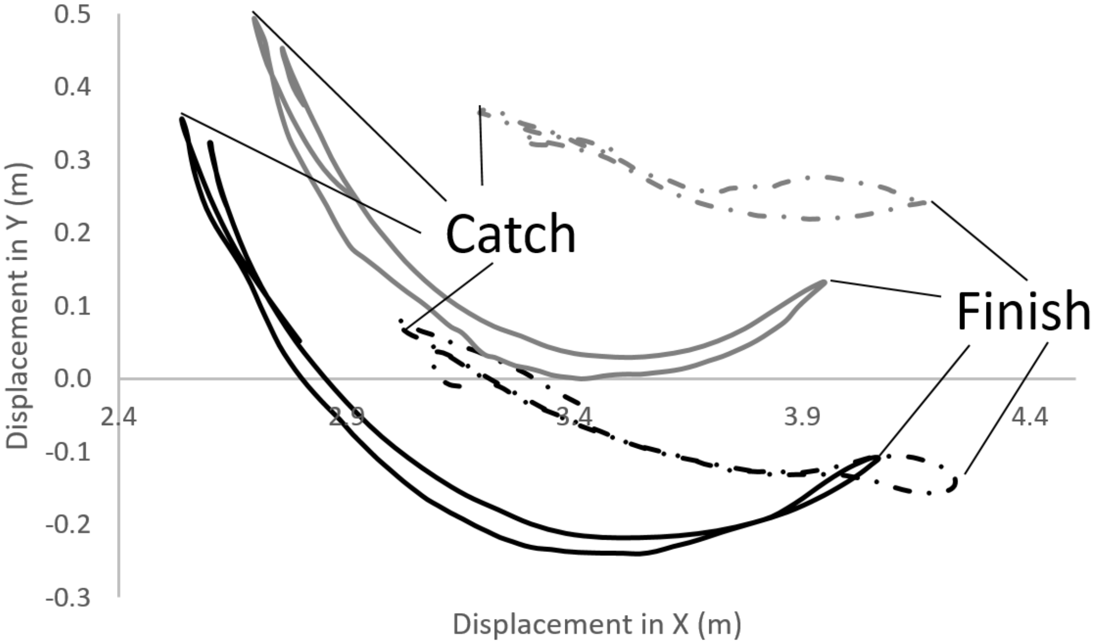


Figure 23. Movement of the hands and shoulder in the X and Y coordinate system for the outside hand (solid black line) outside shoulder (dashed black line) inside hand (solid grey line) and inside shoulder (dashed grey line) for the HWM's 8 at a stroke rate of 20 for seat 7.

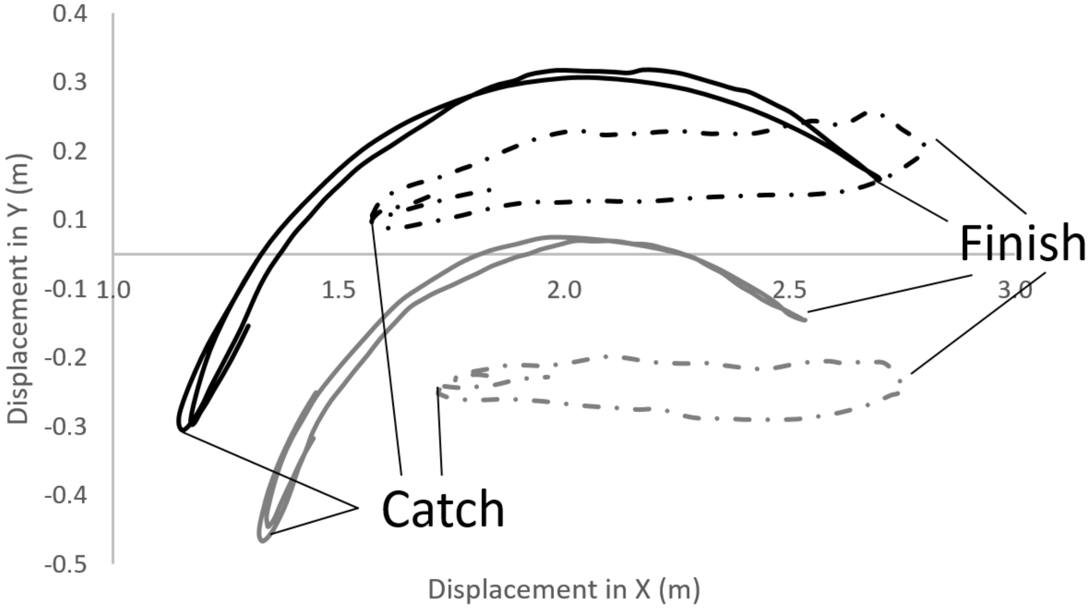


Figure 24. Movement in the X and Y coordinate system for the outside hand (solid black line) outside shoulder (dashed black line) inside hand (solid grey line) and inside shoulder (dashed grey line) for the HWW's 8 seat 8 at a stroke rate of 20.

6 Discussion

The first purpose of this study was to determine if aerial drones can be effective rowing biomechanics research tools and to determine their strengths and limitations in a research and coaching capacity. The aerial drone was used to record the rowers from the perspective of directly above to examine lateral movement. Digitizing and camera error were measured to evaluate the accuracy of the drone. It was hypothesized that the data collected by the drone would be useful to both researchers and coaches.

The second purpose of this study was to quantify oar angle, shoulder angle and lateral displacement of the shoulders and hands during the drive phase of a sweep rowing stroke. Four points on each rower and 10 points on each boat were tracked. Five hypotheses were formulated based on expected lateral movement outcomes (see the purpose and hypotheses section).

6.1 Method of study

There is currently no rowing research that makes use of a drone or examine lateral movement in the shoulders and hands, so comparing the method and results with previous studies is not possible. However, there are studies that have analyzed oar arc. Previous research suggests that the oar arc for Olympic caliber HWM should be approximately 92^o with a catch angle of -59^o and a finish angle of 33^o. This study found a mean oar arc across all stroke conditions of 88.7^o, a catch angle of -57.2^o and a finish angle of 31.1^o for

HWM. For Olympic caliber HWW previous research suggests that the oar arc should be approximately 90^{o} with a catch angle of -58^{o} and a finish angle of 32^{o}. This study found a mean oar arc of 88.8^{o} with a catch angle of -56.6^{o} and a finish angle of 32.1^{o} for HWW. Olympic caliber LWM should have the same oar angles as HWW and in this study LWM were found to have an average oar arc of 89.7^{o} with a catch position of -58.5^{o} and a finish position of 31.0^{o}. These findings are consistent with the literature as it has been stated that lower level rowers at the club or collegiate level are expected to have oar arcs that are 3-5^{o} shorter than Olympic caliber athletes (Kleshnev, 2015). Because LWW do not sweep at the Olympic level, there is no information about their oar arcs, catch and finish positions. The NVM are also expected to have shorter oar arcs as they have very little rowing experience.Despite the encouraging data when examining the oar angles, there were some flaws in the method used for this study. The biggest source of observable error was camera error (Figure 16., Figure 17.). This source of error was especially problematic as it was not consistent from rower to rower. Positive error was observed near the focal point of the camera and negative error the further away from the center of focus. The majority of the tracked points were observed between 7 and -7m in the X direction and 1.5 and -1.5m in the Y direction. The greatest error observed in this range was at the focal point of the camera with a positive error of 2.5cm in X and 2.2cm in Y being found. However, at 7 and -7m in X and 1 and -1m in Y an error of -1.9cm in X and -0.5cm in Y was found. This represents a measurement difference from the focal point of 4.4cm in X and 2.7cm in Y. This varying source of error makes comparisons between individual rowers difficult. However, each rowing boat stayed roughly in the same position relative to the center of the frame. This means that the degree of camera error should be similar for each boat which would allow some conclusions to be formed with regards to general trends and movement patterns when comparing boats.

There was also some digitizing error that was observed in this study. The change in the object of known length was found to be 0.8±0.6cm. This amount of measurement error is within the range of what other studies that examined rowers on the water in the sagittal plane have found. The lowest average error was found by Bechard et al (2009) at 0.42±0.07cm and the largest being found by Martindale & Robertson (1984) at 1.1±0.2cm.

Although camera error would not be identical for each analyzed stroke, a minimum of two strokes were aggregated per stroke condition and a minimum of seven strokes were aggregated per rowing class. Per the principal of aggregation, aggregated scores are more stable than any individual score in a data set (Rushton, Brainerd, & Pressley, 1983). Based on this principal the number of strokes analyzed and aggregated should help to offset changes or fluctuations in error of individual analyzed strokes and allow comparisons between rowing classes to be made. Because of the uncertainty surrounding levels of error in this study these results should be regarded with caution.

For more precise measures, future studies using a drone should consider analyzing fewer rowers per frame as well as examining different altitudes for the drone to fly at in order to minimize both the magnitude of camera and digitizing error. With regards to digitizing error, greater digitizing error was observed when analyzing shoulder angle and the outside shoulder. Future studies should consider using shoulder markers to improve digitizing accuracy.

6.2 Effectiveness and utility of the drone

Despite the measurement problems the drone was determined to be effective as a rowing research tool as the error was comparable to other studies and the oar angles were within the expected range. This indicates that the information collected from the drone is meaningful and the accuracy is good. The drone also provided new information about shoulder angles and lateral movement that would not otherwise be available to researchers and coaches and the data can be used to inform coaching and rowing technique. Feedback was also received from the rowing coaches who stated that the video was useful from a qualitative perspective. The coaches shared the videos with their crews and found them to be beneficial as coaching tools in order to try and improve the technique and performance of their boats.

Despite the accuracy of the information and the usefulness of the data from both a quantitative and qualitative perspective there are some barriers to coaches using drones. The primary barrier is the cost of drones, as drones are expensive. Another major barrier are the rules and regulations surrounding the use of drones. Learning the rules and regulations as well as creating an application for an SFOC can be a difficult process and may be considered too much trouble for some rowing coaches.

6.3 Lateral lean and rotation

As was hypothesized, rowers moved their hands and shoulders laterally towards the oar side at the catch and differences between rowing classes and skill level were observed. The HWM, HWW and LWM all had significantly greater oar arcs than LWW and NVM. HWM, HWW and LWM also had significantly greater lateral movement of the inside and outside hand than NVM and LWW. This was expected as the hands follow the path of the oar. For LWW, the shorter oar arc can be explained by the size of the athlete, as LWW are typically smaller athletes (Schranz et al, 2010). For NVM, this difference can be explained by a lack of rowing experience. Typically, less experienced athletes will have smaller oar angles (Kleshnev, 2015).

When examining the lateral movement of the shoulders of NVM, it was found that they leaned away from the oar side with their inside shoulder while moving their outside shoulder towards the oar side at the catch. The inside shoulder of the NVM was the only tracked point to move away from the oar side at the catch, all other crews moved the inside and outside hand and inside and outside shoulder towards the oar side. NVM also exhibited the significantly smaller lateral lean than HWM, HWW, LWM and LWW in their outside shoulder at the catch indicating the failure of NVM to lean towards the oar side of the boat. This lack of lean most likely contributed to a shorter oar arc. LWM also exhibited very little lateral lean of the inside shoulder, however, they did not lean away from the oar side of the boat like the NVM.

It was also observed that the same significant differences between boats were observed at the catch, with HWM, HWW and LWM having greater catch angles for the oar than NVM and LWW, with no significant differences observed at the finish. This indicates that rowers increased the length of their stroke by reaching further at the catch, not the finish. This finding is in agreement with Kleshnev (2011) who found that rowers typically shorten their oar arc at the catch when increasing their stroke rate to race pace rates (approximately 40 SPM). However, some significant differences were observed at the finish for the outside and inside hand. These differences can potentially be explained by hand position on the oar, length of the inboard as well as possible movement of the hands at the finish.

Although not significantly different and close to within the margin of digitizing error (0.9±0.9), LWM had the greatest overall average oar arcs (89.7^{o}). This was unexpected as based on the size of the rowers and previous research, it was thought that HWM, being the largest athletes, would have the longest oar arcs. This could be partially attributed to the skill level of the rower, however, the rowers experience level beyond novice and varsity was not recorded. LWM were also observed to have significantly greater shoulder angles than HWW, LWW and NVM. LWM had an overall mean shoulder arc of 46.2^{o} despite not being significantly different, HWM had a shoulder arc 5.7^{o} shorter at 40.5^{o}.

This longer shoulder arc could explain the LWM's greater oar arc as the greater rotation allowed them to reach further than any other boat. As observed with oar arc this difference in shoulder angle appears to occur at the catch, as LWM had a catch angle 7.4^o larger (-39.4^o) than HWM (-32.0^o) and no significant differences were observed at the finish. However, despite LWM's greater rotation, they did not lean towards the oar side at the catch significantly. This finding indicates that the primary way in which LWM extended their oar arc was through rotation and increasing their shoulder angle not lateral lean.

These findings indicate that stroke length appears to have many influencing factors, with both lateral lean and shoulder angle playing a role. It is also possible that the rigging played a role in the movement of the athletes, however, differences in spread and inboard were very small (Table 1). Further research needs to be performed to precisely determine the effect of lateral lean and shoulder arc on oar arc and the rowing stroke.

6.4 Stroke rate

There were some significant differences observed between boats at different stroke rates. This was unexpected as it was thought that the range of stroke rates that were chosen were not broad enough for the differences observed to be significant. This hypothesis was formed based on previous studies that have found the longest oar arcs at 24 SPM and with slightly smaller oar arcs being found at both lower and higher stroke rates (Kleshnev, 2011).

The largest difference was observed in HWW, with a significantly smaller shoulder arc (25^{o}) at 26 SPM than LWM (47.9^{o}). When examining the individual athletes, it was found that for two of the three analyzed strokes two of the HWW had a very small shoulder arcs which caused a very low mean shoulder arc to be measured at 26 SPM for HWW. It is unclear what caused this change in shoulder arc for the strokes in question. There were other significant differences in stroke rate that were observed for the inside and outside hand and oar arc. However, these results were very similar to what was discussed in lateral lean and rotation section.

There were also some differences, that despite not being significant, appeared to indicate a trend. For NVM, oar arc was observed to decrease as stroke rate increased, with oar arcs of 83.8^{o} at 20 SPM, 83.1^{o} at 26 SPM and 82.8^{o} at 30 SPM being measured. Although the changes in oar arc were very small and within the margin of error, NVM were also observed to have decreasing shoulder arcs as stroke rates increased, with shoulder arcs of 39.9^{o} at 20 SPM, 36.1^{o} at 26 SPM and 34.0^{o} at 30 SPM. This indicates that NVM appear to be shortening their stroke as well as decreasing their shoulder angles as stroke rate increases. HWM were also found to have shortened oar arc as stroke rate increased, with oar arcs of 91.0^{o} at 20 SPM, 88.2^{o} at 26 SPM and 86.8^{o} at 30 SPM being observed. HWM did not decrease their shoulder arcs as stroke rate increased, however, there were some reductions in lateral lean in both the outside and inside shoulders although these differences were also very small. It appears that stroke rate has some effect on oar arc and lateral movement. However, as these findings were not significant and the differences observed between the oar and shoulder angles and lateral movement at different stroke rates were close to or within the margin of error, further research needs to be performed to form any concrete conclusions with regards to how stroke rate affects shoulder angle and lateral lean.

6.5 Stroke styles

When examining the movement of individual rowers, several distinct styles were observed with regards to both shoulder angle and the lateral lean of the hands and shoulders.

When examining change in shoulder angle, it was observed that each rower had slightly distinct timing and patterns. Although there was a great deal of variation in movement styles when examining shoulder angle, there were three general movement patterns that were commonly observed. The first style that was observed was a smooth movement with no rotation away from the oar side during recovery, as illustrated in Figure 20. The second style involved a rotation away from oar side during the recovery of the stroke, as illustrated in Figure 19. The third style involved sharply protracting the outside shoulder at the finish and then retracting the shoulder and rotating slightly away from the oar side to start the recovery phase of the stroke, as illustrated in Figure 21. It is unclear why rowers adopt specific styles of shoulder movement. Different coaching styles may play a role as well as anthropometry of the athletes. Further study is required to determine why athletes move the way they do and which, if any, of the movement patterns is the most effective.

In all of the observed styles, shoulder angle roughly followed oar angle for the duration of the stroke. The differences in style were primarily observed approaching the finish or in the recovery portion of the stroke, although differences in timing of peak shoulder angle at the finish were observed. There appeared to be consistency in stroke styles amongst rowers. There was also much greater variability observed in both shoulder angle and the tracked points on the shoulders. This can partially be attributed to greater digitizing error. It is unclear what the rest of the variation at the shoulder is caused by. It is possible that rowers are adjusting to slight changes in timing as well as changes to the balance of the boat.

Several different styles of lateral lean were also observed. Like shoulder angle, each athlete appeared to have a slightly unique movement style particularly when observing the shoulders. Primarily three different styles of lateral lean were observed. It is unclear if or how these different styles relate to the different styles observed in shoulder angle. The first style involved very little lateral lean of either the inside or outside shoulder. This style was primarily observed amongst novice rowers and is illustrated in Figure 22. The second style that was observed involved significant lateral lean towards the oar side from both the inside and outside shoulder, as illustrated in Figure 23. The final style that was observed involved a small amount of lateral lean with the inside shoulder, but with a much greater lateral lean or rotation from the outside shoulder, as illustrated in Figure 24. As with shoulder angle, it is unclear why athletes adopt certain lateral lean techniques.

Different styles and patterns of shoulder angle movement and lateral lean were observed. Much greater research is required to evaluate lateral lean patterns and how specifically they interact with shoulder angle to affect the stroke. It is also unclear why certain athletes adopt certain patterns and if these patterns are developed with relation to other rowers or independently of other members of their rowing crew. It is unclear if there is an optimal strategy or movement pattern. Although the pattern commonly observed among novice rowers appears to be the least effective when examining oar arc. Rowing research that examines the stroke in the sagittal plane has found that there is an optimal movement pattern for maximizing handle velocity. This would imply that there is also likely to be an optimal lateral movement strategy to maximize handle velocity, however, what that strategy is has yet to be determined. Further research is required to fully determine what part lateral lean and rotation has to play in the efficiency of a stroke and if lateral movement patterns could potentially relate to the stroke styles observed in the sagittal plane.

6.6 Limitations

There were several limitations associated with this study both with the drone and the analysis process. The primary limitation of the drone was that when collecting data, the drone operator could not see what the camera was filming in real time as there was an equipment malfunction. This made it very difficult to determine where precisely over top of the boat the drone was. This was also compounded by limited flight time, with approximately 15 minutes per battery and two batteries used for a total of 30 minutes. Inconsistency in weather conditions also represented a problem. Despite conditions being similar, they were not identical for each data collection session, which presents another source of potential variance. Fatigue also represented another possible limitation as rowers were recorded after they had completed a training session. Fatigue has been found to have an effect on rowing technique and sequencing (Caldwell et al, 2003; Pollock et al, 2012). In order to determine what effect fatigue has on lateral movement further research needs to be done.

The primary limitation experienced in the analysis process was that camera error was not accounted for. This led to measurement errors, meaning that making comparisons between individual rowers was very difficult. The second limitation was that a 3D motion was being evaluated from a 2D perspective. Rowers raise and lower their shoulders and hands over the duration of the rowing stroke. However, this raising and lowering effect is not visible when only examining the stroke in the transverse plane. Any movement in the frontal and sagittal plane is not being observed.

6.7 Future research

There are a number of possible directions for future research to take, some of which have already been discussed. When considering the limitations of this study, future research should evaluate a smaller number of rowers in each frame. It would also be beneficial to investigate tools and strategies to increase the accuracy of the drone in maintaining its position over top of the rower. This could potentially be achieved by making sure that the drone operator has feedback from the camera. There are also drones that have a function that allows the drone to automatically follow a target that has a GPS marker placed on it. Experimenting with these drones could potentially lead to increased accuracy. Along with improved accuracy, examining research techniques that evaluate the vertical movement of the rower at the same time as lateral movement could prove beneficial and provide a clearer picture of the sweep rowing stroke.

There is currently a lack of research examining lateral movement in rowing. Because of this, there are significant possibilities for future study. This study only made use of eights. Future research should examine the differences in rowing style between pairs, fours and eights to determine if movement patterns and lateral movement changes with different boat sizes. This study also only examined a narrow set of stroke rates. Examining lateral movement at race pace to see how it differs from training pace could also provide useful information to coaches. Anthropometric data was not collected for this study and could be used as a covariate to examine if larger or smaller athletes rotate and lean more or less relative to their size. Lastly, as it has been found that rowers have high incidence of lower back pain (Teitz et al, 2002), future research should examine the how lean and rotation are related to lower back pain.

6.8 Conclusions

The results of this study indicate that drones can be an effective tool for researchers and coaches. These findings are consistent with the hypothesis that the drone would be an effective data collection tool. However, the methodology of this study did have its flaws and future research should experiment with different methods to determine how drones can be used most effectively. If used properly, drones have significant potential to provide valuable information that would otherwise be unavailable to both coaches and researchers.

The findings of this study concerning lateral movement were consistent with four of the five hypotheses that were made. Excluding the inside shoulder of the NVM, athletes moved their shoulders and hands towards the oar side at the catch. Shoulder angle was observed to follow oar angle and individual styles of movement and timing were observed amongst rowers for both shoulder angle and lateral movement. Differences between rowing classes were observed, with HWM, HWW and LWM having greater oar angles and inside and outside hand movement than LWW and NVM. These differences were not observed for shoulder angles and lateral movement of the shoulders. Counter to what was hypothesized, there were significant differences observed between stroke rates, however, these differences were difficult to interpret. There were also several trends observed that were not found to be, significant but merit further investigation.

In conclusion this study attempted to begin to fill a gap in the literature with regards to lateral movement in rowing. It also examined a new method of collecting rowing data. Despite the limitations, this study provides useful information about lateral movement and the utility and limitations of using a drone to collect data. More research still needs to be done to fully understand lateral movement in the sweep rowing stroke and Drones could be an important tool in this research.

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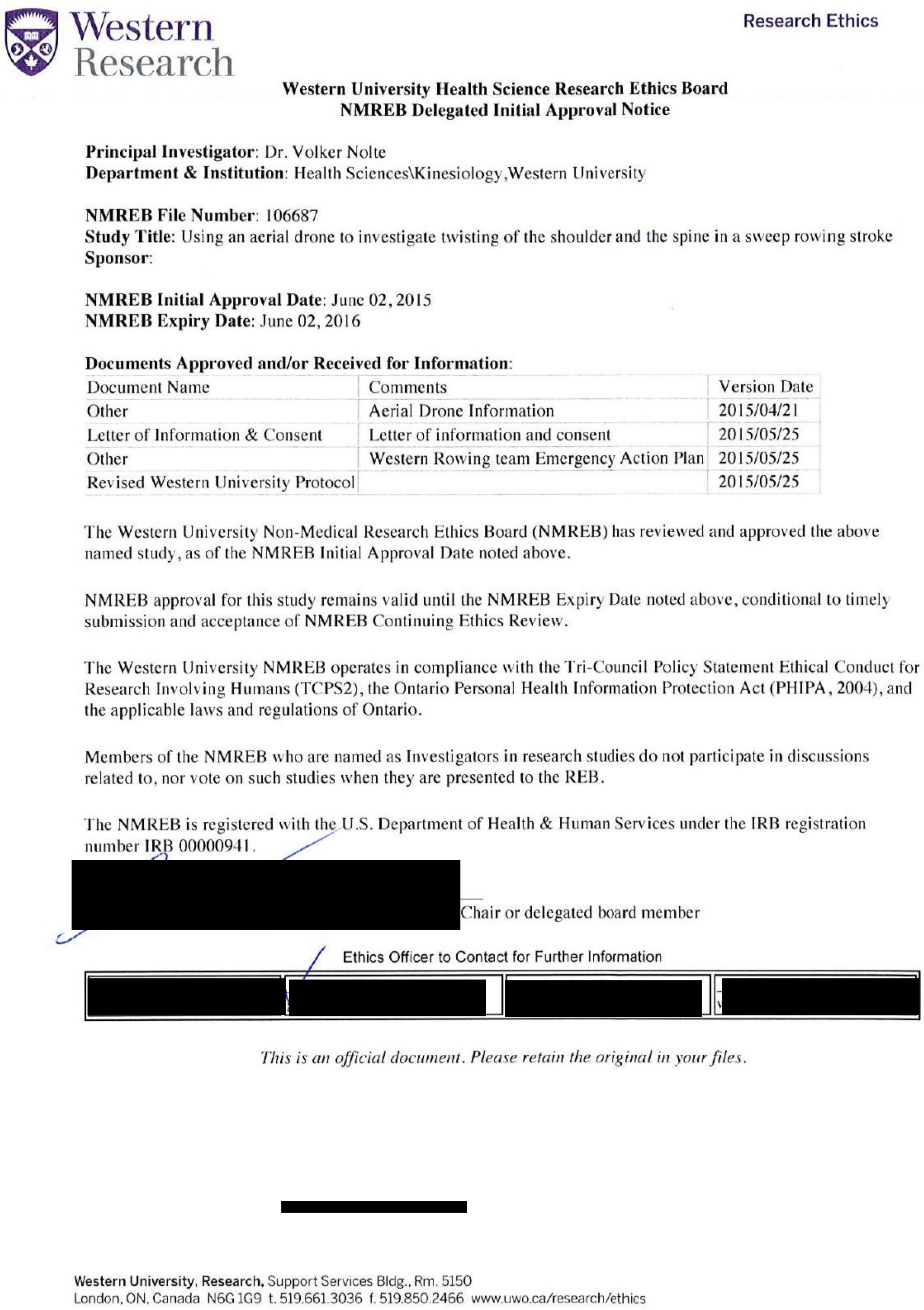
Appendices

Appendix A: Ethics Approval Notice from The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects



Western Research

Research Ethics

Western University Health Science Research Ethics Board
NMREB Delegated Initial Approval Notice

Principal Investigator: Dr. Volker Nolte
Department & Institution: Health Sciences\Kinesiology,Western University

NMREB File Number: 106687
Study Title: Using an aerial drone to investigate twisting of the shoulder and the spine in a sweep rowing stroke
Sponsor:

NMREB Initial Approval Date: June 02, 2015
NMREB Expiry Date: June 02, 2016

Documents Approved and/or Received for Information:

Document Name	Comments	Version Date
Other	Aerial Drone Information	2015/04/21
Letter of Information & Consent	Letter of information and consent	2015/05/25
Other	Western Rowing team Emergency Action Plan	2015/05/25
Revised Western University Protocol		2015/05/25

The Western University Non-Medical Research Ethics Board (NMREB) has reviewed and approved the above named study, as of the NMREB Initial Approval Date noted above.

NMREB approval for this study remains valid until the NMREB Expiry Date noted above, conditional to timely submission and acceptance of NMREB Continuing Ethics Review.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario.

Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

[redacted] Chair or delegated board member

Ethics Officer to Contact for Further Information

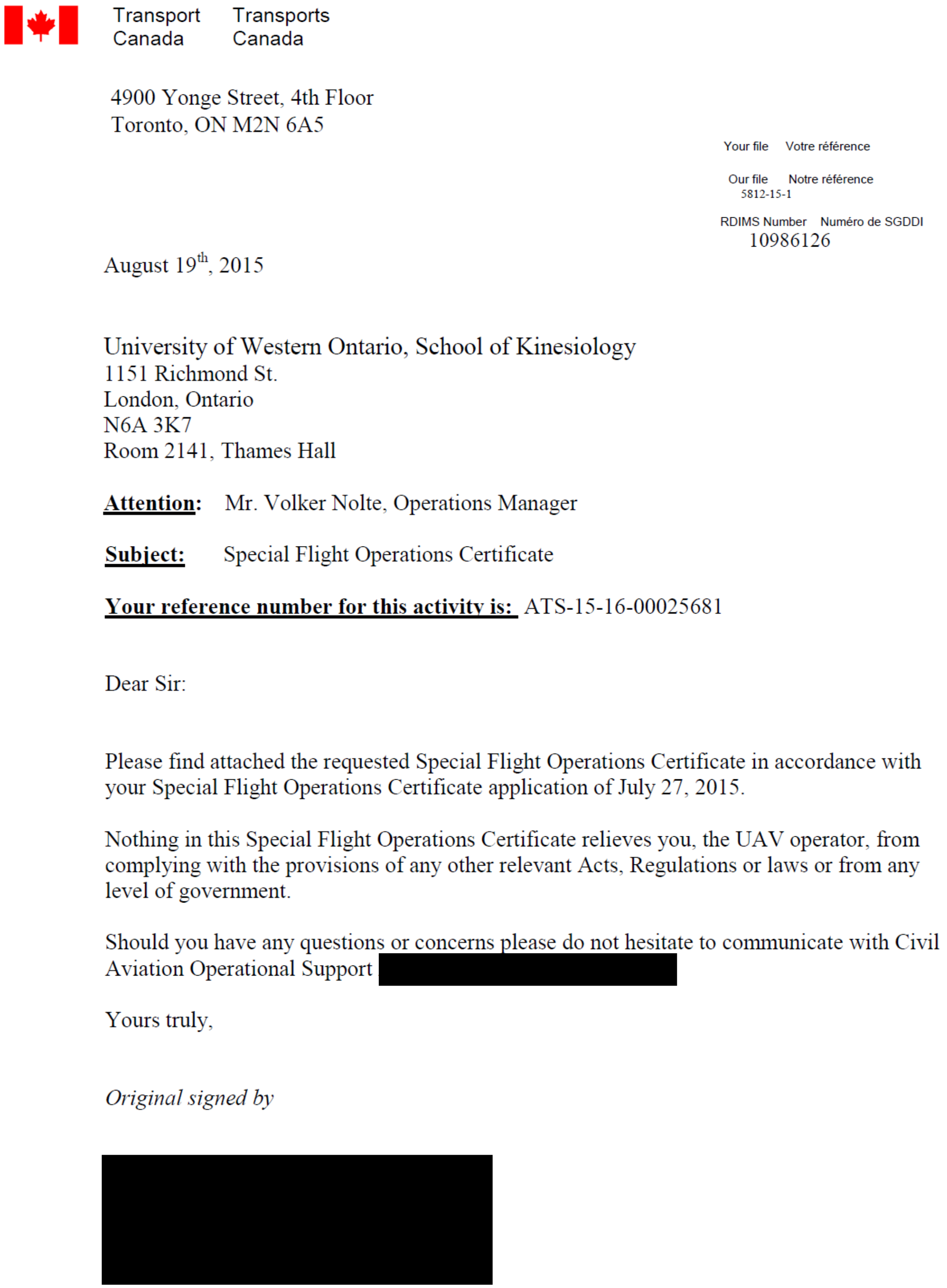
[redacted]	[redacted]	[redacted]	[redacted]

This is an official document. Please retain the original in your files.

[redacted]

Western University, Research, Support Services Bldg., Rm. 5150
London, ON, Canada N6G 1G9 t. 519.661.3036 f. 519.850.2466 www.uwo.ca/research/ethics

Appendix B: Special Flight Operation Certificate Approval Received from Transport Canada.



Transport Canada   Transports Canada

4900 Yonge Street, 4th Floor
Toronto, ON M2N 6A5

Your file   Votre référence

Our file   Notre référence
5812-15-1

RDIMS Number   Numéro de SGDDI
10986126

August 19th, 2015

University of Western Ontario, School of Kinesiology
1151 Richmond St.
London, Ontario
N6A 3K7
Room 2141, Thames Hall

Attention: Mr. Volker Nolte, Operations Manager

Subject: Special Flight Operations Certificate

Your reference number for this activity is: ATS-15-16-00025681

Dear Sir:

Please find attached the requested Special Flight Operations Certificate in accordance with your Special Flight Operations Certificate application of July 27, 2015.

Nothing in this Special Flight Operations Certificate relieves you, the UAV operator, from complying with the provisions of any other relevant Acts, Regulations or laws or from any level of government.

Should you have any questions or concerns please do not hesitate to communicate with Civil Aviation Operational Support [redacted]

Yours truly,

Original signed by

[redacted]

Appendix C: Equations used for the Savitzky-Golay filter.

S is the smoothed value with O representing the corresponding original data point for that frame, with i representing the frame number.

$$S_i = (-252*O_{i-4}+168*O_{i-3}+468*O_{i-2}+648*O_{i-1}+708*O_i-252*O_{i+4}+168*O_{i+3}+468*O_{i+2}+648*O_{i+1})/2772 \tag{10}$$

For the first and last four data points:

$$S_1= (31*O_1 + 9*O_2 - 3*O_3 - 5*O_4 + 3*O_5)/35 \tag{11}$$

$$S_2= (9*O_1 + 13*O_2 + 12*O_3 + 6*O_4 - 5*O_5)/35 \tag{12}$$

$$S_3= (-3*O_1 + 12*O_2 + 17*O_3 + 12*O_4 - 3*O_5)/35 \tag{13}$$

$$S_4= (-2*O_1 + 3*O_2 + 6*O_3 + 7*O_4 + 6*O_5 + 3*O_6 - 2*O_7)/21 \tag{14}$$

$$S_n= (31*O_n + 9*O_{n-1} - 3*O_{n-2} - 5*O_{n-3} + 3*O_{n-4})/35 \tag{15}$$

$$S_{n-1}= (9*O_n + 13*O_{n-1} + 12*O_{n-2} + 6*O_{n-3} - 5*O_{n-4})/35 \tag{16}$$

$$S_{n-2}= (-3*O_n + 12*O_{n-1} + 17*O_{n-2} + 12*O_{n-3} - 3*O_{n-4})/35 \tag{17}$$

$$S_{n-3}= (-2*O_n + 3*O_{n-1} + 6*O_{n-2} + 7*O_{n-3} + 6*O_{n-4} + 3*O_{n-5} - 2*O_{n-6})/21 \tag{18}$$

Curriculum Vitae

Name:	Joseph Munn
Post-secondary Education and Degrees:	University of Toronto Toronto, Ontario, Canada 2007-2011 B.P.H.E The University of Western Ontario London, Ontario, Canada 2014-2016 M.Sc.
Awards:	The University of Western Ontario, Kinesiology Travel Award (2016)
Memberships:	Canadian Society for Biomechanics
Presentations:	Ontario Biomechanics Conference Oral presentation Bodies of Knowledge Conference Oral presentation Kinesiology Graduate Student Association Symposium Oral presentation Canadian Society for Biomechanics Poster presentation
Related Work Experience:	Teaching Assistant The University of Western Ontario 2014-2015 Biomechanics Lab Coordinator The University of Western Ontario 2015