UNIVERSITY OF CHICHESTER

INSTITUTE OF SPORT

DEVELOPMENT OF A METHOD TO DETERMINE OPTIMUM SITTING HEIGHT FOR FEMALE WHITE WATER KAYAKERS USING MARKERS OF STROKE EFFICIENCY

By

Shelley Ann Louise Ellis

Thesis for the degree of Doctor of Philosophy

January 2019

UNIVERSITY OF CHICHESTER

ABSTRACT

INSTITUTE OF SPORT

Doctor of Philosophy

DEVELOPMENT OF A METHOD TO DETERMINE OPTIMUM SITTING HEIGHT FOR FEMALE WHITE WATER KAYAKERS USING MARKERS OF STROKE EFFICIENCY

By Shelley Ann Louise Ellis

White water kayaking has been underrepresented in the scientific literature, largely due to its recreational nature. White water kayaks are manufactured on male body specifications, due to the male dominated history of the sport. Female kayakers have to therefore adapt the kayaks to meet the demands of the environment and task, and their own anthropometry, commonly achieving this through changes to sitting height. The aim of this thesis was to quantify the differences in anthropometry between male and female white water kayakers and, using anthropometry and an observational model of boat kinematics, to develop a method to identify the optimum sitting height for female white water kayakers. An anthropometry study measured 53 kayakers (31 male; 22 female) and identified that the difference in sitting height between males and females was that females were on average 6.93cm shorter than males. This difference is bigger than seen in either slalom paddlers or the normal population. Overall 72.7% of the measures taken were significantly different between male and female white water kayakers. An observational model of boat kinematics was developed, extending our existing understanding into technique analysis of flat water racing kayakers. This doctoral thesis furthered knowledge around what the body does during the stroke cycle in flat water racing, building upon this to identify the patterns of movement caused by the paddle stroke that the white water kayak undergoes. Normalised measurements of patterns of boat movement and paddle forces were established from up to 1154 individual paddle strokes using three-dimensional kinematics and kinetics. This newly created methodology was then employed to develop a technique efficiency method to predict the optimum seat raise for female white water kayakers using a sample of experienced female white water kayakers (n=7). The optimum seat raises identified for the participants were considerably lower (mean 1.86cm (SD 1.46), range 0-4cm, mode 1) than the 6.93cm mean sitting height difference found between male and female white water kayakers in the anthropometric study. The method, based on percentiles, identified seven measures that can be used together to identify optimum sitting height for female white water kayakers. These include 2D kinematic measurement of pitch, velocity change, left arm reach, and stroke length left to right, alongside a timed slalom course and kinetic measurement of both left and right paddle strokes.

Table of Contents

List of Tables

List of Figures

DECLARATION OF AUTHORSHIP

I, Shelley Ann Louise Ellis

declare that the thesis entitled

A method to determine the optimum sitting height for paddle stroke efficiency in female white water kayakers

and the work presented in the thesis are both my own, and have been generated by me as the result of my own original research. I confirm that:

- this work was done wholly or mainly while in candidature for a research degree at this University;
- where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- where I have consulted the published work of others, this is always clearly attributed;
- where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
- none of this work has been published before submission

Signed:…………………………………………………………………..

Date:……………………………………………………………………..

Acknowledgements

I would like to take this opportunity to sincerely thank Professor Mike Lauder and Dr Neal Smith for being diligent and supportive supervisors. There have been many moments where it has been important that they have maintained their sense of humour whilst I have lost mine! Thank you for taking me from my MSc thesis into something that I am proud of.

Thank you Bournemouth University for their sponsorship of this PhD and to Dr Ian Jones for supporting my Doctorate endeavours.

Thank you to Ollie Wainwright and Dagger UK who have helped support this project with the loan of equipment and interesting conversations regarding boat design. I would also like to thank Jason Bayles and the PI staff at the Army Training Regiment Winchester who allowed me to use their swimming pool to collect invaluable data, more than once!!

To Simon and Carla Rahm and South Coast Canoes, you both rock! Thank you for always having coffee on tap when I needed you to help me understand what on earth one of my paddlers was doing to create a graph like that! Your support for me has been incredible and without your contacts I would have struggled to get the help I needed in order to realise this PhD.

Thank you Dr Andrew Callaway. You know that I could not have done this without your unwavering support in so many ways. You have been my sounding board, my data collection support over too many weekends that I can never give you back, my ideas man, and my cover at work! Without you, this would not have happened, fact!

To my fantastic family who have accepted all of my “sorry I’m working on my PhD” excuses, for my poor attendance at family events and gatherings, and understanding why I have not always been able to put you first, thank you! I will make it up to you all now, party?!

Grandma, you were always the first person I’d call to tell my results to during my masters, so I just wanted you to know – I did it!!

To my amazing parents, you have always supported me through every crazy challenge, and this has been the biggest of them yet, and your love and understanding has matched the level of challenge. I would not have made it to where I am today or be the person I am without you. Thank you for being my hotel for Chichester visits, listening to the many issues with sourcing locations, proof reading and emotionally supporting me through the ups and the downs.

To Oz, I am sorry our marriage has been mostly about this document since the day we said “I do” but I am looking forward to going on a holiday where I am not rushing back to the laptop in between outings. It will be novel for us both!! Thank you for holding my hand at my lowest points and helping with my many instances of number blindness! Thank you for proof reading and being my roadie whilst data collecting, all the lifting and carrying was so appreciated. Thank you for accepting that this has had to come before everything else and still loving me! Thank you for being my Rock.

Definitions and Abbreviations

Definitions

White water kayakers	Kayakers who navigate rivers and descend white water rapids as a recreational pursuit
Efficiency	A reduction in the 6 degrees of freedom movements of the craft, specifically focussing on heave, pitch, roll, surge and yaw of the kayak that have been identified as increasing the energy cost of paddling at a given velocity

Abbreviations

1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional
BCU	British Canoe Union
CAD	Computer Aided Design
CoV	Coefficient of variation
ISAK	International Society for the Advancement of Kinanthropometry
P	Percentile
QTM	Qualysis Track Manager
RMS	Root Mean Squared
SEM	Standard error of the mean
SL	Stroke length
SPSS	Statistics Package for the Social Sciences

1.0 Introduction and Rationale

Kayaking in the present day has a number of different disciplines, of which white water kayaking is one (Winning, 2002). It falls under the category of recreational and performance paddle sport, although not within the competitive strands of the sport, according to the British Canoe Union (BCU) definitions (Taylor, 2009). The main goal of white water kayaking is to navigate rivers whilst descending rapids (BCU, 2014b). Therefore the definition of white water kayakers utilised throughout this thesis is “kayakers who navigate rivers and descend white water rapids as a recreational pursuit”.

Kayaking as a sport developed from the use of the skill for hunting by the males of the indigenous Inuit tribe (Mattos, 2009). In the United Kingdom Rob Roy made the sport popular by writing a bestselling book about his first voyage, using kayaking as a means of travel and exploration (Winning, 2002). This early history of the sport of kayaking explains why it has become a male dominated sport throughout history (Winning, 2002), continuing until the present day. The Active People Survey 7 supports this by showing that participation is overwhelmingly towards the male demographic with 87,300 males and 46,000 females participating in the sport of kayaking at least once a month in the October 2012 to October 2013 period (Sport England, 2013). This was further supported by the later Active Lives study (Sport England, 2017), in which it was identified that 37% of participants taking part once a month were female. These studies by Sport England (2013) include all disciplines of kayaking, but unfortunately no data on the white water kayaking population statistics alone exists. This male dominated history has affected the sport, extending through to the design of boats which are made around a male specification

(Levesque, 2008a & b; Manchester, 2008). Therefore female participants have struggled to find boats that fit their, often, smaller frames (Levesque, 2008a); white water boats have tended to be too big to be comfortable for women and smaller people (Manchester, 2008).

Although women have kayaked using this ill-fitting equipment, previous research shows that there is a considerable difference in the anthropometrics of male and female kayakers and that therefore using a male specification to design boats will disadvantage female kayakers. In Ridge, Broad, Kerr and Ackland's (2007) investigation into slalom paddlers' anthropometrics, it was discovered that males recorded larger measurements than their female counterparts in all but two measures. Specifically, female slalom kayakers had a shorter sitting height than their male colleagues (89.7cm and 92.5cm respectively). Slalom kayaking is a good comparison to white water kayaking as it is similar in its aims in terms of navigating rivers and descending rapids, but falls under the performance category of the BCU definitions (Taylor, 2009). However, in further analysis of Ridge et al.'s (2007) results it was identified that slalom paddlers and a non-athlete reference population were not too dissimilar. This finding is contrary to the findings of Ackland, Ong, Kerr and Ridge's (2003) enquiry into the anthropometrics of Olympic sprint kayak and canoe paddlers in which it was found that this kayaking population presented characteristics not often displayed within the general population. These contrasting views of kayaking populations identify the problems with a lack of published reference data specific to the white water kayaking population, particularly how the male measurements relate to their female colleagues as these are the measures reportedly used to design white water kayaks (Manchester, 2008).

The anthropometric measurements the kayak is designed upon and how these measures are specifically related to individual paddlers is important because Ong et al. (2005) state that the internal structure of the kayak must fit the paddler's body dimensions. To enable this to happen, a number of key contact points with the boat itself are necessary in order to have control over the kayak. These are the lumbar back, gluteal region, hips, thighs, knees and toes (Whiting & Varette, 2004). The design of the internal section of the boat will affect the location of these contact points for the individual paddler and this has been suggested to impact on the ability to apply a propulsive force to the boat and also to enable the kayaker to change direction at speed (Ong et al., 2005). It has also been noted that slalom paddlers tend to set their boats up for comfort rather than the mechanical advantage they may provide (Ong et al., 2005), therefore placing the onus on manufacturers to produce mechanically efficient boats, allowing paddlers to concern themselves with comfort.

The efficiency of a paddler can be expressed mechanically as the ratio (Equation 1.1) of the power generated by the paddler (P_{paddle}) to the power required to move the kayak through the water (P_{kayak}). Devices such as the power meter (One Giant Leap, New Zealand) can be used to calculate the power the paddler generates in moving the kayak through the water. This power is directly dependent on the drag forces acting on the hull of the boat. The hydrodynamic equation (Equation 1.2) informs that drag force (F_D) (pressure and viscous) is dependent on area (A), velocity (V) and dynamic pressure (C_D & ρ). Drag force can be used to calculate the work done to move the kayak through the water, and the power required is subsequently dependent on the drag force and the velocity of the kayak (Cengel & Turner, 2012, Equation 1.3). At constant velocity, the efficiency of the paddler is therefore directly related to the drag force on the kayak, which in turn is determined by the motion of the kayak.

$$Efficiency = \frac{P_{kayak}}{P_{paddle}}$$ Equation 1.1

$$F_D = A.\ C_D\ .\ \rho\ .\frac{V^2}{2}$$ Equation 1.2

$$P = F_D.V$$ Equation 1.3

The motion of the kayak in three dimensions has 6 degrees of freedom (Fossati, 2009, Ueng, Lin & Lui, 2008). These are heave, pitch, roll, surge, sway, and yaw (Figure 1.1). Surge, heave and sway are translational motions, while roll, yaw and pitch are rotational motions. During paddling all motions are present to some degree and are created by either the paddler's actions or the environment (waves, wind or current). Any change in kayak motion will change the hydrodynamic forces acting on the kayak hull (Michael, Smith and Rooney, 2009). Michael et al. (2009) go on to state "Interestingly, however, unwanted movement of the kayak, specifically yaw, pitch and roll, and their effects on mean kayak drag have been overlooked in the literature (Michael et al., 2009, pg. 174).

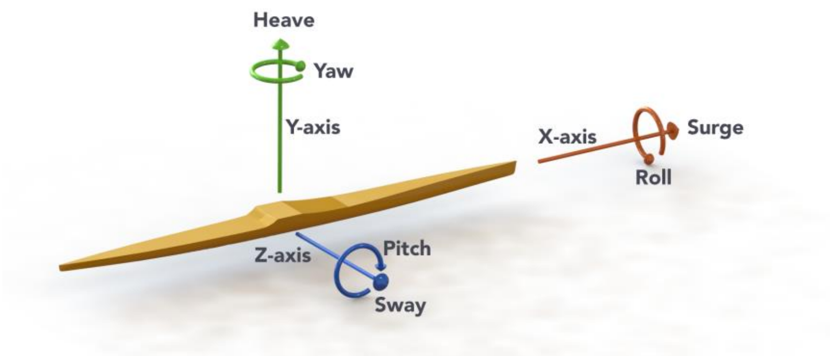


Figure: 1.1 - Motions of the kayak with six degrees of freedom (from Kirkedal & Krantz, 2018)

It is reasonable to assume that a decrease in any or all of these movements would indicate an improvement in mechanical efficiency due to the work done rising in relation to the energy cost (Stainsby, Gladden, Barclay & Wilson, 1980; Toussaint, Knops, De Groot & Hollander, 1990; Whipp & Wasserman, 1969) as a result of the reduction in drag forces. Therefore in this thesis efficiency has been defined as a reduction in the 6 degrees of freedom movements of the craft, specifically focussing on heave, pitch, roll, surge and yaw of the kayak that have been identified as increasing the energy cost of paddling at a given velocity

In order to improve efficiency of the paddle stroke applied to the boat, the kayaker must have full control of the boat using the contact points previously mentioned (Whiting & Varette, 2004). Maintaining contact with the correct points within the boat (Whiting & Varette, 2004) whilst also ensuring the internal dimensions of the kayak fits the paddlers body (Ong et al., 2005) has resulted in the efficiency of the paddle stroke transferring to the boat proving to be a challenge for females who find that boats are too big for them (Levesque, 2008a). Female sitting heights have been identified as shorter than their male counterparts (Ridge et al., 2007) whose anthropometrics have been used to design the boats the females are paddling (Manchester, 2008). Therefore it can be hypothesised that by raising female sitting height to better reflect that of their male colleagues (Ridge et al., 2007), this will have a consequential impact on the location of other contact points within the boat and thus a paddler's boat control should be improved, subsequently improving the mechanical efficiency of the paddler by reducing the unwanted movements of the craft. This has been seen in part in the paper by Broomfield and Lauder (2015) who identified that seat raise changes in a female kayaker's kayak can result in improvements to efficiency, although these changes were found to be individualistic. The paper concluded that identifying the correct seat raise could be dependent on individual anthropometrics and was worth experimenting with further in order to identify whether a method could be created to ascertain the most beneficial seat raise.

A seat raise inclusion into the kayak could potentially aid paddling efficiency for females due to the fact that they would have better control over the kayak through the required contact points as identified by Whiting and Varette (2004). This will in turn help towards ensuring that the internal structure of the kayak will fit the paddler's body dimensions as recommended by Ong et al. (2005). If the female kayakers have more control over the kayak due to these important improvements then the boat movements identified as being less efficient (heave, pitch, roll, yaw and surge) will be able to be reduced by the female kayakers thus enabling them to be able to produce effective strokes when the environment requires, due to being less tired from paddling inefficiently over long periods of time. Therefore they will be able to progress in the sport equal to their male counterparts. At present female kayakers are recommended to raise their sitting height using a trial and error method (Manchester, 2008) which proves difficult for kayakers who set their kayaks up for comfort rather than efficiency (Ong et al., 2005). Therefore this trial and error method is unlikely to produce the best outcomes for the kayaker in terms of efficiency when the focus is more often on comfort. Therefore this Doctoral study will provide kayakers, clubs and coaches with a method to identify how much of a seat raise to add in to each kayaker's kayak in order to help them achieve the most beneficial sitting height for paddle stroke efficiency.

1.1 Aim and Sub-aims

Primary Aim:

To utilise anthropometrics, three-dimensional kinematic and kinetic analysis of technique to identify a method for determining the optimum sitting height for female white water kayakers.

Sub-Aims:

- To establish normative anthropometrics for the white water kayaking population.
- To utilise three-dimensional kinematics, and kinetics to determine female white water kayakers' paddle stroke technique and efficiency related to sitting height.
- To identify the best method of determining optimum sitting height for female white water kayakers.

2.0 Literature Review

2.1 The Sport of Kayaking

2.1.1 History of kayaking

The origins of kayaking have been widely discussed (Fillingham, 1974; Richards & Wade, 1981; Petersen, 1985; Heath & Arima, 2004; Mattos, 2009; Chirazi, 2010) and yet are largely unknown (Petersen, 1985). The kayak is thought to originate from the Dorset culture; the Dorset People came to the coasts of the Bearing Strait in the wake of the Paleo- Eskimos, who, archaeology indicates, did not use kayaks when they inhabited Greenland some 3000-5000 years ago (Petersen, 1985). However, McGhee (2001) and Heath and Arima (2004) do not fully agree with Petersen (1985), with Heath and Arima (2004) stating that the archaeological evidence available only suggests that the Dorset people used a form of watercraft, not necessarily a kayak specifically. The origin of the kayak has been more accepted as a technology used by the early Inuit ancestors (Petersen, 1985; Heath & Arima, 2004; Winning, 2008; Mattos, 2009) or the Thule people (Heath & Arima, 2004; McGhee, 2001) in about 1000AD.

Kayaking in modern day language is also referred to as “canoeing” which is a word used to encompass a wide variety of paddle sports (Richards & Wade, 1981). The canoe, however is thought to originate from North America (Richards & Wade, 1981) and despite its similarities with the kayak in terms of length and the narrowness of the crafts, they were developed geographically far apart and used in different environmental conditions (Fillingham, 1974). This is not the only interesting geographically distant development of the kayaking craft, as Heath and Arima (2004) identify, ancient kayaks have been found at each end of a large migration route used by early northern people; the Koryak kayak being found in eastern Siberia and the East Greenland kayak named after its location of origin in Greenland.

The development of the two crafts of the kayak and the canoe being different, although with strong similarities, is thought to be due to the differing environmental conditions in which they were operating (Richards & Wade, 1981). In the warmer climates of North America the canoe was used to travel on lakes and rivers and therefore had a higher bow and stern to enable the craft to navigate rapids without filling with water (Richards & Wade, 1981). However in Siberia and Greenland with their arctic temperatures, the Inuit created boats within which they were able to sit and make the craft water-tight using seal skins so that they remained dry and warm (Richards & Wade, 1981).

The kayak and the canoe were both designed with two purposes in mind, transport and, in the kayaks case, more often, hunting (Fillingham, 1974; Richards & Wade, 1981; Petersen, 1985; Heath & Arima, 2004; Rosen, 2008; Mattos, 2009; Chirazi, 2010). There is also indication that both craft were also used in war (Fillingham, 1974; Mattos, 2009). The word kayak comes from the Eskimo word “quaja” (Fillingham, 1974) and means “hunting boat” (Richards & Wade, 1981). The Inuit’s also designed a more canoe like (Rosen, 2008), slower and more stable counterpart to the kayak, an “umiak” this means “woman’s boat” indicating that the hunting kayak was used predominantly by men (Richards & Wade, 1981). There are several references to the use of kayaks by males only within the literature. Dall (1870, as cited in Deschner, 1997) noted a kayak as being a smaller boat for a single man. Petersen (1985) identified that the Inuit’s would go out to hunt whilst their wives watched from the cliff tops. Heath and Arima (2004) discuss legends in which wives watch their husbands hunt seals from their kayaks. Finally, Petersen (2008) also discusses how from very early ages mothers started kayak training with their sons, playing kayak games whilst sat on their laps. These games as children, moved into serious hunting as adults with only limited use of the craft for recreation (Fillingham, 1974; Winning, 2008). However the mainly male participation in kayaking continues through history when kayaking moved from a hunting tool to a recreational activity within the UK.

In 1830 it was reported in the news that Mr Canham, a Londoner, canoed from Cherbourg to Alderney (Winning, 2008), and although the higher class Victorians were an adventurous population, the sport of kayaking was little known until Scotsman John MacGregor wrote a best-selling book about his adventures in the Rob Roy Canoe (Fillingham, 1974; Skilling & Sutcliffe, 1980; Richards & Wade, 1981; Winning, 2008; Mattos, 2009). MacGregor designed his own boat (Skilling and Sutcliffe, 1980), which was in fact of kayak descent (Mattos, 2009), and paddled one thousand miles within Europe, discovering the waterways (Skilling & Sutcliffe, 1980). Due to his adventures and his books which recorded them, he is credited with being the forefather of the recreational sport of canoeing in the United Kingdom (Richards & Wade, 1981).

2.1.2 Kayaking as a recreational activity

From around 1600AD kayaking had become a popular recreational activity (Fillingham, 1974). Initially canoeing was more often practiced, and undertaken in conjunction with other outdoor activities such as fishing and camping (Fillingham, 1974; Rosen, 2008).

However kayaking, seen to be a more individual sport than canoeing, soon became the fashion and in North America; according to Rosen (2008), at the beginning of the twenty-first century, around three hundred thousand kayaks were produced annually. Kayaking, or canoeing which is used as the more general term, has a number of different disciplines (Richards & Wade, 1981; Mattos, 2009). In Winning's (2008) chapter he identifies eleven different disciplines of paddlesport. Within these eleven disciplines, white water kayaking is included under the banner of 'touring and expeditioning' (Winning, 2008), however later on in the same book it is given its own chapter (Collins, 2008) suggesting that it is a discipline in its own right. The BCU (2014a) has identified seventeen different disciplines on their "Our Sport" page of their website, white water kayaking is one of these seventeen disciplines.

Taylor (2009) sets out the Long Term Paddler Development (LTPD) Plan that was developed by the BCU (2004). In this document the BCU (2004) identify three key areas of paddlesport; Foundation Paddlesport, Recreational Paddlesport and Performance Paddlesport. White water largely falls under the recreational area (Taylor, 2009). However it is also included within the performance area which includes both competitive disciplines as well as non-competitive disciplines such as white water. White water kayaking is not competitive in its aim and is simply about navigating rivers and descending rapids (BCU, 2014b). The competitive equivalent of white water kayaking is slalom kayaking, British Canoeing (2017) states that slalom involves paddlers negotiating a 300m white water rapid, racing through a succession of up to 25 gates made up of red and green poles similar to ski slalom, although this requires specialist crafts different to those used for white water kayaking (BCU, 2014b). Therefore the definition of white water kayakers to be used throughout this thesis is “kayakers who navigate rivers and descend white water rapids as a recreational pursuit”.

In the recreational area of paddlesport, Taylor (2009) identifies that this is about satisfaction and enjoyment and that it can be pursued at whatever level the individual paddler desires. This makes this area of paddlesport very accessible to a large number of participants. A smaller number of participants will fit into the performance area which involves the paddler maximising their potential (BCU, 2004; Taylor, 2009). Whiting and Varette (2008, p.IX) agree with white water fitting mainly into the recreational area of the BCU’s LTPD Plan, indicating that white water kayaking is fun, easy to progress within and that the sport is possible to be these things “regardless of your shape or size” suggesting the open nature of white water kayaking to a large variety of participants.

2.1.3 Participation in kayaking

With white water kayaking being a predominantly recreational sport, it is clear that the number of participants will be difficult to accurately record. The Watersports Participation Survey (WPS; Arkenford Ltd., 2013) identified that there were 1,213,877 canoeing/ kayaking participants taking part in the activity at least once in 12 months in the UK. This includes all kayaking and canoeing activity. By the calculations used in the survey and the population statistics used of 23,813,000 and 25,231,000 male to female respectively, it was estimated that 904,894 males and 580,313 females participated in canoeing activity once in the 12 month period. This is a 1.56:1 male to female ratio of participation. This survey provides numbers of irregular participation, and to be a participant of white water kayaking, it can be assumed that more regular participation would be required due to the skill level needed (Whiting & Varette, 2008). The Active People Survey 7 (APS7; Sport England, 2013) looked at participants in canoeing at least once per month in which 133,300 adults participated; 87,300 male and 46,000 females this provided a ratio of 1.9:1 males to females. This was supported by the later Active Lives study (Sport England, 2017), in which it was identified that 37% of participants taking part once a month were female, a ratio of 2.70:1 males to females. The Active People Survey 7 went on to identify the number of participants that took part in canoeing at least once a week. The number of adult participants in this case was 42,100. Of these, 35,400 were male and 7,600 were female, providing a ratio of 4.66:1 males to females. Under the terms of the survey “canoeing” included canoeing, canoe polo, kayaking, white water kayaking, and rafting.

The APS7 (Sport England, 2013) and the WPS (Arkenford Ltd., 2013) both use the term “canoeing” to encompass a number of disciplines of paddlesport and therefore it is difficult to obtain accurate numbers of participation for any of these individual disciplines. Membership of the BCU, the National Governing Body (NGB) indicated 65,119 members in its Annual Report (BCU 2013). However, despite membership of the NGB indicating that members are more serious canoeing participants, the BCU still does not record which of the seventeen disciplines that they support, the members enjoy. Therefore the sample size of white water kayakers is largely unknown, however what is clear is that the ratio of males to females in canoeing and kayaking generally, shows a distinct difference.

This difference appears to get larger the more regularly the participants enjoy paddlesport. Participating once per year the ratio is 1.56:1 (Arkenford Ltd., 2013), participating once per month the ratio is 1.9:1 (Sport England, 2013) or 2.7:1 (Sport England, 2017) and participating once per week the ratio is 4.66:1 (Sport England, 2013) males to females respectively. The male dominated history of paddlesport indicates that this difference in male to female participation should be expected, however APS7 (Sport England, 2013) indicates that there is an increase in female participation whilst the male participation is on a decline. Due to the large difference in regularly participating males to females, it should also be expected that kayak designs are built around a male specification (Levesque, 2008a & b; Manchester, 2008). Ergonomics of equipment design suggests that equipment which just fits the average person, or in this case the male gender, is insufficient and that to ensure the maximum number of people are able to use the equipment, design limits of the 5th and 95th percentiles of the populous should be imposed (Pheasant, 1996).

2.2 Ergonomics of Equipment

Pheasant (1991, pg4) defines ergonomics as “the application of scientific information concerning human beings to the design of objects, systems and environments for human use.” Reilly (2010) takes a sporting stance of ergonomic design and helps translate Pheasant’s (1996; 1991) view of ergonomics in everyday life into meaningful terminology for the sporting domain. Reilly (2010) explains that the athlete’s interface with the equipment will play a main role in the design process along with the task it is used for. In white water kayaking the environment that the equipment needs to function within is paramount to determining the shape and materials used in the kayak design (Rosen, 2008). As important as Reilly (2010) has identified the environment, task and athlete interface as being in the design process, Reilly's (2010) model of ergonomic design (Figure 2.1) puts the athlete at the centre of the design process. This position of the athlete agrees with Pheasant's (1996) views where he identified the user should be the centre of ergonomic design. Within kayak design, the athlete being the centre of the design process, as well as heeding Pheasant's (1996) much later recommendations on the importance of anthropometrics in ensuring that the ergonomics were correct, was clear in the methods used by the Inuit tribe in early kayak design (Petersen, 1985).

Figure 2.1: Model of sport ergonomic design (adapted from Reilly, 2010)

2.2.1 Inuit boat design

Inuit kayaks, or the 'equipment' in Reilly's (2010) model, were made from a frame of either animal bones or wood (Fillingham, 1974; Chirazi, 2010). The frame was held together by gut (Fillingham, 1974) and covered with animal skin, usually seal (Fillingham, 1974; Chirazi, 2010). The sealskins were greased to aid waterproofing (Richards & Wade, 1981), the grease used was whale fat (Chirazi, 2010). In order to maintain the waterproofing of the sealskin, no holes were made all the way through the skin when sewing them together (Heath & Arima, 2004). Heath and Arima (2004) discuss the design of the kayaks at great length: The boats were designed with long gunwales shaped together so that they match, with holes made for the ribs and thwarts. Petersen (1985) discusses similar design methods, with slightly different terminology, referring to the gunwales as ‘sheer boards’ and thwarts as ‘cross beams’. The ribs were then bent into shape and inserted into the gunwales to make the shape of the hull; the thwarts were inserted to make the shape of the deck (Heath & Arima, 2004). The cockpit hoop was only attached to the skin and not the framework, in other words it floated (Heath & Arima, 2004). The shape of the kayak designed by the Inuit tribe was engineered for speed and strength in rough seas or entry and exit on rocky terrain (Heath & Arima, 2004). There are vast similarities in the shapes of the East Greenland kayak design and the classic designs of sea kayaks used in the modern era (Richards & Wade, 1981; Heath & Arima, 2004; Mackereth, 2008), the changes seen are in the materials used, not the shape, upon which it would be difficult to improve (Mackereth, 2008).

The original kayaks used by the indigenous Inuit tribe were made specifically for the boat user (Petersen, 1985). Measurements used were subjective units rather than exact measurement systems and were often based on the users body dimensions (Petersen, 1985). Examples presented in Petersen’s (1985, p. 19) text, one of the few that actually discuss the building process, identify measurements such as the “Isanneq” this is an arm-span, which Petersen (1985), noted can vary greatly from individual to individual despite always being measured on a grown man. These “made-to-measure” crafts ensured that the Inuit boat users had a snug fit into the cockpit (Richards & Wade, 1981) enabling them to manoeuvre the boat and even to right themselves if overturned by a wave or animal (Richards & Wade, 1981). This evidence of understanding the great differences between individuals in these early kayak designs is important when looking forwards to the ergonomics of boat design in modern day mass production of kayaks (Rosen, 2008).

2.2.2 Modern boat design

The white water kayaks that are paddled today are more similar in design to the Koryak kayaks found in eastern Siberia (Heath & Arima, 2004). They were shorter and wider than the East Greenland kayak, which, as previously stated, reflects the design of today's sea kayaks and flat water racing kayaks (Heath & Arima, 2004). The shape is where the similarity ends, however, as the materials used in today's kayaks are tougher and enable the kayak to be made in one piece (Mackereth, 2008). Despite the change in materials used, the manufacturers have also had to ensure that the kayaks made maintain the stability seen in the Koryak kayaks, especially if the craft is designed for use in white water (Chirazi, 2010).

The white water kayaks seen on rivers in the present day are plastic (Whiting & Varette, 2004), made in one piece (Mackereth, 2008) and are shorter and wider than kayaks used for other purposes, enhancing their ability to turn quickly and remain stable despite often confined environments. Flat water racing kayaks, however, tend to be longer and narrower in order to enable the craft to travel in a straight line fast. The hull shape of a flat water racing kayak, similar to sea kayaks, have a "U" hull which enables them to track in a straight line (Mackereth, 2008). A white water kayak hull however is either planing or displacement depending on the type of white water kayaking environment they are being used in, these hull shapes promote fast turning ability (Ford, 1995; Whiting & Varette, 2004; Rosen, 2008). The type of white water kayaking defined for this thesis, navigating rivers and descending white water rapids as a recreational pursuit, most often require the use of flat hulled kayaks.

Kayaks are now designed using Computer Aided Design (CAD) software and are created for mass production, no longer to fit one individual, but a group of people who have a similar set of anthropometrics, skill level, and needs (Rosen, 2008). These 'needs' that Rosen (2008) refers to fulfil both the 'equipment', or boat, and 'workspace', or cockpit, elements that Reilly's (2010) model identifies. However the boat and cockpit designs are also largely defined by the 'environment' the craft will be used in (Reilly, 2010). In a similar way to the early design of the kayak by the Inuit tribe being due to the need to hunt in rough seas and be fully water tight so as to allow the tribesmen to right themselves if overturned (Richards & Wade, 1981; Heath & Arima, 2004); the environment that white water kayaks are used in determine their design.

2.2.2.1 Environment in Reilly's (2010) model

When looking into the "environment", identified by Reilly (2010) as being the outermost shell in his model of sporting ergonomic design, in more detail, it is clear that white water kayaking involves navigating rivers and descending rapids (BCU, 2014b). Rapids are often formed by rocks in the water (Berry, 2008). The boats need to be designed to take repeated impacts from the rocks hence the need for tougher materials (Mackereth, 2008), this is why plastic has been the material of choice since the 1970s (Whiting & Varette, 2004). The environment paddled in, not only helped determine the materials used in today’s boats, but also the type of rivers paddled helps the kayaker decide the hull shape to be used (Rosen, 2008). In most cases the more modern planing hull is the shape of choice due to the improved stability in this design (Whiting & Varette, 2004). However, the displacement hull or creek boat, is more often chosen for running waterfalls due to its resurfacing ability (Ford, 1995; Whiting & Varette, 2004). The boats used for running white water rivers tend to be longer in comparison to white water play boats in order to carry speed, although they are shorter than sea kayaks and flat water racing kayaks due to the need to change direction at speed and possible confinement on a river (Ford, 1995; Whiting & Varette, 2004; Rosen, 2008). White water kayaks also have higher volume in the bow and stern to stop them from submerging (Whiting & Varette, 2004). These distinguishing features of the white water kayak are determined by the environment, but in order to allow the craft to be controlled, the “workspace” also needs to be considered and is the next ring in Reilly’s (2010) model (Figure 2.1).

2.2.2.2 Workspace in Reilly’s (2010) model

In this kayaking instance, the “workspace” is the cockpit that the kayaker propels the kayak from within. Rosen (2008) indicates the problem facing designers when it comes to cockpits is that there are not many sitting positions available to them, and most importantly, the main option is not an ergonomic one. The sitting position adopted by the Inuit tribe was known as the “L position”, in other words the kayaker sat on the floor of the boat with legs extended in front of them (Rosen, 2008). Modern kayakers spend little time in general sitting in the “L position”, unlike the native kayakers, due to the variety of every-day sitting options available to them in terms of stools and chairs (Rosen, 2008).

However, due to the aforementioned limited choice of sitting options in a kayak, an adapted version of this sitting position is what is used within modern kayaks. Rosen (2008) goes on to discuss the major change between early Inuit kayaks and modern kayaks is the introduction of a back band and foot support. Whiting and Varette (2004) stated that the internal design of kayaks is one of the major areas of design improvement. Alongside the introduction of back bands and foot rests, moulded and adaptable seats and thigh braces have also been included as standard in most new boat models (Whiting & Varette, 2004). In order to maintain control over the kayak, Whiting and Varette (2004) and Mattos (2009) identify a number of key contact points within the boat; lumbar back, gluteal region, hips, thighs, knees and toes; these contact points are precisely the athlete interface with the equipment that Reilly (2010) was referring to. It is also clear that, due to the majority of the weight being located on the gluteal region, that this is the start of the chain, any position change at this point will subsequently affect the position of all of the other points in the chain, hence the focus of this doctoral research being on the seat height position and its impact on paddle stroke efficiency. Langford (1980) also understood the importance of the interface and these key contact points in the boat and even went so far as to suggest the internal fittings of a kayak used on white water were so important that the paddler should feel as though they were wearing their kayak, not sitting in it. Ong et al. (2005) further discovered that this interface within the cockpit must not only fit the paddler’s anthropometrics but that this is in fact necessary in order for the paddler to apply propulsive forces to the boat and to change directions at speed.

Despite this necessity, Ong, Elliott, Ackland and Lyttle (2006) identified that there is very little available normative data regarding equipment set up for kayaking in scientific literature. It is clear that Ong and colleagues have attempted to begin to fill this gap with two papers, one focusing on sprint kayaking (Ong et al., 2006) and one comparing sprint and slalom kayaking (Ong et al., 2005). In the study on sprint kayakers (Ong et al., 2006) an intervention was carried out comparing three athletes' predicted set up, based on a regression analysis of a larger sample size of anthropometrics and boat set up measurements (Ong et al., 2005), to their preferred set up. The results showed varying results, which, depending on the athlete, showed some improvements and some worse performances with the predicted set up when compared to the athletes preferred set up. However, the equations obtained through the regression analysis and used to predict boat set up were not stated as being different for male and female paddlers, rather they used one equation to predict all sprint kayakers boat set up. This is a questionable methodological choice, especially when regarding the findings of their earlier study in 2005, which looked into how Olympic Sprint and Slalom paddlers set their equipment up (Ong et al., 2005).

Slalom kayaking is arguably the competitive aspect of its recreational counterpart, white water kayaking; they have similar aims that the kayakers are trying to achieve, in terms of navigating rapids on rivers (Taylor, 2009). The boats used are somewhat different to the recreational white water kayak, often being made from composite materials to help minimise weight (Maddock, 2008), however their general shape remains similar due to the resemblance between the aims of the two sports (Taylor, 2009).

Ong et al. (2005) identified that paddlers of both sprint and slalom crafts often set their boats up for comfort through a trial and error system, rather than focussing on the advantages that can be achieved mechanically through effective equipment set up. This provides a reason for this Doctoral thesis to focus on equipment set up in terms of sitting height and its impact on paddle stroke efficiency. This will help paddlers understand how best to determine the most beneficial sitting height for themselves in order to set up their boats for mechanical advantage as well as comfort and to reduce the trial and error method currently used. The aim of Ong et al.'s (2005) paper was to provide other slalom athletes with evidence to help them identify their own ideal kayak set up with reference to the decisions made by elite athletes. In the slalom section of the paper they measured 12 female and 12 male competitors in the 2000 Olympic Games. Athletes' anthropometrics were measured according to International Society for the Advancement of Kinanthropometry (ISAK) principles (Stewart, Marfell-Jones, Olds & de Ridder, 2011) and then a selection of both boat and paddle measures were taken.

The results showed that there was a large difference in the seat height of sprint compared to slalom paddlers, with slalom being on average 72mm lower; the authors identified that this was largely expected due to the need for balance being so vital in slalom events. However, male slalom paddlers had their seats 2mm higher in the boat from the hull than their female colleagues, although the lowest point on the seat was 217mm from the cockpit rim for males compared to 209mm for female athletes (Figure 2.2). This means that the depth of the boat from hull to cockpit rim was different for males to females by 10mm, but that the height of the seat from the hull of the boat was also considerably different as a percentage of this depth. For males the seat height was at 18% of the depth of their boats from the hull, but for females it was only 12.9% of the depth of their boats from the hull, sitting females, on average, 5.1% lower in their boats than males. This is despite the finding that males were on average 5.3%, or 94mm, taller than their female colleagues.

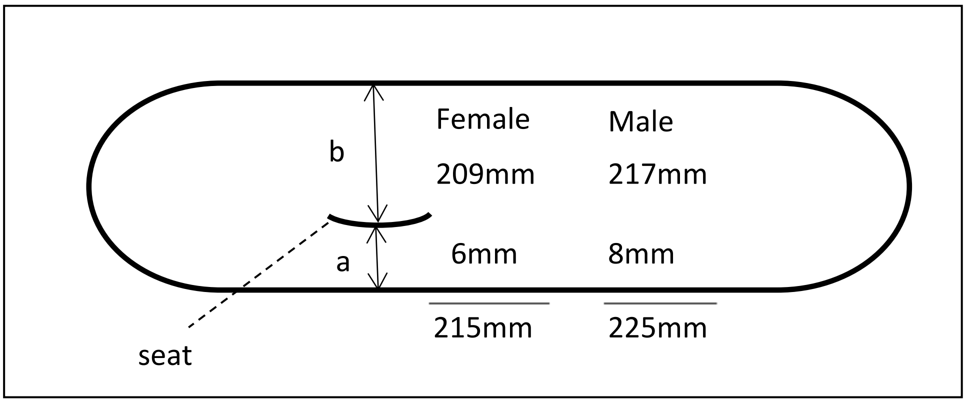


Figure 2.2: Lateral view of sitting position of slalom athletes in their boat (Ong et al., 2005)

Another finding regarding the cockpit set up of slalom paddlers in Ong et al.'s (2005) paper came from the foot bar distance from the seat. Despite females being on average 94mm shorter than male slalom paddlers, the difference in foot plate distance is recorded as only 34mm closer for females. Similar findings were observed between the sprint paddlers, with a height difference for females being on average 159mm shorter than male sprint kayakers, and their foot plates being only 77mm closer. Interestingly the male sprint and slalom paddlers showed a significant difference in footplate set up; an expected finding due to the different aims of the sports and the craft or in Reilly's (2010) terms "equipment" being paddled. However, there was no significant difference identified between female sprint and slalom paddlers' foot plate distance. The fact that the males have indicated a significant difference suggests that the crafts would allow for females to have this larger differentiation, but either they are choosing not to, or the boats are not as adaptable to the smaller female frames; meaning that by introducing these changes in footplate distance, a reduction in the contact points suggested by Whiting and Varette (2004) and Mattos (2009) is found. This lack of difference between "workspace" set up seen in female sprint and slalom kayaks, as well as the minimal difference in male to female workspace set up despite the difference in their heights, is important to note because Reilly (2010) clearly put the athlete at the centre of the sports ergonomics of design model, and this questions whether this is truly the case with female kayakers.

2.2.2.3 Putting the Athlete at the centre of Reilly's (2010) model

The modern kayaks designed for the masses (Rosen, 2008) have come away from the made to measure designs used by the Inuits (Petersen, 1985) which truly put the paddler at the centre of the process. What has not changed in this time, however, is that the main user of the craft remains male (Sport England, 2013; Sport England, 2017). However, meeting the needs of the average person using the equipment does not agree with the ergonomic limits of meeting the 5^{th} and 95^{th} percentile of the population (Pheasant, 1996) and does not put the athlete, or certainly not the female athlete, at the centre of the model as Reilly (2010) suggests. Therefore just meeting the needs of the male population when designing the craft would not be ergonomically acceptable (Pheasant, 1996), especially whilst considering female participation is growing and male participation appears to be on the decline (Sport England, 2013).

Unfortunately the lack of female specific kayaking equipment is all too apparent in any kayaking equipment shop. The boats sold for white water kayaking are unisex, although often come in varying sizes. However, Levesque (2008a), an international freestyle competitor and kayak coach, identified on a female specific paddling DVD that females struggle to find appropriately fitting boats. In the same DVD Manchester (2008), the Canadian Freestyle Champion, agrees with Levesque's (2008a) comments and suggests that white water boats, particularly, tend to be too big for women and smaller people to provide the comfort that Ong et al. (2005) stated that fit was important for. This inability to find equipment which fits the female frame tends to come from the male dominated history of the sport discussed earlier in this chapter. The male dominated history has meant that male paddlers remain located at the centre of the design process when it comes to designing white water kayaks (Levesque, 2008a & b; Manchester, 2008). Despite this being the case, females have managed to find ways to adapt the kayak to attempt to fit their generally smaller anthropometrics, raising seat height using a trial and error method has been one such adaptation (Manchester, 2008). However, as was found in the study by Ong et al. (2005), the male slalom paddlers were 94mm taller than their female counterparts and they were also 13.5kg heavier. This gives us an indication of the large difference in the anthropometrics of male to female slalom paddlers, however this difference needs to be investigated more thoroughly to provide a true picture of what impact the boats being designed around a male specification (Levesque, 2008a & b; Manchester, 2008) has on female white water paddlers.

2.3 Anthropometrics of the Kayaker

It has been identified, when studying anthropometric measurement, that within elite sports populations there are very similar anthropometrics, these often exhibit common distinguishing features (Leone, Lariviere & Comtois, 2002) and differ from the "normal" population in some ways (Pheasant, 1996), this has been referred to as "morphological optimisation" (Norton, Olds, Olive & Craig, 1996, p.289). There are countless studies on elite populations in sport and how they have changed over the years. For the purposes of this review, cyclical water sports, similar to kayaking (Bily, Suss & Buchtel, 2011), have been chosen to identify how elite populations display these similar characteristics and whether there are comparisons between cyclical water sports. Therefore the sports of swimming and rowing will be discussed in relation to this.

2.3.1 Anthropometrics of elite cyclic water sport populations

2.3.1.1 Anthropometrics of swimmers

In a study by Toussaint et al. (1990) the athletes in the sample exhibited a taller height and increased body mass when compared to their similarly aged counterparts in Pheasant's (1996) general population statistics. On average Toussaint et al.'s (1990) athletes were 6.4% and 9.5% (male and female respectively) taller and 7.2% and 3.8% heavier (male and female respectively) than the general population figures provided by Pheasant (1996). Despite the small sample of ten (6 males and 4 females) used in Toussaint et al.'s (1990) paper, this suggests that swimmers in 1990 exhibited a taller stature and heavier body mass than the general population and therefore these were a feature of the elite population sampled, which separated them from the general population. Small samples in elite studies are somewhat expected due to the smaller population from which the sample is drawn, however there are variations in the sample sizes seen in the papers reviewed.

In Pelayo, Sidney, Kherif, Chollet and Tourny's (1996) later paper, the authors used a larger sample size (88 male and 85 female) than Toussaint et al. (1990) and split the swimmers into their respective events (21.6 swimmers per event on average) to identify whether there were population differences between event populations. Despite these event separations it is clear that there are still similarities which distinguish the elite swimmers from Pheasant's (1996) general population. All event samples were taller than their general population counterparts, ranging from 4.1% to 6.4% taller for females and 3.8% to 5.4% taller for males. All event samples also exhibited a longer arm span than their general population equivalents, ranging from 5.2% to 10.2% longer for females and 4.1% to 5.9% longer for males. This finding of increased arm span was also shared in Geladas, Nassis and Pavlicevic's (2005) later paper looking at young swimmers, in which the athletes upper limb lengths were found to be 6.1% and 5.2% longer (male to female respectively) than the general population statistics for the same age.

In terms of body mass data Pelayo et al. (1996) found there were inconsistencies; in contrast to Toussaint et al. (1990) all the female athletes regardless of event were lighter than their general population colleagues, ranging from 1.1% to 9.4% lighter. However the males were heavier in two events, 100m and 200m (2.9% and 1.9% heavier respectively), which was consistent with the findings of Toussaint et al. (1990). Despite this finding for some events, in the 50m and 400m the male athletes were lighter again (5.1% and 0.5% lighter respectively), similar to the female athletes in this study. This suggests that although Pelayo et al. (1996) agrees with the findings on height in Toussaint et al.'s (1990) study and adds another distinguishing feature of elite swimmers to be their span, whether weight differences from the general population are another feature is not yet clear from these two studies.

Height as a distinguishing factor has been found in swimmers even as early as 11 years old. Bencke et al. (2002) compared elite swimmers of age 11 years to their non-elite swimming colleagues. In a sample size of 29 elite swimmers and 21 non-elite, the elite participants were found to be taller than both their non-elite colleagues (1.9% and 6.2% taller, male and female respectively) and the British general population statistics provided by Pheasant (1996) for 11 year olds (6.5% and 6.8% taller, male and female respectively). Although it must be recognised that using British general population data as a comparison to Danish athletes is not perfect, in a number of other studies looking at anthropometrics of elite populations, the nationality of the athletes are not taken into consideration (Ackland et al., 2003; Barlow, Findlay, Gresty & Cooke, 2014; Pelayo et al., 1996) suggesting that differences in nationality is not always of considerable importance. This finding from Bencke et al. (2002) is also echoed in Leone et al.’s (2002) paper in which female adolescent swimmers were investigated. Leone et al.’s (2002) data, again indicates height as a distinguishing factor of elite swimmers, putting the swimmers as 1.85% taller than the general population statistics for their similarly aged counterparts (Pheasant, 1996).

The body mass differences seen in Bencke et al.’s (2002) paper are, again, inconsistent, which is in-keeping with Pelayo et al.’s (1996) findings. The elite athletes were heavier than their non-elite counterparts (4.1% and 24.3% heavier, male and female respectively) and also the British 11 year old general population data (Pheasant, 1996; 12.5% and

15.2% heavier male and female respectively), which was similar to the findings of Toussaint et al. (1990) and also Leone et al. (2002) whose athletes were 4.24% heavier than their general population associates. However the non-elite swimmers showed differing results when compared to the general population, female non-elite swimmers were 10.8% lighter and male non-elite swimmers were 8.8% heavier. This could be because non-elite populations, more commonly, closer reflect the general population, however it is also consistent with Pelayo et al.'s (1996) findings, so it is unclear whether this is a similarity in all swimmers, elite or non-elite, or whether weight is not as important as height and arm span within swimming and therefore is not seen to be a distinguishing feature of the swimming population.

Within ultra-marathon swimmers though, the weight findings are more clear, with Knechtle, Baumann, Knechtle and Rosemann (2010) finding that the athletes in their sample were not only taller than the general population figures (3.6% and 3.9% taller male and female respectively) from Pheasant (1996), but also heavier, with males being 12.6% heavier than the general population and females being 10.5%, however in this particular event this could be due to the longer distances in cold waters requiring them to carry more weight in the form of fat for insulation purposes. Their findings also agree with Pelayo et al. (1996) and Geladas et al. (2005) in that the arm length is longer than the general population (5.2% and 5.1% longer for males and females respectively).

From the papers reviewed on the cyclic water sport of swimming, it is clear that there are two distinguishing features of elite swimmers, being height and arm span/ length, this appears to be the case regardless of gender or event choice. Body mass, however, is not as clear in terms of a distinguishing feature, although in many events, ages and both genders, the body mass of elite swimmers tends to be heavier than the general population statistics.

2.3.1.2 Anthropometrics of rowing

The findings in rowing appear to be similar to that of swimming. In Bourgois et al.'s (2000) paper looking at elite junior male rowers, the athletes were taller in height (6.4%), taller in sitting height (5.6%) and were heavier (21.3%) than their Belgian non-rowing reference populations. When comparing these figures to the British equivalent, to be in-keeping with the previous discussion on population comparisons in swimming, the results are similar, the elite rowers were taller (6.62%), sit taller (6%), heavier (20.32%) and also have a longer arm length (4.7%) than the British general population (Pheasant, 1996). Arm length was not compared to the Belgian reference population in the Bourgois et al. (2000) paper due to data not being available for this measure. However they did compare some other measurements to the Belgian population, showing the rowers also had longer legs, a wider biacromial diameter, larger humerus and femur width, a larger bicep, thigh and calf girth.

Bourgois et al. (2001) also looked into elite junior female rowers and their findings were similar. In this paper they compared their elite athletes to a Flemish reference population and identified the percentile (P) of this population the rowers would fit into. For height (P97), sitting height (P90), leg length (P93) and body mass (P93), it is clear that they recorded greater measurements than the general Flemish population. They also, overall, recorded increased length, breadth and girth measurements than the reference population. When comparing their results to the British general population statistics, the rowers had increased height (7.16%), sitting height (5.84%), upper limb length (6.5%), leg length (2.26%) and weight (19.42%) (Pheasant, 1996).

In both the Bourgois et al. (2000,2001) papers, despite the sample being from a variety of countries, the reference data compared to was from one country alone, in both papers this was from within Europe however, and the sample was indicated in the method as being mostly from Europe (83.8% and 77%, 2000 and 2001 respectively). This supports the earlier notion of comparing data to British figures provided by Pheasant (1996) due to the multinational nature of many of the papers looking at elite populations.

Barrett and Manning (2004), however, focussed their paper on one nationality; male Australian rowers competing in a national selection regatta. The paper was similar in aim to that of the earlier discussed Ong et al. (2005) article on kayak set up, although in this paper Barrett and Manning (2004) were focussing on single sculler rigging set up. Barrett and Manning (2004) reported anthropometrics of the rowers as part of the analysis of rigging set up and when comparing them to Pheasant’s (1996) data it is clear that they had taller height (7.79%), sitting height (4.81%), longer arm span (7.45%), higher body mass (10.29%) and longer legs (6.60%).

Schranz, Tomkinson, Olds and Daniell (2010), also focussed their study on Australian rowers, however they were looking to compare elite Australian rowers to the general population using three-dimensional anthropometric measurements. Due to the three dimensional nature of the measurements taken, the results are different to other papers reviewed here and therefore the comparisons are difficult to draw, however the lightweight female rowers exhibited longer legs and arms as well as sitting height than the general population, similar findings to the previous papers discussed (Barrett & Manning, 2004; Bourgois et al., 2000; Bourgois et al., 2001). Further supporting these findings, heavyweight female rowers also had longer legs, arms and sitting height, as well as height and mass being larger in size than the general population (Schranz et al., 2010). In contrast, light weight male rowers were smaller than the general population statistics, with very few measures recording larger effect sizes, this was also the case for length measures overall, which is different from other rowing studies reviewed here (Barrett & Manning, 2004; Bourgois et al., 2000; Bourgois et al., 2001; Mikulic, 2008), although in previous studies they were not often split into their weight categories. Heavyweight male rowers, however, recorded measures similar to their female counterparts, showing larger height, sitting height, body mass, arm length and leg length than the general population.

Mikulic (2008) found his results agreed with that of Barrett and Manning (2004), Bourgois et al. (2000), Bourgois et al. (2001) and largely agreed with the findings of Schranz et al. (2010). Mikulic (2008) studied Croatian rowers of varying ability levels; his findings suggest that elite senior male rowers exhibit stronger homogeneity than their non-elite colleagues. Elite rowers were taller (2.80%), heavier (4.42%), had a longer arm span (3.09%) and leg length (4.51%) than their non-elite counterparts. When comparing to Pheasant’s (1996) general population statistics, the differences between the elite sample of 12 athletes in Mikulic’s (2008) study and the general population were even bigger than those seen when comparing to the non-elite rowers. Again, elite rowers were taller (10.05%), heavier (22.84%), had a longer arm span (10.27%) and leg length (18.21%).

It is interesting that rowers show similar indications in homogeneity to swimmers; showing increased arm span/ length, height and body mass. Although the increased body mass appears to be a more consistent finding for rowers, and a bigger increase than that of swimmers, when compared to the reference population as seen in the earlier papers discussed (Barrett & Manning, 2004; Bourgois et al., 2000; Bourgois et al., 2001; Mikulic, 2008; Schranz et al., 2010). In the swimming papers, however, there was rarely mention of leg length measures being taken, despite several rowing papers showing that leg length increase was a common finding within the elite population when compared to the reference population. When considering the cyclical water sport commonalities between rowing and swimming it would have been interesting to see more leg length measures being taken in swimming to see if this was a common finding here too, especially as the only paper reviewed to provide a leg length measure found inconsistent results for males and females; 1.94% longer for females and 4.46% shorter for males (Knechtle et al., 2010), this was despite Knechtle et al. (2010) taking the leg measurement from greater trochanter to lateral malleolus and Pheasant (1996) taking the measurement from greater trochanter to floor.

Regardless of the lacking leg length measures in swimming studies, it appears from the review of literature in swimming and rowing that elite cyclical water sports athletes do display common anthropometric traits. These are similar in many ways to the traits that can also be seen in elite kayakers.

2.3.2 Anthropometrics of kayakers

The elite kayaking papers can be split into two categories of the sport: firstly, and most common, are papers looking into flat water sprint kayaking; secondly are papers looking at slalom kayaking.

Tables 2.1 and 2.2 provide an overview of the findings of these papers when compared to Pheasant's (1996) measurements for the general population. It is clear when looking at these findings that there are differences in anthropometrics between elite kayakers and the general population.

Elite kayakers are taller than the general population (Ackland et al., 2003; Aitken & Jenkins, 1998; Akca & Muniroglu, 2008; Alacid, Marfell-Jones, Lopez-Minarro, Martinez & Muyor, 2011; Bily et al., 2011; Bishop, 2000; Fernandes, 2013; López-Plaza, Alacid, Muyor, & López-Miñarro, 2017; López-Plaza et al., 2018; Ong et al., 2005; Ridge et al., 2007; van Someren & Howatson, 2008; van Someren & Palmer, 2003; Vedat, 2012) when compared to Pheasant's (1996) data and also have an increased sitting height (Ackland et al., 2003; Aitken & Jenkins, 1998; Akca & Muniroglu, 2008; Alacid et al., 2011; Fernandes, 2013; López-Plaza et al., 2017; López-Plaza et al., 2018; Ridge et al., 2007; van Someren & Howatson, 2008; van Someren & Palmer, 2003) and arm span (Ackland et al., 2003; Aitken & Jenkins, 1998; Akca & Muniroglu, 2008; Alacid et al., 2011; Bily et al., 2011; Fernandes, 2013; Ridge et al., 2007; van Someren & Howatson, 2008; van Someren & Palmer, 2003). Although, not all papers specify the exact method of measuring these anthropometrics, they are all consistently producing the same increased results for kayakers. These findings are also in-keeping with the overall findings from both rowing and swimming and suggests that all elite cyclical water sports populations may present similar evidence of homogeneity or morphological optimisation (Norton et al., 1996).

Table 2.1: A comparison of the percentage difference in results from each flat water kayaking paper listed to Pheasant's (1996) results for the general population. All results are larger for kayakers except for negative percentage differences which indicate that the figure was smaller for kayakers than the general population.

		Sprint kayaking												
	Journal article:	Ackland et al. (2003)	Aitken & Jenkins (1998)	Akca & Muniroglu (2008)	Alacid et al. (2011)		Bishop (2000)	Fernandes (2013)	López-Plaza et al. (2017)	López-Plaza et al. (2018)	Ong et al. (2005)	Van Someron & Howatson (2008)	Van Someron & Palmer (2003)	
	Key characteristics of sample:	Olympic	Elite	Turkish National	13 & 14 years old elite		National-international	Portuguese national	Spanish youth develop-ment squad	Spanish youth develop-ment squad top 10	Olympic	Club-international	National-international	
					13	14							I	N
Measurement:														
Male	Body mass (%)	11.97	13.59	3.10	16.87	13.96		10.38	1.90		11.56	9.9	11.2	5.06
Male	Height (%)	5.32	5.16	2.45	5.19	3.62		2.20	2.09		5.42	4.5	3.77	3.51
Male	Sitting height (%)	5.57	2.66	1.70	7.19	5.49		5.02	3.78			4.4	4.49	3.07
Male	Arm span (%)	5.56	5.51	1.14	5.25	4.03		2.08				5.5	4.97	5.17
Male	Shoulder breadth (%)	7.19												
Female	Body mass (%)	6.94	6.60		13.40	7.59	4.72			14.24	2.17			
Female	Height (%)	5.22	5.56		4.56	3.55	10.51			5.14	4.21			
Female	Sitting height (%)	5.40	5.00		6.20	4.87				8.31				
Female	Arm span (%)	6.5	5.94		6.59	4.76								
Female	Shoulder breadth (%)	8.40												

Table 2.2: A comparison of the percentage difference in results from each slalom kayaking paper listed to Pheasant's (1996) results for the general population. All results are larger for the kayakers except for negative percentage differences which indicate that the figure was smaller for kayakers than the general population.

		Slalom kayaking			
	Journal article:	Bily et al. (2011)	Ong et al. (2005)	Ridge et al. (2007)	Vedat (2012)
Measurement:					
Male	Body mass (%)	-1.33%	-3.33%	-4.4%	-0.61%
	Height (%)	1.30%	1.47%	1.41%	1.25%
	Sitting height (%)			1.08%	
	Arm span (%)	1.10%		0.83%	
	Shoulder breadth (%)			2.91%	
Female	Body mass (%)	-5.56%	-6.35%	-6.35%	
	Height (%)	2.77%	3.70%	3.70%	
	Sitting height (%)			4.68%	
	Arm span (%)	4.21%		3.64%	
	Shoulder breadth (%)			3.74%	

Although some of the kayaking papers did provide measures for leg lengths (Ackland et al., 2003; Aitken & Jenkins, 1998; Akca & Muniroglu, 2008; Ridge et al., 2007), in contrast to the previously discussed rowing studies, the kayaking researchers only provided results for thigh length and lower leg length. This has resulted in the data being incomparable to Pheasant's (1996) data, where hip height is used. Fortunately, in the Aitken and Jenkins (1998) paper they provided their own age-matched university students, who were not kayakers but were recreationally active, to compare to the elite kayakers in the sample. There were significant differences between the two populations for both males and females in the following measures: body mass, upper arm length, forearm length, thigh length, lower leg length, biacromial breadth and biceps girth; kayakers were larger than their recreationally active counterparts in all of these measures. Although having the age matched controls has meant it was possible to identify how the elite kayakers in this sample differed from the general population, the sample was small in comparison to the data gathered by Pheasant (1996), both the elite kayakers and control population had a sample size of 25 total (15 male; 10 female). When looking to general population measures it is more useful to have figures from a larger sample of data hence the usefulness of Pheasant's (1996) population statistics, however these are only for length and breadth measures which are useful in the pursuit of ergonomic design. Therefore using measures such as hip height, seen in the earlier rowing articles, ensures the data is comparable. However, it must be noted that there is no information on skinfold or girth data in Pheasant's (1996) figures, meaning that this data can only be compared between different population samples in articles which publish this data.

Skinfold and girth data were published in the paper by Ackland et al. (2003) as well as Ridge et al. (2007). The different focus of these 2 papers in terms of sprint and slalom, allows us to directly compare the differences between the 2 sports. In all 19 comparable measures, for both male and female kayakers, slalom kayakers are smaller than their sprint counterparts excepting for one measure of thigh length for female slalom kayakers where they exhibit an average thigh length of just 0.68% longer than their sprint colleagues. If we investigate this further, returning to Table 2.2, it can be seen that when comparing the slalom kayakers from Ridge et al. (2007) to the general population (Pheasant, 1996) and also comparing Ackland et al. (2003) in Table 2.1 to the general population (Pheasant, 1996) the differences for the slalom kayakers are smaller, considerably so when focussing on male kayakers. The biggest difference the male slalom population exhibit from the general population is that they are 4.4% lighter than the general population, whereas the male sprint kayakers show a much larger 11.97% heavier than the general population, indicating that the differences between the general population and male slalom kayakers, particularly, are much less than the sprint kayakers and the general population. This is also supported further by López-Plaza et al. (2018) who identified in junior female sprint kayakers that the best (top-10 ranking in Olympic disciplines) were heavier than the rest of the sample despite having slightly lower sum of 6 and sum of 8 skinfold measures. Gomes et al. (2015a) identified that regardless of the size of kayak a paddler is kayaking; the larger the mass of the kayaker results in an increase in passive drag on the hull. This suggests that due to the need to change directions at speed, the lighter paddler is better suited to the slalom discipline than flat water racing. The female kayakers in Ridge et al.'s (2007) paper also exhibit smaller differences for all comparable measures than their sprint colleagues in Ackland et al.'s (2003) paper, however these are much less exaggerated than with the males.

This finding of the slalom kayakers being more closely aligned to the general population than their sprint colleagues can be seen throughout the papers reviewed in Table 2.2. The findings of Vedat (2012) and Bily et al. (2011) also suggest that males are not that dissimilar from the general population (Pheasant, 1996), and again the females in Bily et al.'s (2011) paper also exhibit generally smaller differences from the general population when compared to the female sprint kayakers, however these are less emphasised than that with the male population.

It is clear from the findings in the above papers that elite populations exhibit homogeneity in their anthropometrics, however when focussing on the lesser examined population of slalom kayakers there is evidence that they could be more reflective of the general population (Bily et al., 2011). It can be assumed that the general population would also be more representative of a recreational sport population, which would not be expected to exhibit the homogeneity seen within elite populations. Recreational sports attract a wider variety of participants based on their more open nature and would therefore be expected to be more reflective of the general population.

2.3.3 Anthropometrics of recreational populations

Purely recreational sports are still in the minority of sports available to the public. Although, in some cases people choose to participate within a sport recreationally and not for its competitive element, there are few sports that have no competitive element, or even reject the competitive element. These sports have been coined “lifestyle sports” (Wheaton, 2004). Although Wheaton (2004) does not specifically mention white water kayaking within the suggested lifestyle sports it meets many of the common identities stated of such sports, such as; it is primarily about participation rather than spectating; being based around consumption of new objects; a collective social identity around the activity; an ideology that focuses on intrinsic rewards such as adrenaline rushes and fun; rarely conducted for competition and are more often about being expressive; often individualistic; occur in a non-urban environment. The sports stated by Wheaton (2004) to be lifestyle sports include surfing, sport climbing, skate boarding and snowboarding amongst others.

Due to the limited research into lifestyle sports, and particularly due to the fact that all of the sports above also have a competitive counterpart to the lifestyle, non-competitive sport, there is little data available on the anthropometrics in these sports. In both surfing and climbing the recreational data collected was compared to an elite reference population (Barlow et al., 2014; Grant et al., 2001; Grant, Hynes, Whittaker & Aitchison, 1996), whereas in white water kayaking the data was compared to the closest competitive reference population of slalom kayakers (Broomfield & Lauder, 2015).

In the climbing papers, the recreational sample was also compared to a non-climbing, physically active population alongside the elite climbers (Grant et al., 2001; Grant et al., 1996). Grant et al.’s (1996) paper focussing on male climbers had a sample of 10 participants in each of the elite, recreational and non-climbers groups. The findings were that anthropometrically there was no significant difference between any of the 3 groups. However the results showed the recreational climbers were older than their elite and non-climbing counterparts (13.13% and 17.19% respectively) and taller (0.28% and 0% different although with a larger SD). They also had a larger percentage of body fat (8.5% and 16.99%), arm length (3.02% and 0.92%) and leg length (3.86% and 1.43%). Somewhat unsurprisingly based on the previous results, they had a higher body mass than their non-climbing colleagues (2.74%), however they had a lower body mass than the elite climbing group (2.14% lower) suggesting that perhaps the elite climbing group had a larger muscle mass than the recreational climbers. Grant et al.’s (2001) paper on female climbers also had 10 participants per group in the same groupings seen in Grant et al.’s (1996) earlier paper. Despite this, the results differed somewhat with the recreational climbers being younger than both the elite and non-climbers (23.0% and 15.44% younger respectively), and significantly younger than the elite group, they were also shorter (1.20% and 1.20%). However, similar to Grant et al.'s (1996) paper, the recreational climbers had a larger percentage body fat (4.62% and 12.31%, elite and non-climbers respectively) and leg length (0.96% and 0.96%). Although the arm length was longer than the elite climbers (1.04%), as was seen with the male climbers in Grant et al.'s (1996) earlier work, it was however shorter than the non-climbing group (0.74% shorter). Body mass was also somewhat different to the male group (Grant et al., 1996) the recreational female climbers had a slightly higher body mass than both the elite and non-climbers (0.67% and 1.34%). In the paper for female climbers (Grant et al., 2001) the researchers also measured a sum of skinfolds which showed the recreational climbers to have a higher sum than both elite and non-climbing groups (14.7% and 20.85%). Although there are clear differences between the groups, such a small sample in each group has made patterns of comparisons difficult to see, suggesting a larger sample may be needed in order to determine clear anthropometric patterns or 'morphological optimisation' as stated by Norton et al. (1996, p. 289).

Barlow et al. (2014) used a larger sample of recreational (termed 'intermediate') surfers at 47 males and compared this to 17 elite male surfers and 15 junior male surfers, however due to the much lower mean age (15.61 years compared to 34.12 for elite and 22.47 for the intermediate) for the junior surfers, and therefore the fact that they are still in a developmental age, the differences in anthropometrics shall not be compared for this sample group in this literature review. However when comparing the elite to the intermediate surfers in Barlow et al.’s (2014) article, the intermediate surfers were taller (1.46%) and lighter (0.94%) than their elite counterparts, albeit by a very small amount. When looking at the significantly different results found, the intermediate surfers had a much higher supraspinale skinfold measurement (30.05%) as well as smaller humerus breadth and femur breadth (6.84% and 6.47% respectively). Interestingly the intermediate surfers’ mesomorphy rating on the Heath – Carter (1967) somatotype method was significantly lower than their elite colleagues (-28.6%) but their ectomorphy was considerably higher (57.44%). This shows that the intermediate surfers were taller and thinner and carrying less musculature than the elite surfing group, however caution should be taken as Carter (2002) suggests the whole somatotype rating should be analysed before the separate components are further analysed, rules which Barlow et al. (2014) did not follow in their analysis for this paper. Interestingly, Barlow et al.’s (2014) paper focused on girths, skin folds and somatotype rather than the lengths and breadths seen in the papers concentrating on more competitive sports discussed in the previous sections.

The paper by Broomfield and Lauder (2015) combined lengths, breadths and girths in their paper focussing on female recreational white water kayakers. This paper identified the anthropometrics of the kayakers and compared them to female slalom kayakers. The sample in this paper was again very limited, looking at only 6 female white water kayakers; a more representative sample has been utilised in this doctoral study. One finding was that white water kayakers have a smaller sitting height than the slalom kayakers (4.17% shorter). Due to the height of the centre of gravity this would have a large impact on boat design, with white water kayakers finding that they would sit lower in boats designed for the average female slalom paddler. The paper identifies some clear differences between both white water kayakers and slalom paddlers, such as a shorter arm span (1.37% shorter), but a much larger shoulder breadth (12.21% bigger), however with such a small sample it is difficult to spot clear patterns. Despite this, perhaps the most pertinent finding from Broomfield and Lauder (2015) was that they identify that sitting height alone may not be the only anthropometric measure affecting paddle stroke efficiency when related to boat design, and more importantly for this study, a seat raise in a white water kayak. They note that upper limb length could also have an impact and indicate that other measures may also be important in determining the correct sitting height. This finding forms the basis of the use of a full ISAK profile being used within the methodology of this doctoral research.

Another key finding within the Broomfield and Lauder (2015) paper was that, if boats are designed around a male specification, as discussed in section 2.2.2.3, then the female white water kayakers, who sit shorter than their slalom counterparts, will sit lower again than their male white water and male slalom associates. This then puts female white water kayakers even lower in boats designed around a male specification. As Whiting and Varette (2004) and Mattos (2009) have noted, there are key contact points within the boat (section 2.2.2.2) the start point in the kinetic chain of these contact points has also already been identified as the gluteal region due to the fact that the movement of this point will subsequently affect all other points in the boat. Therefore the anthropometrics measured for the female white water kayakers will have a key influence on their boat set up, which has already been identified should include a seat raise (Manchester, 2008) and also should be set up for comfort (Ong et al., 2005). However the size of the seat raise is yet to be determined (Broomfield & Lauder, 2015) and therefore the method to determine this will form the basis of this doctoral thesis. The anthropometrics measured in the Broomfield and Lauder (2015) paper also indicated that a potential technique change could be seen due to the seat raise in terms of reach and stroke length, and therefore it is of importance to have a clear understanding of the technique used in kayaking.

2.4 Kayaker Technique

Kayaking technique has been investigated in depth since the 1970s, however this has largely been looking into the technique of flat water racing kayaks. Flat water racing kayakers choose to race with winged paddles, different to those used by white water kayakers, coined 'drag blades' by Jackson (1995). However this change in flat water racing to the use of winged paddles has been a more recent development, around 1986 (Jackson, 1995), in comparison to kayaking's long history. This has meant that an investigation into the differences between winged and drag blades has been carried out by Jackson, Locke and Brown (1992) and Jackson (1995). Jackson (1995) identifies that the blade path through the water for a drag blade follows the hull track of the boat and creates a 'U' shaped vortex. The winged paddle blades are asymmetrical in comparison to their reasonably symmetrical counterparts in the drag blades, and the lateral path travelled, away to the side of the hull, creates a continuous loop vortex in a similar semicircle shape as seen with the drag blades, but is twice the area as the vortex created by the drag blades. This increase in vortex size and shape gives a 15% increase in efficiency from 74% efficiency for the drag blades to 89% for the winged paddles (Jackson, 1995). As previously mentioned white water kayakers paddle with a drag blade rather than a winged blade, largely due to the need to control the position of the boat in the turbulent water to enable them to travel the safest path. In comparison, a flat water racing kayaker is only trying to move in a continuous straight line and therefore the wings are far more efficient in this environment. Due to this different blade choice between the disciplines, when comparing technique papers between flat water racing and white water kayaking, it must be acknowledged that there will be some differences, largely due to the different manors in which the blades work and also the path alongside the hull that the blade travels. However, far more research has been carried out into flat water racing than white water kayaking, mainly due to the increased predictability of flat water and therefore in order to understand the technique used in kayaking, it would be an oversight not to explore flat water technique as well as white water based technique.

2.4.1 Flat Water Kayak Technique

Kemecsey and Lauder (1998) identified four phases of the kayak stroke: catch, pull, recovery, air work. These phases were very similar to those described by Plagenhoef (1979) and have somewhat been later supported by McDonnell, Hume and Nolte (2012) who aimed to identify an observational model for sprint kayaking in order to produce a consistent method of analysing technique. McDonnell et al. (2012) split the stroke into 2 clear phases; water phase and aerial phase. The water phase was then further split into sub-phases based on visibility of the blade to separate these sub-phases, but also due to the fact that the water phase has most influence over velocity of the boat. The sub-phases identified were entry, pull and exit. Although the terminology used by McDonnell et al. (2012) was different to that of Kemecsey and Lauder (1998), the overall descriptions of the phases were similar.

The phases identified by Kemecsey and Lauder (1998) were also used as a part of the analysis of technique within Brown's (2009) doctoral thesis investigating the biomechanics of flat water sprint kayaking. A large amount of the research carried out on flat water technique has also been carried out on ergometers rather than on-water analysis. Despite Páez, Díaz, de Hoyo Lora, Corrales and Ochiana's (2010) findings that, physiologically, and also using basic biomechanical measures of stroke rate and velocity, there was no difference between on-water and on-ergometer paddling, Brown (2009), supporting Fleming, Donne and Mahony's (2007) earlier findings, has identified that there is evidence of a difference in muscle activation between the two methodologies and suggests that different leg muscles are used in order to produce the movement seen. This may come from the balance required on-water compared to ergometer paddling (Murtagh, Brooks, Sinclair & Atkins, 2016). Aside from Fleming et al. (2007), Brown (2009) and more recently Murtagh et al. (2016), there are few studies that have looked at muscle activation in kayaking, with the majority focussing on kinematic analysis of technique (Kendal & Sanders, 1992; Mann & Kearney, 1980; Plagenhoef, 1979; Sanders & Kendal, 1992a; Sanders & Kendal, 1992b). This is despite the issues associated with filming a multi-planar movement in two dimensions, and thus the need for three-dimensional video whilst on water and coupled with the aforementioned issue of ergometer's not providing a valid measure of more complex kayaking technique (Brown, 2009). Some studies have also carried out on-water three- dimensional analysis of technique (Brown, 2009; Baker, Rath, Sanders & Kelly, 1999), but these tend to be limited in nature due to the difficulties of three- dimensional filming on water. Regardless of the methodology utilised, the findings across many of the papers are fairly similar when it comes to identifying the aspects of the technique which are most important to performance. Many use boat velocity to indicate a successful performance (Baker, 2012; Baker et al., 1999; Hay, 2002; Kendal & Sanders, 1992; Mann & Kearney, 1980; McDonnell, Hume & Nolte, 2013; Michael et al., 2009; Mononen & Viitasalo, 1995; Plagenhoef, 1979; Sanders & Kendal, 1992a; van Someren & Howatson, 2008) as would be expected in a racing sport such as flatwater sprinting. Beyond average boat velocity, other factors of importance that have been identified are stroke rate, stroke length and reach.

Stroke rate has been discussed at great length by several authors indicating differing viewpoints. Plagenhoef's (1979) early study into the biomechanics of the flatwater kayak stroke identified that the best paddlers were those with a more rhythmic kayak stroke and often they did not have the fastest overall stroke rate. Sanders and Kendal (1992a) also aimed to provide a description of the flatwater technique. They investigated five paddlers ranging from novice to elite with regards to their use of the wing paddle. Their findings regarding stroke rate were contradictory to Plagenhoef (1979), suggesting that as velocity of the kayaker increased, so too did their stroke rate. Kendal and Sanders (1992) also investigated the technique of flatwater kayaking, however they focussed purely on five elite male kayakers who were of international level. The findings of this study again provided a differing viewpoint on stroke rate in kayaking, proposing that there was no relationship found between stroke rate and boat velocity. This was despite the participant with the fastest average boat velocity also having the largest average stroke rate. Such small sample sizes of five participants in the two papers (Sanders & Kendal, 1992a; Kendal & Sanders, 1992) cannot assist with finding relationships, especially when Plagenhoef's (1979) paper utilised a 9 year period of data collection of kayakers in numerous events. Plagenhoef (1979) however was investigating the drag blade rather than the winged paddle. It has been suggested that the winged blade requires a slower stroke rate, however in Kendal and Sanders (1992) study, some of the stroke rates reported were reflective of those found by Plagenhoef (1979) with the drag blade, this led the authors themselves to question the distance used in the experimental design of the study. Interestingly, two unpublished reports, one to the United States Olympic Committee and one to the Australian Canoe Federation both identified that there was a relationship between stroke rate and kayak velocity (Hay & Yani, 1996, cited in Sanders & Baker, 1998; Rath & Baker, 1997, cited in Sanders & Baker, 1998). Although there is no information available on the number of participants utilised in these reports, it can be assumed that due to their nature that the sample was a homogenous group of elite flat water kayakers. The later findings of Hay (2002) support these reports regarding elite kayakers suggesting that in cyclical human locomotion, the general law that has been identified is that stroke rate becomes much more important at a higher speed, whereas stroke length becomes more important at slower speeds, thus supporting the notion that elite kayakers would be travelling at a faster speed and therefore that their stroke rate would naturally be higher in order to increase velocity. Kerwin (1992, as cited in Lauder, 2008) also wrote an unpublished report to the British Canoe Union, using a three-dimensional analysis, again of an unidentified sample size of paddlers, they also found that an increase in average kayak velocity went hand in hand with an increased stroke rate.

The method of increasing this stroke rate has also received contradicting findings in the literature. In Mann and Kearney's (1980) paper they investigated the stroke in terms of percentage. The faster paddlers clearly spent a larger percentage of time in the "in-water" phase than the slower paddlers, in fact the percentage spent in the "out of water" phase was almost 10% more in slower paddlers than in the faster paddlers. This differed to the findings in Sanders and Kendal's (1992a) paper, they identified that both the pull time and the glide time were reduced suggesting that the kayakers reduced the time that the paddle was in contact with the water as well as the time they spent in recovery, when there was no forward motion being applied to the boat. This was in part agreed with by the findings of Hay and Yani (1996, as cited in Sanders & Baker, 1998) who indicated that there was a negative correlation found between stroke rate and average pull time, but that the negative correlation found between stroke rate and glide time was much stronger. This links to the findings of Baker and Trouville (1997, as cited in Sanders & Baker, 1998) who also indicated that the glide time was primarily the part of the stroke which was reduced. This can be further seen in the ratios of pull to glide time discussed in several of the papers; Kendal and Sanders (1992) discovered that the ratio ranged between 72%:28% and 65%:35% for their international paddlers. Hay and Yani (1996, as cited in Sanders & Baker, 1998) agreed with the findings of Kendal and Sanders (1992) also finding a ratio of 65%:35% for their elite paddlers.

Stroke length has also been looked at in many technique based papers. Plagenhoef (1979) gave some considerable attention to this area and also had both male and female participants, something later papers appear to have neglected whilst favouring male participants. Plagenhoef (1979) measured the entry point forward of the cockpit and the exit point behind the cockpit, both of these measures were given in centimeters, but it was unclear as to where on the cockpit this was calculated from, or even whether they were taken from the same location on the cockpit. If these measures were taken from the front of the cockpit and then the back of the cockpit, the cockpit length was not included in the stroke length, which was calculated in a meta-analysis, by adding these 2 numbers together. This suggests why the numbers for stroke length in Plagenhoef's (1979) paper are shorter than those in later papers. However, when comparing male to female stroke lengths, this is still possible from this data and Plagenhoef (1979) found that male stroke lengths were on average 79cm on the right side and 76.6cm on the left side. Female stroke length was on average 68.8cm right and 63.6cm on the left. This indicates a difference of 10.2cm on the right side between male and female paddlers and a difference of 13cm between males and females on the left side. Sanders and Kendal (1992a) went one step further and compared stroke length to average kayak velocity, they found no correlation between the two measures, however the authors conceded that with a larger sample than five, the results may have been different. Looking at the specific lengths measured, they were not comparable to those of Plagenhoef (1979) with an average for the male sample of 2.32m due to a different method of measurement focussing on boat movement rather than paddle entry to exit points. Sanders and Kendal (1992a) measured stroke length by measuring the distance travelled by the centre of the boat between entry of paddle one, through to entry of paddle two. Kendal and Sanders (1992) used a similar method of measuring stroke length as Sanders and Kendal (1992a), they found an average stroke length of 2.43m for the male sample, but similarly to Sanders and Kendal (1992a) found that there was no relationship between stroke length and velocity. The findings of Kendal and Sanders (1992) is supported by the aforementioned rule identified by Hay (2002) which suggested that at lower speeds stroke length has an increased importance to velocity, the speeds that these international level kayakers travelled at in the Kendal and Sanders (1992) paper would suggest that stroke rate would have increased importance (Hay, 2002). Baker et al. (1999) also utilised the method of measurement coined by Sanders and Kendal (1992a). The aim of the paper was to identify whether there was a difference between technique for male and female kayakers and therefore required coaching style; in general, no difference was found, also when looking at stroke length there were no differences found between the genders, however similar to the concessions of Sanders and Kendal (1992a), Baker et al. (1999) also identified an issue with the sample size of 10 (6male and 4 female). Baker et al. (1999) suggested that as the figures approached significance ($p=0.08$ for left and $p=0.06$ for right) that it would be possible to draw the conclusion that there was a difference in stroke length. They also went on to pool the left and right stroke length data for the 2 genders and this pooled data supported the earlier conclusion in difference in stroke length, showing a significantly different result ($p=0.03$). This leads to the question as to whether the difference in stroke length is, in part, due to the boat set up, and further, possibly due to the sitting height differences seen by Ong et al. (2005) in the kayaks; a question which this doctoral work aims to address.

The method of measuring stroke length has been different in different papers, identifying a difficulty in comparing findings as noted by McDonnell et al. (2013) in their pursuit of creating a deterministic model in order to move the analysis of kayaking technique forward by ensuring data collected is comparable across papers. McDonnell et al. (2013, p.3) identify the same method of measuring stroke length as used by Sanders and Kendal (1992a), however they rename the term as “stroke displacement”. Due to this being the most commonly used method within the literature (Baker et al., 1999; Kendal & Sanders, 1992; Sanders & Kendal, 1992a) it is also the method used to calculate stroke length within this doctoral work.

Reach and stroke length would appear to be related due to the fact that the amount of distance a boat can travel due to a stroke taken, can be impacted upon by the position in which the paddle enters the water. This is clear within the work of Plagenhoef (1979), in this paper Plagenhoef (1979) looked at paddle entry in two manners, firstly at distance forwards of the cockpit and secondly in terms of angle of entry. When looking at distance Plagenhoef (1979) found that males were on average 38.8cm and 45.6cm forward, right and left sides respectively, females were 37.8cm and 31.4cm on average, right and left respectively. It can be seen that males have a longer reach according to Plagenhoef’s (1979) findings, however without anthropometric measurements of the athletes it is difficult to identify the expected difference due to upper limb length, this doctoral work aims to link these two aspects. Plagenhoef (1979) also investigated angle of entry, this is an interesting addition to stroke reach as Plagenhoef (1979) identified that a small angle of entry indicated over-reaching and that the ideal set up is a large angle of entry to indicate that the paddle is entering as close to vertical as possible, whilst also coupled with a long reach. In order to achieve this, athletes need to reach forwards from the trunk, with both arms extended. When looking at the angle of entry for the paddlers in the study, males were on average 38^{o} and 38.2^{o} right and left respectively; females were on average 32.4 ^{o} and 39 ^{o} right and left respectively. Plagenhoef (1979) suggested the ideal to be between 35 and 40 ^{o}. On the male left hand entry the paddle must be well forwards with both arms extended and good body rotation to achieve a very similar entry angle to the right and yet be 6.8cm on average further forwards. However this is not the case for the female right side entry where the angle falls outside of the recommended range made for angle of entry but the reach is 6.4cm further forwards. It can be seen that the female right side is over reaching as this 6.4cm additional distance on the stroke entry is not translated into stroke length, with only an increase of 5.2cm on the right side. When taking all of this into account Plagenhoef (1979, p.458) stated that “a strong pull position begins well forward of the body.” However, Mann and Kearney (1980) do not fully support this view point as a shifting of the centre of gravity forwards before paddle entry decelerates the boat, so further movement of the trunk forwards would in turn lead to further deceleration of the boat. The change in velocity seen from this movement of the centre of gravity and its impact on the boat is not measured in many of the papers, although it is briefly discussed as impacting power output, defined as the drag force multiplied by the velocity of the kayak, in the review by Michael et al. (2009). Despite this lack of attention in kayaking papers, change in velocity measurements have been found to be more commonplace in swimming papers (Alberty et al., 2008; Barbosa et al., 2013; Barbosa et al., 2012; Barbosa et al., 2006; Barbosa, Marinho, Costa & Silva, 2011; de Groot & van Ingen Schenau, 1988; Figueiredo, Pendergast, Vilas-Boas & Fernandes, 2013; Vilas-Boas, 1996). However Sanders and Kendal (1992a) did look at the relationship between reach and velocity; despite a lack of significant results for this relationship, the paddler with the fastest average velocity also had the longest forward reach and the paddler with the lowest average velocity had the shortest forward reach. The authors suggest that the small sample size impacted upon the return of a significant result. Kendal and Sanders (1992) found similar results to that of Sanders and Kendal (1992a), there was no significant relationship between forward reach and velocity. They suggest that increasing forward reach does not benefit the paddler due to the potential reduction in stroke frequency. However, they go on to agree with Plagenhoef's (1979) findings that the forward reach should only be so far as allowing the paddle at entry to immediately produce large propulsive forces. In spite of this, Sanders and Kendal (1992a, p.250) conclude by stating that the faster paddlers have a paddle entry which is "well forward" when compared to less fast paddlers.

One of the major differences between the winged paddle used for flat water kayaking and the flat blade paddle used for white water kayaking, is that the winged paddle reduces the braking effect seen at the point of paddle entry, and also at exit if the paddle is not removed whilst still in a backwards motion and therefore not at full extension (Sanders &

Baker, 1998). This technique when paddling white water kayaks and paddles must be investigated further, despite considerably less attention paid to this within the literature.

2.4.2 White water kayak technique

Janura, Kratochvil, Lehnert and Vaverka (2005) carried out an analysis of the forward stroke in a wild water kayak on flat waters, similar to the method utilised within this PhD thesis. The findings of this study were similar in many ways to those findings for flat water kayakers. The better paddlers displayed a faster overall average velocity and decreased loss of speed in the recovery phase of the stroke. Paddlers performing better also had increased stroke rate and a higher percentage of time spent in the "in-water" phase of the stroke. They also identified that white water kayakers exhibited an effective technique when showing a symmetrical movement of the hands and minimum movement of the trunk in a forwards–backwards position, this links to the findings of Mann and Kearney (1980) suggesting that forwards movement of the trunk can decelerate the boat, which is why change in velocity or surge of the kayak has been recorded as a method of identifying efficiency within this doctoral thesis in that reduction of this surge will encourage the craft to travel more smoothly through the water in turn reducing the work done at a given velocity.

Reitz (2016) talks about technique more in terms of coaching than the specific scientific papers discussed above. One key point made regarded the reach of the blade and agreeing with what previous flat water papers had discussed, Reitz (2016) identified rotation in order to reach forwards as being an important aspect of the technique of wild water racing. He suggests that a lack of rotation from the base of the spine, or rotation prior to the paddle being fully in the water can impact considerably on stroke length and thus mean the stroke is less efficient; another reason for stroke length being measured as a marker of efficiency identification within this doctoral work.

In terms of technique, the literature for both flat and white water are similar in their recommendations; forwards reach is important, as is stroke length and stroke rate. These measures have been utilised within this doctoral thesis in order to identify whether an improvement in technique is observed with the change in sitting height. Alongside these, common discussion around forwards trunk movement, and more importantly its impact on the boat speed has been discussed. Reduction of boat movements within the water can indicate efficiency as well as the physical technique used by the paddler as discussed in this section, and also the power required by the paddler to move the craft can help to identify efficiency of movement.

2.5 Paddling Efficiency

Toussaint et al. (1990) and Stainsby et al. (1980) identify efficiency as being the work achieved divided by the energy cost of doing said work. The efficiency of a paddler can be expressed mechanically as the ratio (Equation 1.1) of the power generated by the paddler (P_{paddle}) to the power required to move the kayak through the water (P_{kayak}). Devices such as the power meter (One Giant Leap, New Zealand) can be used to calculate the power the paddler generates in moving the kayak through the water. This power is directly dependent on the drag forces acting on the hull of the boat. The hydrodynamic equation

(Equation 1.2) informs that drag force (F_D) (pressure and viscous) is dependent on area (A), velocity (V) and dynamic pressure (C_D & ρ). Drag force can be used to calculate the work done to move the kayak through the water, and the power required is subsequently dependent on the drag force and the velocity of the kayak (Cengel & Turner, 2012, Equation 1.3). At constant velocity, the efficiency of the paddler is therefore directly related to the drag force on the kayak, which in turn is determined by the motion of the kayak. The motion of the kayak in three dimensions has 6 degrees of freedom (Fossati, 2009, Ueng, et al., 2008). These are heave, pitch, roll, surge, sway, and yaw (Figure 1.1). Surge, heave and sway are translational motions, while roll, yaw and pitch are rotational motions. During paddling all motions are present to some degree and are created by either the paddler's actions or the environment (waves, wind or current). Any change in kayak motion will change the hydrodynamic forces acting on the kayak hull (Michael et al., 2009). Therefore in this doctoral work the efficiency has been defined as a reduction in the 6 degrees of freedom movements of the craft, specifically focussing on heave, pitch, roll, surge and yaw of the kayak, that have been identified as increasing the energy cost of paddling at a given velocity. This improved efficiency will enable the kayaker to put in effective paddle strokes when the environment requires. When kayakers are navigating white water rivers over long periods of time if they are paddling inefficiently then they will get tired more quickly, this means that then their paddle strokes will in turn get more ineffective and thus the technique will break down. Therefore paddling efficiently over the period of time the kayaker is navigating rivers and descending rapids will enable the kayaker to produce effective paddle strokes for a longer period of time.

Therefore this doctoral thesis has aimed to identify a method to determine the optimum sitting height for paddle stroke efficiency in female white water kayakers. In order to achieve this it was important to identify what factors were being measured in order to determine whether a sitting height improved the paddle stroke or not. Factors already identified are stroke rate, length and forwards reach as discussed in the previous section. Mann and Kearney (1980) also discussed the fact that a forwards movement of the centre of gravity of the body prior to paddle entry caused the boat to decelerate. This change in speed whilst travelling through water has been discussed within swimming in detail (Alberty et al., 2008; Barbosa et al., 2013; Barbosa et al., 2012; Barbosa et al., 2006; Barbosa et al., 2011; de Groot & van Ingen Schenau, 1988; Figueiredo et al., 2013; Vilas-Boas, 1996), but has not had the same attention within the kayaking literature.

2.5.1 Boat speed

Speed fluctuations in swimming have been seen especially in breast stroke, in which the arms propel the swimmer followed by the legs, resulting in a 2-peak profile in which the switch between arms and legs results in a lag in forwards velocity (Barbosa et al., 2012). This lag in speed in kayaking or surge would indicate a lack of efficiency as it affects power output (Michael et al., 2009), a similar view is held within swimming and therefore different arm coordinations have been discussed in order to identify the method of reducing this lag as much as possible (Alberty et al., 2008; Chollet, Chalies & Chatard, 2000). These different coordinations in swimming are referred to as: opposition, where the one arm is starting in the pull phase whilst the other arm is completing the push phase; catch up, in which there is a lag between the 2 arms propelling the swimmer forwards; and superposition, where there is a point in the stroke where both arms are propelling (Chollet et al., 2000). In kayaking there is no option for superposition as the paddles are fixed on the end of a rigid shaft and therefore only one paddle can be in the water at a time. In Chollet et al.'s (2000) study, they found that the higher performing swimmers were able to reduce catch up coordination in favour of either opposition or superposition. Superposition was identified as being the most favourable due to the reduction in the energy cost due to a reduction in drag. In kayaking, in which superposition is not achievable, therefore, kayakers should aim to achieve opposition, in which a constant propulsion is applied to the boat. Again this is not fully possible due to the rigid structure of the paddle meaning that there will be a delay from paddle blade left completing the propulsion phase and paddle blade right entering the water, and therefore there will always be a small lag time, but the reduction of this shows efficiency in paddling the boat. Kendal and Sanders (1992) found this lag time to be most clear around the time the opposite blade re-entered the water, indicative of support for the theory that due to the rigid shaft, lag time can never be entirely eliminated. This reduction in deceleration of the boat, however, is only one element of boat movements that need to be reduced in order to achieve a more efficient paddle stroke.

2.5.2 Boat movements

There are 6 degrees of freedom or boat movements referred to, as can be seen in the text by Fossati (2009); the first of these, surge, which happens along the x axis (Figure 2.3), could be seen as very similar to the change of boat speed as discussed in section 2.5.1 above. Sway, happens along the y axis as the boat shifts from side to side, this is largely to do with the sails on a sailing boat and in kayaking, on flat water at least, this movement would happen rarely, only in strong cross winds. In white water kayaking, waves could push the boat sideways, however when looking at efficiency of paddling forwards, sway is an unlikely boat movement that will be seen, due to it more often being a reaction to an environmental factor rather than an outcome related specifically to technique. Heave, takes place along the z axis as the boat centre of gravity moves up and down, this movement will be seen in a kayak as the paddler paddles the boat forwards, each placement of the paddle in the water will lift the boat before returning back down as the paddle is out of the water. Roll is a rotation movement around the x axis, this is a movement also seen within kayaking especially as the paddler puts the paddle in on each side of the boat meaning that the boat is likely to rotate to the side of the paddle entry and then rotate back to the other side as the alternate paddle is put in the water. Pitch, is also a rotation movement, but this time around the y axis, in kayaking this can be seen as similar to Mann and Kearney's (1980) discussion around the paddler leaning forwards which will dip the front of the boat and cause deceleration. Finally, yaw is rotation around the z axis, in kayaking this would be seen as the boat snaking through the water as each paddle stroke will rotate the flat hull around the z axis.

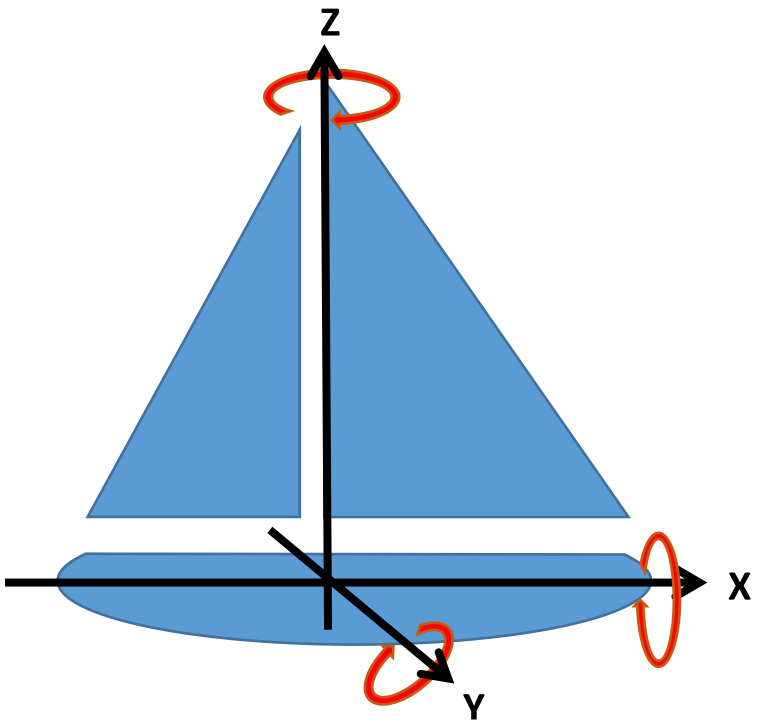


Figure 2.3: Six degrees of freedom of sailing yacht movement (adapted from Fossati, 2009)

In rowing Wagner, Bartmus and Marees (1993) and Loschner et al. (2000) also identified the rotational movements of roll, pitch and yaw in single sculls. They found increased skill level affected the amount of yaw and roll identified, particularly with roll the more skilled athletes were able to maintain stability around the x axis. There are differences in the way the boat is rowed in sculling compared to kayaking, for example the movement of the seat in rowing impacts upon the pitch of the boat, in kayaking it is the movement of the paddlers body alone which impacts pitch due to a fixed seat (Loschner et al., 2000; Mann & Kearney, 1980). This impact of pitch on energy cost has also been identified within swimming; Zamparo, Capelli, Termin, Pendergast and Prampero (1996) identified that underwater torque increase, in terms of the legs sinking, and therefore an increase in pitch of the body resulted in increased energy cost of swimming freestyle per unit of distance. The relationship between the parameters of torque and energy cost of swimming was presented as the equation $C_s = 0.688 + 0.312 \cdot T$, where C_s was the energy cost of swimming freestyle per unit of distance and T was the underwater torque. This gives an indication of the impact pitch could have on the energy cost of kayaking, albeit an impact that should be approached cautiously due to the fact that more of the body is under the water in swimming as well as the fact that it cannot be seen as a rigid body in the way a kayak is, due to there being more moving parts in a human body than a kayak. This research in rowing and swimming, which has already been identified in this chapter as a similar cyclical water sport to kayaking, shows a lack of literature in this area within kayaking. A postulation which Michael et al. (2009) agree with, stating that these undesirable movements of a kayak specifically in terms of pitch, roll and yaw have been omitted in the literature, a gap which this doctoral thesis aims to fill. Despite this lack of empirical research on these movements and their impact on a white water kayak it is clear from the fundamental mechanics that if a boat is running through the water more smoothly, then the hydrodynamic forces acting on the kayak hull will change (Michael et al., 2009) and therefore work done at a given velocity will be reduced. Thus the kayak is moving more efficiently as can be seen within the definition of efficiency for this doctoral work: a reduction in the 6 degrees of freedom movements of the craft, specifically focussing on heave, pitch, roll, surge and yaw of the kayak that have been identified as increasing the energy cost of paddling at a given velocity.

However, some literature has recognised these movements as being important within kayaking although they have given them different terms. Kemecsey and Lauder (1998) and Lauder and Kemecsey (1999) discuss movements of the kayak in their articles on technique diagnosis. This work was published within Canoe Focus, a magazine directly written for the kayak and kayak coach, usually aimed at club level participants. The aim of the articles was to present to the flat water kayaker a method of allowing them to experience unwanted movements of the boat created by the kayaker themselves. This intimated that if the flat water kayaker was aware of how they could create these undesirable movements within the kayak then they should also be able to correct their own body positions to reduce these movements creating a smoother path of the boat through the water and thus reducing the work done at a given velocity, due to a change in the hydrodynamic forces acting on the kayak hull (Michael et al., 2009). Although this work was a theoretical piece on technique and there was no data presented, with such limited work in the area of kayaking the information presented should be considered alongside the other works from rowing and swimming discussed in this literature review. Kemecsey and Lauder (1998) and Lauder and Kemecsey (1999) identify certain boat movements as being detrimental to the efficiency of technique of a paddler. The first movement they mention is bouncing of the kayak where the centre of the kayak moves in a vertical direction, or heave as previously discussed (Fossati, 2009). Plagenhoef (1979) also identified this up and down movement or "bobbing" as being unwanted when paddling forwards in flat water. Lauder and Kemecsey (1999) then discuss the ends of the kayak moving vertically, also a type of bouncing, but in this case the ends bouncing rather than the centre, also known as the pitch (Fossati, 2009). Rocking of the kayak is then discussed in the article by Kemecsey and Lauder (1998) this is when one side of the kayak submerges in the water whilst the other rises and vice versa; this is also known as roll

Fossati (2009). Finally, Lauder and Kemecsey (1999) discuss snaking, the ends of the kayak moving sideways about the z axis (Figure 2.3), also known as yaw (Fossati, 2009). These movements were also used as a measure of efficiency within the Broomfield and Lauder (2015) paper in which a seat height was introduced to identify differences in paddle stroke efficiency. The seat height was found to show improvements in each of the boat movements for at least 2 of the paddlers, although there was no pattern in the findings of improved efficiency of boat movements. However, the paddlers which showed the least improvement in boat movements were the tallest and shortest paddlers indicating anthropometrics may play a part in the choice of seat height. Thus leading to the question in this thesis of whether there is a method which will enable the identification of the most beneficial sitting height to the technique of female paddlers. As discussed previously, when identifying the most beneficial sitting height, a reduction of the unwanted boat movements indicate improved efficiency. The accepted definition of efficiency for this thesis was: a reduction in the 6 degrees of freedom movements of the craft, specifically focussing on heave, pitch, roll, surge and yaw of the kayak that have been identified as increasing the energy cost of paddling at a given velocity. However, the kinematic measurements of boat movement reductions alone, do not indicate the energy cost of producing a technique that minimises these whilst remaining at consistent velocity (Michael et al., 2009), therefore this needs to be measured in a separate manner, most often through kinetics and the use of strain gauges as a method of determining force applied to the paddle shaft (Aitken & Neal, 1992; Gomes et al., 2015b; Mononen & Viitasalo, 1995; Sturm, Yousaf, Brodin & Halvorsen, 2013; Sturm, Yousaf & Eriksson, 2010).

2.5.3 Strain gauges to measure work done

The kinetics of kayaking has largely focussed on attaching strain gauges to paddle shafts, despite attention being paid to this area for over two decades, papers utilising this method of data collection in kayaking remains limited. Wellicome (1967, as cited in Secher, 1993) identified that in rowing, drag on a boat increases as a square of the speed, thus as the boat gets faster the force required is increased. This can clearly be seen in Smith and Loschner's (2000) article looking at how different boat velocities caused different velocity costs for the rowers. This was calculated by using strain gauges on the handle of the oar, however the exact location of these strain gauges was not made clear within the method section, a restriction of this paper. An interesting finding that links with the afore discussed boat movements, was that one pair rowing at 24 strokes per minute (spm) and 28spm obtained different boat speeds, however had the same average power output. Smith and Loschner (2000) identified that the yaw of the boat increased at 28spm and therefore the drag increased resulting in an increased velocity cost for the rowers at 28spm.

In Henry, Clark, McCabe and Vanderby's (1995) article looking at tank rowing as a method of assessing rowing performance, the location of the measurement tools was made explicit in the methodology and a Wheatstone bridge method was utilised, however the results were only based on 30 seconds of maximal output in the tank and were carried out by collegiate level rowers. The conclusions made by the authors emphasise the use of instrumentation of the oar and its value to coach and athlete in improving skill and testing power. Therefore the use of paddle instrumentation is conspicuous by its absence in published kayaking literature.

Aitken and Neal (1992) looked to identify an on water method of analysing force during kayaking events. A Wheatstone bridge method of applying strain gauges to the paddle shaft was also utilised by these authors. Strain gauges were attached between where the hand applies the force and the blade join to the shaft. Calibration of the shaft was undertaken utilising a range of static masses being applied at the hand location whilst a support was placed in the centre of the blade. This calibration was then repeated to determine reliability. Although this or very similar methodologies have been used in previous studies, a note of caution must be taken for a static reliability testing of a dynamic movement. Despite this the authors identified strong linear relationships between the mass applied and the output of the strain gauges and reliability was more than 95%. The testing method was then sampled using a case study, the authors were aiming only to identify the potential of using the system within kayaking and not to formally take measurements, therefore a case study, albeit limited, was adequate for this purpose. The case study identified average forces of 200.6N:213.5N left to right respectively, showing a possible imbalance between left and right paddle strokes showing the importance of looking at a full stroke cycle when identifying force characteristics. This was similar to the finding of Sturm et al. (2010) who also identified an imbalance in the strokes, although the difference in maximum force over the 2 strokes was clear, the profile between the left and right was also very different, with the left showing 2 peaks and the right only one. Bjerkefors, Tarassova, Rosen, Zakaria and Arndt (2018) also found the right side was stronger in their ergometer testing, although no force profile was shown. Aitken and Neal (1992) identified a limitation of their on-water system as the inability to view the data output in real time and the impact this had on its use as a coaching tool.

Sturm et al. (2010) were also attempting to design an on water measurement system, similar to Aitken and Neal (1992). However, alongside a paddle force measurement utilising strain gauges, Sturm et al. (2010) also introduced foot plate force measurement in order to identify how the 2 synchronised. The calibration method used for the paddle was similar to that indicated by Aitken and Neal (1992). The reliability of the system was not discussed and validity was assessed by using an ergometer as a method of matching the outputs from the 2 systems, only one participant was used to do this and they only used one left stroke and one right stroke. Therefore their assessment of a valid system having been designed was somewhat presumptuous. However Sturm et al. (2013) went on to further test and develop the system, in this instance the sensors were mounted towards the middle of the shaft, but just to the side of where the hand grips the shaft. This was designed in this manner as the sensors will then pick up both a left and right paddle stroke. Again the calibration of the system was limited to static calibration, however the authors suggest this is due to practicality for when using with athletes. Although this is the case, the system also does need to show reliability in motion. An error in the calibration of the system was found in the detachment and then reattachment of the sensors to a new paddle shaft. Without calibration between each of these movements the error increases two-fold. It was also found that the system reliability was impacted by the location of the sensors on the paddle and also the surface of the shaft where the sensors were attached. Often the shaft surface was not entirely flat and therefore the movement of the sensors along the shaft could mean they encounter a different landscape on the paddle and this affected the readings. This means that utilising individual paddlers paddle, although important as stated by the authors designing the system in order to ensure the athlete is able to use equipment familiar to them, in the case of achieving reliable readings from sensors, having an immovable sensor would be more reliable.

As Aitken and Neal (1992), Sturm et al. (2010) and Sturm et al. (2013) were only looking to develop a potential measurement system, there was no attempt to link force output to velocity as was seen in Smith and Loschner's (2000) rowing article. However Mononen and Viitasalo (1995) attempted just this. They identified that by using band transducers on the paddle to measure force and a transducer on the bow of the kayak to measure velocity they could determine whether there was a correlation between the two. Their findings showed that there was a high correlation between mean velocity and mean paddle force (r=0.79) as well as stroke time (r=0.86) and peak paddle force (r=0.70). However, as with many studies in this area, the findings were based upon a case study, indicating that further study is required.

Gomes et al. (2015b) went beyond the case study design used by Sturm et al. (2013) and used a sample of 5 males and 5 females to determine whether different stroke rates (60spm, 80spm, 100spm and race pace) and therefore boat velocities were indicative of different force patterns. The first study of its kind in kayaking, utilising force as a measure of performance, uncovered some interesting findings. The mean force found increased as the stroke rate increased for both males (118N, 128N, 157N, 171N respectively for the four stroke rates) and females (72N, 80N, 92N, 99N respectively) indicating that as the velocity increased, so did the force applied to the paddle shaft. One of the main indicators used by the authors was the mean force to peak force ratio. As stroke rate and mean velocity went up, so did this ratio, this shows a move towards a more rectangle shaped force profile rather than a triangle one. A rectangle profile indicates that the time spent at the peak force is longer which, it is suggested, is more valuable than having a larger peak for a shorter time frame. It was also found that the time lag between boat deceleration and the end of the water phase of the stroke reduced as the stroke rate increased, this indicated that at the lower stroke rates the paddle was left in the water phase for longer and may in fact be slowing the kayak. Therefore at faster stroke rates the paddlers spent less time in parts of the water phase of the stroke which were ineffective. The authors conclude that in order to assess technique of kayaking, a force profile should be a part of the analysis. Although this thesis did not aim to identify technique per se, good technique is part of paddle stroke efficiency and therefore force is vital in order to assess efficiency of the stroke as different seat raises are introduced.

This doctoral work will focus on flat water assessment of the white water kayaks due to the unpredictable and turbulent nature of white water, however some authors have tried to measure force in this moving water environment. Sperlich and Klauck (1992) used strain gauges attached to the athletes own paddle and clear force curves for left and right were identified which were matched to the acceleration captured from an accelerometer on the boat. Sperlich and Klauck (1992) went onto look at the force seen when turning through slalom gates and using a case study design and 3 trials of kayaking through 3 gates, it was clear that the athlete produced similar force patterns each time, however as a case study this information was of limited use. Macdermid and Fink (2017) have also used a case study design to validate a newer force measurement system. The Power Meter (One Giant Leap, New Zealand) was first validated statically in a laboratory environment by hanging known weights from the hand location on the shaft a method often used to assess validity of strain gauges (Aitken and Neal, 1992; Sturm et al., 2013). The results from this laboratory based test showed the Power Meter to be both reliable (coefficient of variation ranged from 0.12-1.48% for left and right sides and all 3 weights) and valid (0.12-1.4% validity reported) in measurement. Macdermid and Fink (2017) then continued to on water testing, they were using previous rowing research which has stated that power output would be proportional to the cube of the velocity in order to calculate whether the Power Meter was valid in the field. The first field test, and most relevant to the methodology utilised in this doctoral thesis, involved a straight line sprint. This was a 17m stretch from a sitting start to a finish gate and 30 trials of varying velocities (1.4-2.5m/s). Power outputs from the Power Meter in this test ranged from 47.2- 491.5W, the results matching this power to the velocity indicate that the velocity was cubed when plotted against the mean power, again indicating validity of the device. A final slalom test on flat water was carried out, the slalom aspect of the Power Meter device is a new addition to the Power Meter and is the first commercially available device of this nature. Again the slalom test was carried out at varying velocities (1.4-2.2m/s) and was carried out over a 3 gate course from a sitting start. The time over the course varied from 18.48-

28.39s and the mean power ranged from 42.4-308.5W, again there was a strong relationship between the mean power output and the velocity cubed, indicating validity. As a clearly valid tool for measuring power output, the Power Meter was used within this Doctoral work. However, the slalom study only looked at time versus mean power output and there were questions from the authors as to whether the difficulty of the course or the introduction of white water may impact the results (Macdermid & Fink, 2017) and therefore the Power Meter was only utilised during the straight line recording in this doctoral methodology. The benefit of using the Power Meter Pro instead of the more traditional strain gauges was that the Power Meter Pro was adaptable to be reflective of the participants own paddle without need for swapping strain gauges between paddles, a known source of error (Sturm et al., 2013). The other benefit is that traditional strain gauge methods of measurement allow only measurement of the pulling hand, despite recognition in kayaking that the kayaker pulls with the bottom hand whilst simultaneously pushing with the top hand (Plagenhoef, 1979). The Power Meter Pro allowed measurement of both push and pull hands enabling a combined force by adding these together. This combined force for both hands has not been presented in papers before and therefore provides a more ecologically valid and more representative force result of the total force applied to the paddle when compared to papers presenting force captured by strain gauges.

The previously discussed papers on force measurement in kayaking have largely been based upon flat water kayaking, this is because the areas of slalom and white water kayaking have had little technology applied in terms of scientific analysis (Lauder, 2008), an area addressed by this doctorate thesis.

2.5.4 Slalom testing

Alongside the formerly discussed measures of efficiency in terms of force, reduced boat movements and technique based kinematic measures, in sports that require direction changes efficiency has been tested using a timed agility course (Mason et al., 2012; Sterzing et al., 2009). Mason et al. (2012) was investigating the impact of wheel camber on wheelchair court sport athletes. A battery of tests was used to test both linear speed and manoeuvrability. Similar to white water kayaking, wheelchair court sports require changes of direction at speed as well as speed in a straight line. To test this manoeuvrability a slalom course was set out for the athletes and they were requested to complete this at maximum speed. No statistically significant differences were found in the manoeuvrability tests regardless of the camber placed upon the wheels, although large effect sizes over segments of the course indicated 18^{o} camber had improvements over 15^{o} and 24^{o}. Sterzing et al. (2009) also used a slalom type course to investigate the differences between soccer shoes. The slalom course used in this study was 26m in length, with 12 accelerations, 10 cutting moves and one turning move. The description of the course used by Mason et al. (2012) was not as detailed as that presented by Sterzing (2009), however it included a straight 9m acceleration followed by an approximately 230 degree turn culminating in several cutting motions similar to those seen in Sterzing et al. (2009). Sterzing et al. (2009) differed from the findings of Mason et al. (2012) in that they found that slalom running times were greatly affected by different shoes and surfaces, whereas the straight line acceleration test showed only a small impact on times. These findings provide reason for a slalom type course to assess efficiency in direction changes, to be included within this doctoral study.

2.6 Methods Utilised for Ranking Measures

The aim of this doctoral thesis was to utilise anthropometrics, three- dimensional kinematic and kinetic analysis of technique to identify a method for determining the optimum sitting height for female white water kayakers. In order to determine which seat raise was most beneficial for paddle stroke efficiency, methods of being able to rank measures were identified in order to inform the methodological decisions made within chapter 6. Due to certain criteria within the data several options were considered, regression analysis, functional data analysis and a ranking methodology.

Warmenhoven, Cobley, Draper, Harrison, Bargary and Smith (2017) utilised bivariate functional principal components analysis in their study in order to assess whether there were discernible differences in performance of highly skilled rowers. They investigated the characteristics of force-angle graphs of the female sculler’s paddle strokes. They defined the performance of the rowers by both level of competition and also average boat velocity. With recreational white water kayaking not having a performance measure associated with it as can be seen by the definition: to navigate rivers and descend white water rapids as a recreational pursuit, as well as the use of constant speed within the methodology, it would be difficult to use functional principal component analysis in the way Warmenhoven et al. (2017) have.

However functional data analysis has a place in this type of work because functional data analysis identifies the whole sequence of time-series measurements as a single entity (Warmenhoven et al., 2019a) rather than each point on the curve as a discrete measure such as with regression analysis (Tran, 2008), rendering regression analysis not possible for the type of data in this thesis. Functional data analysis, however was considered for this work, but at this point of limited knowledge about these measurements (Warmenhoven 2019a), comparing one measure against time (Warmenhoven 2019a) for the seat raises for one person, or even two measures compared in bivariate functional principal component analysis (Warmenhoven 2019) with no performance measure such as ability level or speed to give indications of performance was seen as limiting. In these cases the interactions between the movements would have been lost for example an increase in reach may also increase pitch but if pitch was assessed against time and then reach was assessed separately against time, the interaction of the two measures would not be visible. With the lack of any empirical research in fluid mechanics of the 6 degrees of freedom of white water kayaks (Michael et al., 2009) and no performance measure available for white water kayaking it would not be possible to produce a model in this doctoral work, hence why a method for identifying the most beneficial seat raise was sought. With this in mind, it was important to recognise that identifying differences in the individual efficiency measures identified in section 2.4 and 2.5 would not enable achievement of the aim. Instead it was important to look at the combined influence of the efficiency measures taken on the reduction of boat movement. The importance of this was seen in the work by Broomfield and Lauder (2015) in which it was identified that there were improvements in efficiency measures seen for all participants when a seat raise was introduced but that these were individualistic to the participant, with no one measure showing improvements for all participants. This finding indicated that there was no way of identifying a particular measure as being the most likely to indicate efficiency improvements and thus a combination of all measures should be considered. Therefore another method of identifying the most efficient seat raise was required.

When investigating other methods of assessing efficiency when a number of efficiency measures are involved it became clear that this has not been done in previous works and therefore similar efficiency investigations in other fields were sought in order to determine the best methods to use. Previous studies looking into efficiencies of systems have used panels of experts in order for their subjective opinion to be used to determine whether one system is more efficient than another (Sherman, 1984; Triantafillou, Pomportsis & Demetriadis, 2003). In this case a subjective opinion would not result in the deeper understanding of the impact the combined efficiency measures had on the overall ability to rank the seat raises in pursuit of a recommendation of the optimum seat raise and therefore it was decided to look into the position or rank of the seat raises overall.

Grehaigne et al. (1997) identified methods of assessing an individual’s performance within a team sport setting. Their goal was to enable educators and coaches within sports to be better able to assess and develop individual athletes. Grehaigne et al. (1997) identified that frequency measures were used, albeit more often by coaches than teachers, in order to record how many times an athlete carried out a specific event such as how many times a shot was taken (Grehaigne et al., 1997). Grehaigne et al. (1997) identified that this frequency count did not provide enough detail. They then identified that a frequency count of events in a sports match did not give any detail as to whether they were a result of technique or tactics or a combination of the two and therefore more detailed methods of individual assessment were required. Grehaigne et al. (1997) went on to discuss how Pinheiro (1994) produced a method of using rating scales to assess the quality of motor skills in a variety of environments including sports. Grehaigne et al. (1997) then went on to investigate the impact positive and negative actions had on an overall efficiency score by dividing the results of the positive actions such as a successful shot by the results of the negative actions such as lost balls. However, this type of scoring method is not possible with the efficiency measures in this study, due to there being no identified negative actions as such. Instead it was identified that reduction of negative actions such as yaw and pitch (Kemecsey & Lauder, 1998; Broomfield and Lauder, 2015) is seen to indicate an improvement in efficiency for that seat raise. Thus, knowing how much of an impact on the efficiency this seat raise has had is important to being able to fully identify the seat raise which has had the biggest improvement in efficiency for all measures. Therefore the method of calculating the percentage difference was created in this doctoral work. From here novel ground was broached and the further methods identified extended the work of Grehaigne et al. (1997).

Utilising these methods enabled efficiency measures to be identified for each participant and enabled them to be investigated holistically.

2.7 Summary

Throughout this literature review it has been identified that kayaking has come from a male dominated history with the initial use of kayaks by male Inuits for hunting, followed by Rob Roy popularising kayaking as a past time within the Victorian era. This has meant that current kayaking participation is still overwhelmingly towards the male section of the population by as much as 4.66:1 males to females participating at least once a week. Due to this make-up of the kayaking population, boat design has been based upon male anthropometrics, in spite of the fact that female participation is rising faster than male. For females to participate successfully in the sport, having equipment that fits them is vital for continued improvement and engagement. Therefore it has been recommended that sitting height should be raised in order to help the internal dimensions of a kayak fit more ergonomically appropriately for a female. However, more recent studies have led to the question of how much this should be raised by due to differing results dependent on anthropometrics (Broomfield & Lauder, 2015). The same paper also identified a lack of knowledge regarding anthropometrics of this recreational population of white water kayakers, a finding that this literature review has highlighted as similar throughout recreational populations, despite knowing a lot about more homogenous competitive populations. A lack of understanding of anthropometrics of the population means that boat design becomes more of an art than a science. It has also been seen that anthropometrics have an overall impact on technique and therefore in order to identify a method to determine optimum sitting height, anthropometrics must be taken into account. These early literature review sections aimed to set out the overall purpose of the study and the reasons why it is necessary and important. Thus the sub-aims identified were:

- To establish normative anthropometrics for the white water kayaking population.
- To utilise three-dimensional kinematics, and kinetics to determine female white water kayakers' paddle stroke technique and efficiency related to sitting height.
- To identify the best method of determining optimum sitting height for female white water kayakers.

The sections on technique and efficiency within this literature review were intended to identify the measures required to be taken in sub-aim 2 in order to identify whether increasing sitting height does or does not improve overall efficiency. The measures identified in terms of technique based kinematic measures were;

- forwards reach
- stroke length
- speed over a slalom course

In terms of reducing boat movement, kinematic measures identified were;

- Constant velocity of movement, or surge.
- Heave
- Pitch
- Roll
- Yaw

Showing an increase in the technique based movements whilst decreasing the boat based movements would give an indication of efficiency as can be seen in the definition of efficiency in this thesis: a reduction in the 6 degrees of freedom movements of the craft, specifically focussing on heave, pitch, roll, surge and yaw of the kayak that have been identified as increasing the energy cost of paddling at a given velocity. However it is clear that the kinematic studies alone do not give a full picture, especially when looking at Toussaint et al. (1990) and Stainsby et al.'s (1980) definition of efficiency being the work achieved divided by the energy cost of doing said work. Kinematics alone give no picture of the energy cost mentioned, and therefore it is important to measure kinetics in the form of strain gauges attached to a paddle shaft or use of a Power Meter.

Taking all these measures into account alongside the aforementioned reasons behind the study combine to provide the primary aim of the study being:

To utilise anthropometrics, three-dimensional kinematic and kinetic analysis of technique to identify a method for determining the optimum sitting height for female white water kayakers.

3.0 Anthropometrics of White Water Kayakers

3.1 Anthropometrics of White Water Kayakers – Introduction

Most studies investigating anthropometrics of sporting populations have focussed on elite level participants due to the fact that researchers are often investigating the homogeneity seen within the athletes competing at a high level (Leone et al., 2002). This has been evidenced within cyclical water sports such as swimming and rowing, which are similar in their cyclical nature to kayaking (Bily et al., 2011). Papers studying elite swimmer anthropometrics have identified two distinguishing features of swimmers which make them differ from the normal population. These are height (Bencke et al., 2002; Knechtle et al., 2010; Leone et al., 2002; Pelayo et al., 1996; Toussaint et al., 1990) and arm span/ length (Geladas et al., 2005; Knechtle et al., 2010; Pelayo et al., 1996). There is conflicting information throughout the same papers regarding body mass and swimmers with some papers suggesting swimmers are lighter than the general population whilst others indicated they were heavier.

Rowers displayed similar anthropometric characteristics to the swimmers, when compared to the general population, with increased height/ sitting height (Barrett & Manning, 2004; Bourgois et al., 2000; Bourgois et al., 2001; Mikulic, 2008; Schranz et al., 2010) and arm span/ length (Barrett & Manning, 2004; Bourgois et al., 2000; Bourgois et al., 2001; Mikulic, 2008; Schranz et al., 2010), but also showed more consistent information regarding body mass, with rowers being generally heavier than the normal population (Barrett & Manning, 2004; Bourgois et al., 2000; Bourgois et al., 2001; Mikulic, 2008; Schranz et al., 2010). Rowing papers also tended to measure leg length, finding that rowers also had increased leg length (Barrett & Manning, 2004; Bourgois et al., 2000; Bourgois et al., 2001; Mikulic, 2008; Schranz et al., 2010). Swimming papers however, appeared to deem leg length less important than rowing by their absence of reporting.

The similarities between swimming and rowing can also be seen within the kayaking population which tends to focus on two separate populations of sprint and slalom kayaking. Regardless of which population the kayakers fit into, elite kayakers are taller than the general population (Ackland et al., 2003; Aitken & Jenkins, 1998; Akca & Muniroglu, 2008; Alacid et al., 2011; Bily et al., 2011; Bishop, 2000; Fernandes, 2013; López-Plaza et al., 2017; López-Plaza et al., 2018; Ong et al., 2005; Ridge et al., 2007; van Someren & Howatson, 2008; van Someren & Palmer, 2003; Vedat, 2012) with taller sitting height (Ackland et al., 2003; Aitken & Jenkins, 1998; Akca & Muniroglu, 2008; Alacid et al., 2011; Fernandes, 2013; López-Plaza et al., 2017; López-Plaza et al., 2018; Ridge et al., 2007; van Someren & Howatson, 2008; van Someren & Palmer, 2003). Elite kayakers also have a larger arm span (Ackland et al., 2003; Aitken & Jenkins, 1998; Akca & Muniroglu, 2008; Alacid et al., 2011; Bily et al., 2011; Fernandes, 2013; Ridge et al., 2007; van Someren & Howatson, 2008; van Someren & Palmer, 2003) and wider shoulder breadth (Ackland et al., 2003; Ridge et al., 2007). Body mass is the measure which differs between sprint and slalom kayakers, sprint kayakers are heavier than the general population (Ackland et al., 2003; Aitken & Jenkins, 1998; Akca & Muniroglu, 2008; Alacid et al., 2011; Bishop, 2000; Fernandes, 2013; López-Plaza et al., 2017; López-Plaza et al., 2018; Ong et al., 2005; van Someren & Howatson, 2008; van Someren & Palmer, 2003), however slalom kayakers are lighter (Bily et al., 2011; Ong et al., 2005; Ridge et al., 2007; Vedat, 2012).

Despite the differences between the sprint and slalom kayakers and the general population, it is clear that the slalom paddlers, which more closely reflect white water kayakers, have lesser differences than their sprint counterparts. This is evident in the body mass which indicates that slalom paddlers, although lighter than the general population, display a smaller disparity than the heavier sprint athletes. This suggests that white water kayakers, who are more closely aligned with the sport of slalom kayaking than sprint, may also be more similar to the general population, a hypothesis which is exacerbated due to their recreational past time.

Broomfield and Lauder (2015) investigated the anthropometrics of white water kayakers and compared their findings to female slalom kayaker's data. They found that the six white water kayakers had a shorter sitting height and also a smaller arm span, but had a much larger shoulder breadth. With such a small sample size, and only looking at female recreational white water kayakers, it is difficult to see patterns and therefore the aim of this study was to establish normative anthropometrics for the white water kayaking population.

The overall aim of the thesis was to utilise anthropometrics, three-dimensional kinematic and kinetic analysis of technique to identify a method for determining the optimum sitting height for female white water kayakers. A sub-aim of establishing normative anthropometrics for the white water kayaking population was also presented for this doctoral work. This chapter intended to achieve this sub-aim by identifying normative anthropometrics for the white water population. This was important in achieving the overall aim due to the need to establish the difference between white water kayakers and other kayaking disciplines, specifically slalom, and the general population. This provided further understanding of recreational populations and whether they exhibit the same homogeneity seen in elite sports populations. It also enabled the understanding of the differences seen between male and female white water kayakers. As well as the impact that having to paddle kayaks designed for male participants (Levesque, 2008a & b; Manchester, 2008) may have on the fit and therefore efficiency of paddling, in terms of reducing the 6 degrees of freedom movements of the craft that have been identified as increasing the energy cost of paddling at a given velocity, for female white water kayakers. Finally this chapter intended to identify the difference specifically in sitting height between male and female white water kayakers in order to determine the number of seat raises to include in the experimental work in this doctoral thesis.

3.2 Anthropometrics of White Water Kayakers – Methodology

3.2.1 Sample

With institutional ethical approval from the University of Chichester, fifty-three participants (mean 41.6 years, SD 12.9) were recruited via talks at kayaking conferences and gatherings as well as social media requests and a snowball sampling method (Jones, 2015). All participants were from across the United Kingdom including, the English regions of the South, South West and Midlands, and Wales. Thirty-one male participants (mean 42.5 years, SD 14.0) and 22 female participants (mean 40.3 years, SD 11.2) were measured. All participants were over the age of 18 years and would describe themselves as “white water kayakers”. They had a mean number of years of white water kayaking experience of 11.68 years (SD 10.33).

3.2.2 Procedure

Upon arrival participants were provided with the information sheet (Appendix A) and asked to give informed consent (Appendix B). Participants were asked for demographic information and then a full International Society of Advancement of Kinanthropometry (ISAK) profile was completed, by a Level 2 accredited ISAK anthropometrist. Included within the profile were 42 measurements: Body mass, stretch stature, sitting height, arm span, 8 skinfolds (triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh, medial calf), 13 girth measurements (head, neck, arm relaxed, arm flexed and tensed, forearm, wrist, chest, waist, gluteal, thigh (1cm distal from the gluteal line), thigh (mid trocanterion- tibale lateral), calf, ankle), 9 length measurements (upper arm, forearm, hand, leg (to illiospinale), leg (to trochanterion), upper leg, lower leg, medial lower leg, foot) and 8 breadth measurements (shoulder, abdominal (anterior- posterior), hip, chest (transverse), chest (anterior- posterior), humerus, wrist, femur). Measurements were taken on the right hand side of the body, unless this was not representative of what was “normal” for their body or a full profile was not possible for the right side. All measurements were taken twice and were subject to error of <1.0% for all measurements except for skinfolds which were subject to <5.0% error as stated by the ISAK standards of assessment (Stewart et al., 2011). The technical error measurements (TEMs) for the Level 2 accredited ISAK anthropometrist were reported to be 2.21% for skinfolds and 0.2% for all other measurements. This indicated that the anthropometrist had a technical error well within the accepted error range. If the 2 measurements taken fell within the accepted error then a mean of the 2 measures was recorded, however if the 2 measurements fell outside of the accepted error range then a third measurement was taken and the median of the 3 measurements taken was recorded in accordance with the ISAK standards of assessment (Stewart et al., 2011). All first measurements were completed before the second measures were taken in order to reduce the effect of skin compression. Participants were measured in privacy and wore minimal clothing, usually comprising shorts and bare chest for males and shorts and vest top for females; dignity was maintained at all times.

A variety of equipment was utilised to achieve the measurements, this included a stadiometer (SECA, UK), electronic weighing scales (SECA, UK) skinfold callipers (Harpenden, UK), a steel tape measure (Rosscraft, Canada), a small bone calliper (Cescorf, Brazil), a large bone calliper (Cescorf, Brazil) and a segmometer (Cescorf, Brazil). Landmarking was the first stage of the procedure, starting at the top and working down the body, these landmarks are points on the skeleton that enable the location of repeatable measurement sites. Then all measurements were taken following the ISAK accredited method (Stewart et al., 2011).

After the data collection was completed, each participant was sent a full profile of their measurements if requested.

3.2.3 Analysis

The data was assessed for normality using the Shapiro-Wilk test in IBM Statistical Package for the Social Sciences (SPSS) v22.0. The whole sample was tested for all 42 measures as well as the male and the female sample respectively to ensure that a normal representation of the population of white water kayakers was achieved. As would be expected for a mixed gender sample, some measures came back as not normally distributed (Table 3.1). However for male and female separated Shapiro-Wilk test there were also some measures which showed as not normal (Table 3.1). For males, the front thigh skinfold was not normally distributed, however the sum of 6 and sum of 8 skinfolds, which utilises the front thigh skinfold measure were normally distributed. Also for males the bistyloid breadth and for females the foot length was not normally distributed.

Table 3.1: Measures which were indicated to not be normally distributed according to the Shapiro-Wilk test

All	Male	Female
Subscapular skinfold	Front thigh skinfold	Foot length
Front thigh skinfold	Bistyloid breadth	
Thigh girth 1cm distal from gluteal fold		

As such a small number of the 42 measures were determined not to be normal, a T-test was then carried out again using SPSS, to identify differences between male and female white water kayaker anthropometrics across all 42 measures. Finally effect sizes were calculated using the method presented by Coe (2002). The data was also compared to the slalom kayaker data collected by Ridge et al. (2007) as well as general population statistics as identified by Pheasant (1996).

3.3 Anthropometrics of White Water Kayakers - Results

3.3.1 Comparison of anthropometrics of male and female white water kayakers

When comparing the anthropometrics of male and female participants, of the 44 measures, 32 were significantly different and 19 had an effect size of -1 or lower (Tables 3.2 and 3.3) indicating that at least 84% of females in those measures will fall below the average male in the sample (Coe, 2002). Importantly all four of the overall body measures (Table 3.2) were significantly different, with females being significantly lighter (male (m)= 81.88kg; female (f)=70.60kg) with an effect size of -0.76, shorter in stature (m=176.35cm; f=162.35cm) with an effect size of -2.06 , a smaller sitting height (m= 82.75cm; f=75.82cm) with an effect size of -2.01, and a smaller arm span (m=179.69cm; f=163.22cm) with an effect size of -2.15, than their male counterparts. These effect sizes of -2 or lower for stature, sitting height and arm span indicate that 98% of the females in the sample would fall below the average male from the male sample for these measures (Coe, 2002), showing the difference in the samples for these measures is considerable. The ratio of sitting height to height, calculated as sitting height/height, was equivalent for both males (0.47) and females (0.47) indicating that the distribution of sitting height and leg length to the combined overall stature was the same for males and females. This can also be seen through the sitting height as a percentage of height, and the illiospinale height as a percentage of height for both men (46.9% and 61.4% respectively) and women (46.7% and 61.6% respectively).

However, when investigating skinfold measurements in more detail, females were found to have a significantly increased sum of 6 (m= 88.07mm; f=116.26mm; effect size=0.87) and sum of 8 (m= 113.84mm; f=147.72mm; effect size=0.82) skinfold measurement (Table 3.2). When looking at the individual skinfold measurements it is clear to see that this difference largely came from the subcutaneous adipose tissue located on the limbs, rather than the trunk, indicating that trunk adipose tissue was not significantly increased when comparing males to females.

Of the girth measurements, the females were smaller than the males in all but three measurements (Table 3.3), which agrees with the previous findings of the skinfold measurements. Females were found to have larger girth measurements of the gluteal girth, thigh girth 1cm distal from gluteal fold, and thigh girth, again on the limbs rather than the trunk, although these were not significantly bigger.

Of the lengths and breadths, as would be expected from the previously discussed overall body measures, the females were significantly smaller in 14 of the 17 measures (Table 3.4) of these, 12 of the 14 significant measures also showed an effect size of -1.0 or less. The only length and breadth measurement that the females were larger than the males was for the biilliocristal breadth taken across the breadth of the pelvis, this would be expected due the biological adaptation of the female pelvis for pregnancy, however this finding was not significant (p= .837).

Table 3.2: T-test comparing male to female overall body measurements and skin folds

	Male			Female				degrees of		Effect
	N	Mean	Std. Deviation	N	Mean	Std. Deviation	t	freedom	p value	size
Body mass (kg)	31	81.88	13.31	22	70.60	16.71	2.733	51	.009 *	-0.76
Stature (cm)	31	176.35	6.59	22	162.35	7.08	7.391	51	.000 *	-2.06
Sit height (cm)	31	82.75	3.51	22	75.82	3.35	7.217	51	.000 *	-2.01
Arm span (cm)	31	179.69	7.68	22	163.22	7.65	7.706	51	.000 *	-2.15
Triceps skinfold (mm)	31	11.66	3.91	22	18.61	4.73	-5.843	51	.000 *	1.63
Subscapular skinfold (mm)	31	15.88	5.72	22	17.78	8.26	-.989	51	.327	0.28
Biceps skinfold (mm)	31	7.38	3.13	21	12.30	4.59	-4.285	32.422	.000 *	1.30
Illiac crest skinfold (mm)	31	18.39	5.67	22	18.14	5.80	.158	51	.875	-0.04
Supraspinale skinfold (mm)	31	13.19	5.58	22	14.59	6.42	-.844	51	.403	0.24
Abdominal skinfold (mm)	31	19.84	7.14	22	17.37	5.81	1.336	51	.187	-0.37
Front thigh skinfold (mm)	31	16.50	7.85	22	30.24	8.86	-5.950	51	.000 *	1.66
Medial calf skinfold (mm)	31	11.00	5.04	22	17.68	5.69	-4.508	51	.000 *	1.26
Sum of 6 skinfolds^X (mm)	31	88.07	31.52	22	116.26	33.97	-3.107	51	.003 *	0.87
Sum of 8 skinfolds^Y (mm)	31	113.84	39.23	22	147.72	43.78	-2.953	51	.005 *	0.82

*Denotes a significant result. ^{X} Sum of all skinfolds reported except biceps and iliac crest. ^{Y} Sum of all skinfolds

Table 3.3: T-test comparing male to female girth measurements

	Male			Female						Effect
	N	Mean	Std. Deviation	N	Mean	Std. Deviation	t	degrees of freedom	p value	Size
Head girth (cm)	31	56.57	1.13	22	54.98	1.53	4.128	36.61	.000 *	-1.21
Neck girth (cm)	31	39.04	2.62	22	33.87	1.94	7.848	51	.000 *	-2.19
Arm girth relaxed (cm)	31	32.87	3.19	22	31.53	3.76	1.405	51	.166	-0.39
Arm girth flexed and tensed (cm)	31	33.21	2.65	22	30.61	3.39	3.134	51	.003 *	-0.87
Forearm girth (cm)	31	28.44	1.71	22	25.78	3.13	3.975	51	.000 *	-1.11
Wrist girth (cm)	31	17.07	1.04	22	15.04	0.98	7.185	51	.000 *	-2.00
Chest girth (cm)	31	101.47	7.19	22	94.33	9.54	3.110	51	.003 *	-0.87
Waist girth (cm)	31	91.57	12.01	22	81.15	11.64	3.151	51	.003 *	-0.88
Gluteal girth (cm)	31	98.83	7.88	22	102.58	10.14	-1.515	51	.136	0.42
Thigh girth 1cm distal from gluteal fold (cm)	31	57.41	4.79	22	59.75	7.72	-1.362	51	.179	0.38
Thigh girth (cm)	31	53.23	3.97	22	53.79	6.48	-.361	32.08	.721	0.11
Calf girth (cm)	31	38.97	2.57	22	38.95	4.27	.028	31.70	.978	-0.01
Ankle girth (cm)	31	22.55	1.65	22	21.47	2.08	2.115	51	.039 *	-0.59

*Denotes a significant result.

Table 3.4: T-test comparing male to female length & breadth measurements

	Male			Female							
	N	Mean	Std. Deviation	N	Mean	Std. Deviation	t	degrees of freedom	p value		Effect Size
Acromiale radiale length (cm)	31	33.87	1.58	22	30.77	1.58	7.019	51	.000	*	-1.96
Radiale stylion length (cm)	31	26.93	1.20	22	24.09	1.28	8.264	51	.000	*	-2.30
Midstylion dactylion length (cm)	31	20.41	0.88	22	18.44	0.97	7.681	51	.000	*	-2.14
Illiospinale height (cm)	30	108.35	4.46	22	99.98	4.90	6.413	50	.000	*	-1.80
Trochanterion height (cm)	31	99.62	4.14	22	91.43	4.54	6.823	51	.000	*	-1.90
Trochanterion -tibiale laterale length (cm)	31	41.76	2.57	22	38.78	2.65	4.105	51	.000	*	-1.14
Tibiale laterale height (cm)	31	48.54	2.46	22	43.81	2.66	6.683	51	.000	*	-1.86
Tibiale mediale-sphyrion tibiale length (cm)	31	38.96	2.57	22	35.44	2.28	5.127	51	.000	*	-1.43
Biacromial breadth (cm)	31	37.06	2.46	22	33.41	2.11	5.639	51	.000	*	-1.57
Anterior-Posterior abdominal depth (cm)	31	20.52	4.29	22	18.27	3.90	1.956	51	.056		-0.55
Biilliocristal breadth (cm)	31	25.50	2.44	22	25.66	2.99	-.207	51	.837		0.06
Foot length (cm)	31	22.13	1.69	22	20.17	1.96	3.891	51	.000	*	-1.08
Transverse chest breadth (cm)	31	27.44	2.14	22	25.18	2.92	3.264	51	.002	*	-0.91
Anterior-Posterior chest depth (cm)	31	16.54	2.08	22	15.26	2.72	1.956	51	.056		-0.55
Humerus breadth (cm)	31	7.07	0.39	22	6.19	0.43	7.723	51	.000	*	-2.15
Bistyloid breadth (cm)	31	5.76	0.38	22	4.99	0.31	7.868	51	.000	*	-2.19
Femur breadth (cm)	31	9.81	0.64	22	9.20	0.77	3.160	51	.003	*	-0.88

*Denotes a significant result.

3.3.2 Comparison of white water kayakers to slalom kayakers

Using the data presented in Ridge et al.'s (2007) paper it is possible to compare the data collected in this doctoral thesis to that of slalom paddlers, white water kayaking's competitive counterpart (Table 3.5). Both male and female white water kayakers were heavier than their slalom colleagues (12.43% and 16.43% respectively). However, even though the stature of paddlers was similar for both males and females (-0.37% and -3.36% respectively), the sitting height was considerably less for white water kayakers both male and female (-10.54% and -15.47% respectively). Arm span was also similar between the two kayaking disciplines (-1.00% males and -2.60% females), this would be expected due to the similar stature. When investigating arm lengths further, the acromiale radiale lengths (m=-0.96%; f=-2.32%) and radiale stylion lengths (m=2.71%; f=0.37%) were also not dissimilar between slalom and white water kayakers regardless of gender. However when presenting these as a brachial index (forearm length relative to the upper arm length) white water kayakers have a higher brachial index (m=79.7%; f=78.3%) than their slalom colleagues (m= 76.6%; f=76.2%).

The biggest differences between the recreational white water kayakers and the competitive slalom kayakers can be seen in the skinfold measurements. Male white water kayakers had a sum of 6 skinfolds measurement 64.46% larger than their slalom counterparts and a sum of 8 skinfolds measurement of 59.77% greater. Female white water kayakers were also larger for both sum of 6 skinfolds (61.47%) and sum of 8 skinfolds (53.36%). Interestingly, thigh girth for males and females (1.18% and 1.66%

respectively) and arm girth flexed and tensed for females (1.67%) were similar for both disciplines; indicating that there was increased subcutaneous adipose tissue through the sum of 6 and 8 skinfolds for white water kayakers and therefore more than likely increased muscle mass in the limbs for slalom kayakers. The male and female waist girth (12.85% and 13.86% respectively) and gluteal girth (8.43% and 12.55% respectively) were also larger for white water kayakers than for slalom kayakers, which would also have been expected with such an increased sum of skinfolds for white water kayakers.

When looking at the standard deviations of the two samples (Table 3.5), for both males and females the standard deviations were larger for white water kayakers for every single measure. This indicates that, as expected, the slalom population is more homogenous and therefore the recreational white water population involves a larger cross section of the population, which is why comparison to the normal population is required.

Table 3.5: Comparison of means for anthropometrics of male and female white water and slalom kayakers. Slalom data adapted from Ridge et al. (2007). A negative percentage difference indicates that the white water kayakers were smaller than their slalom counterparts.

	Male (slalom N=12, white water N=31)			Female (slalom N=12, white water N=22)		
	White water mean (SD)	Slalom mean (SD)	%difference	White water mean (SD)	Slalom mean (SD)	%difference
Body mass (kg)	81.88 (13.31)	71.7 (4.8)	12.43	70.60 (16.71)	59.0 (4.5)	16.43
Stature (cm)	176.35 (6.59)	177.0 (0.05)	-0.37	162.35 (7.08)	168.0 (0.05)	-3.36
Sit height (cm)	82.75 (3.51)	92.5 (2.2)	-10.54	75.82 (3.35)	89.7 (3.3)	-15.47
Arm span (cm)	179.69 (7.68)	181.5 (6.3)	-1.00	163.22 (7.65)	167.6 (4.8)	-2.6
Sum of 6 skinfolds (mm)	88.07 (31.52)	31.3 (5.7)	64.46	116.26 (33.97)	44.8 (9.8)	61.47
Sum of 8 skinfolds (mm)	113.84 (39.23)	45.8 (9.0)	59.77	147.72 (43.78)	68.9 (13.9)	53.36
Arm girth flexed and tensed (cm)	33.21 (2.65)	35.2 (1.5)	-5.65	30.61 (3.39)	30.1 (1.0)	1.67
Chest girth (cm)	101.47 (7.19)	102.9 (4.9)	-1.39	94.33 (9.54)	91.0 (3.6)	3.53
Waist girth (cm)	91.57 (12.01)	79.8 (3.2)	12.85	81.15 (11.64)	69.9 (2.6)	13.86
Gluteal girth (cm)	98.83 (7.88)	90.5 (3.8)	8.43	102.58 (10.14)	89.7 (2.7)	12.55
Thigh girth (cm)	53.23 (3.97)	52.6 (1.8)	1.18	53.79 (6.48)	52.9 (2.1)	1.66
Calf girth (cm)	38.97 (2.57)	35.7 (1.1)	8.39	38.95 (4.27)	34.1 (1.2)	12.45
Acromiale radiale length (cm)	33.87 (1.58)	34.2 (1.5)	-0.96	30.77 (1.58)	31.5 (1.0)	-2.32
Radiale stylion length (cm)	26.93 (1.20)	26.2 (1.0)	2.71	24.09 (1.28)	24.0 (0.7)	0.37
Trochanterion -tibiale laterale length (cm)	41.76 (2.57)	45.6 (2.4)	-8.42	38.78 (2.65)	44.1 (2.4)	-12.06
Tibiale laterale height (cm)	48.54 (2.46)	47.8 (1.7)	1.52	43.81 (2.66)	43.8 (1.3)	0.02
Biacromial breadth (cm)	37.06 (2.46)	41.2 (1.5)	-10.05	33.41 (2.11)	37.4 (1.2)	-10.67
Anterior-Posterior chest depth (cm)	16.54 (2.08)	19.8 (1.7)	-16.46	15.26 (2.72)	18.0 (1.6)	-15.22
Humerus breadth (cm)	7.07 (0.39)	7.2 (0.3)	-1.81	6.19 (0.43)	6.3 (0.2)	-1.75
Femur breadth (cm)	9.81 (0.64)	9.7 (0.4)	1.12	9.20 (0.77)	8.9 (0.4)	3.26

3.3.3 Comparison of white water kayakers to the normal population

The data of the normal population from Pheasant (1996) included 36 measures, however they followed a different collection methodology to the ISAK principles used here. Therefore there are only 5 comparable measures to the kayaking sample collected in this doctoral thesis (Table 3.6).

Stature (m=0.20%; f=0.22%) and arm span (m=-1.0%; f=1.05%) of the normal population are more closely reflective of the white water kayakers than the slalom kayakers. The standard deviations are also more similar between white water kayakers and the normal population. The sitting height of white water kayakers was smaller than the normal population for both males and females (-9.56% and -11.32% respectively), as was the biacromial breadth measured across the shoulders (-8.49% and -7.19% respectively). However the body mass was higher for white water kayakers when compared to the normal population (m=8.40%; f= 10.76%).

Table 3.6: Comparison of means for anthropometrics of male and female white water and the normal population. Normal population data adapted from Pheasant (1996). A negative percentage difference indicates that the white water kayakers were smaller than their normal population counterparts.

	Male			Female		
	White water mean (SD)	Normal pop mean (SD)	%difference	White water mean (SD)	Normal pop mean (SD)	%difference
Body mass (kg)	81.88 (13.31)	75.0 (12)	8.40	70.60 (16.71)	63.0 (11)	10.76
Stature (cm)	176.35 (6.59)	176.0 (7.3)	0.20	162.35 (7.08)	162.0 (6.1)	0.22
Sit height (cm)	82.75 (3.51)	91.5 (3.7)	-9.56	75.82 (3.35)	85.5 (3.5)	-11.32
Arm span (cm)	179.69 (7.68)	181.5 (8.6)	-1.00	163.22 (7.65)	161.5 (7.0)	1.05
Biacromial breadth (cm)	37.06 (2.46)	40.5 (2.1)	-8.49	33.41 (2.11)	36.0 (1.8)	-7.19

3.4 Anthropometrics of White Water Kayakers - Discussion

Focussing initially on the difference in sitting heights between male and female white water kayakers, this ranged from 7.9cm to 8.7cm with an average difference of 6.93cm. This was far more than the difference seen between male and female slalom kayakers (Ridge et al., 2007), which was on average 2.8cm. It was also more than was seen between male and female normal population statistics which stood at 6cm difference (Pheasant, 1996). This is important for boat manufacturers to consider when designing new boats; such a difference in sitting height between males and females means that the adjustment required in terms of sitting height within the boat for females is larger than perhaps imagined prior to having this population data. Males, with their naturally larger sitting height do not need to worry about achieving the required contact points (Whiting and Varette,2004; Mattos, 2009) whilst experiencing discomfort in their legs because the male and female distribution of sitting height to height was found to be the same (0.47 sitting height to height ratio for both males and females). This means that they have an equally proportioned leg length to height ratio as the females and therefore they should be able to maintain comfortable contact whilst also having a larger sitting height, something females cannot achieve without artificially increasing the seat height. This ratio of sitting height to height has been used with children in order to establish age references in order to be able to determine growth disorders (Fredriks et al., 2005). In Fredriks et al.'s (2005) paper it was established that at 21, full maturation, females had a sitting height/height ratio of 0.526 and males had a ratio of 0.513. This indicated, not only that the sample of Dutch 21 year olds utilised indicated a larger sitting height proportion of their height than British white water kayakers, but that the males had a slightly smaller sitting height in relation to their height than the females, which is different to that seen in white water kayakers. This can also be seen in data on canoe slalom presented in Norton et al. (1996), Norton et al. (1996) utilised a different method to Fredriks et al. (2005) and presented their figures as a percentage, but the numbers are still comparable when taking this into account. Females in Norton et al.'s (1996) study, had a sitting height/height ratio of 53.3%, above the normal reference data they presented of 52.9%, and males had a ratio of 51% below the normal reference data presented of 52.2%. This again shows that the white water kayakers sit lower than slalom kayakers and Norton et al.'s (1996) reference population, with percentages of 46.7% for females and 46.9% for males. Norton et al.'s (1996) findings also support the findings of Fredrik et al. (2005), that females tend to have a larger sitting height to height ratio than males. This can also be seen in the normal population data presented by Pheasant (1996) although the difference is smaller; males have a ratio of 0.52 to compare to Fredrik et al. (2005) and 52.0% to compare to Norton et al. (1996); females have a very slightly higher ratio of 0.53 or 53%. Despite the difference between male and female sitting height/height ratio not being as exaggerated in Pheasant's (1996) normal population data, the difference in the ratio is still considerable when compared to white water kayakers. This large difference in the findings for both male and female white water kayakers suggests some morphological optimisation for white water kayakers. Perhaps, as Ridge et al. (2007) suggested for slalom kayakers, a lower centre of gravity is an advantage in order to maintain balance in constantly changing environmental conditions. This may be exacerbated further for white water kayakers who may undertake explorations of longer sections of river (BCU, 2014b) and therefore balance over a longer period of time is important (Schoen & Stano, 2002).

When comparing male and female white water kayakers beyond sitting height it is clear that males and females are significantly different with 72.7% of measures resulting in a p-value of less than 0.05. Similar results have been seen in other populations with clear differences seen between male and female slalom kayakers in Ridge et al. (2007) and when comparing to males and females in Pheasant's (1996) normal population data. Although neither study aimed to compare the male and female populations and therefore significant differences were not identified, it can be seen from a percentage difference of the means that there are clear differences between the two populations. In Ridge et al.'s (2007) work, 15 of the 20 measures showed more than 5% difference, and, of those, 7 were over 10% different. In Pheasant's (1996) study 29 of the 31 measures were more than 5% different and, of those, 14 were over 10% different.

Looking specifically at arm length, a measure identified as important within Broomfield and Lauder's (2015) paper, females were found to have a significantly smaller arm span ($p<.001$), upper arm length (acromiale radiale length, $p<.001$), lower arm length (radiale stylion length, $p<.001$) and hand length (midstylion dactylion length, $p<.001$) than their male counterparts. Broomfield and Lauder (2015) recognised the importance of arm length when discussing sitting height because it can impact the 'lean' required in order to reach the water and therefore can in turn affect the boat movements measured in chapter 5 and 6. When seat height is artificially raised, as has been carried out in chapter 6 of this doctoral thesis, having significantly shorter arm length means that the participants will have to reach further in order to place the paddle in the water, this can in turn result in the paddling efficiency being reduced despite the seat raise possibly being required in order to achieve an overall efficiency improvement. Therefore this significantly shorter arm length for females must be considered when analysing the results of chapter 6.

Ridge et al. (2007) also identified an arm length difference between male and female slalom kayakers, however when comparing white water and slalom kayakers, arm length was not that dissimilar regardless of gender with a maximum difference of 2.71% for any of the arm length measures (Table 3.5). Norton et al. (1996) also recognised that a shorter sitting height/height ratio as seen in white water kayakers usually indicated longer arms thus creating longer levers, this would be advantageous in kayaking when it comes to increasing paddle reach (Plagenhoef, 1979). This is supported by the brachial index identified within the white water kayakers (m=79.7%; f=78.3%) which was larger than that of the slalom kayakers (m= 76.6%; f=76.2%, Ridge et al., 2007). Norton et al. (1996) suggests that an increase in brachial index is advantageous for longer stroke lengths, they also show their data on male canoe slalom athletes to have a higher brachial index (79.2%) than Ridge et al. (2007) a figure which is more reflective of that found for white water kayakers in this doctoral work. However the figure presented for female canoe slalom kayakers (75.6%, Norton et al., 1996) is not far off that from Ridge et al. (2007). It should be recognised that the data for slalom kayakers from both sources is older than the new data collected on white water kayakers in this doctoral thesis. Therefore, as Norton et al. (1996) suggests that optimisation of athletes can evolve, it is possible that newer data on slalom kayakers would show this same increase in brachial index and is certainly an area worthy of future investigation to identify this evolution of optimisation which Norton et al. (1996) identify is seldom discussed.

As well as the similarities seen in terms of arm lengths when comparing slalom and white water kayakers, there were also some large differences seen in other measures. For example body mass (m=12.43%; f=16.43%), sum of 6 skinfolds (m=64.46%; f=61.47%), sum of 8 skinfolds (m=59.77%; f=53.36%), and waist girth (m=12.85%; f=13.86%) were all considerably larger for white water kayakers than for slalom kayakers (Ridge et al., 2007). This difference is expected when comparing a trained competitive population to a recreational one. Supporting this postulation, Norton et al. (1996) identified that canoe slalom participants have a mean mass which falls below that of the normal population as was found for the data presented by Ridge et al. (2007, Table 2.2). Further to this, Norton et al. (1996) also identified that even those sports in which athletes are found to have a larger body mass than the general population on average, they still tended to have lower levels of fat, this would be expected in highly trained individuals in the majority of sports due to the quantity of training carried out and the musculature required to undertake the sport at a competitive level.

This increased musculature for slalom kayakers when compared to the recreational white water kayakers can also be seen for males in their increased arm girth flexed and tensed (-5.65%), however for females there is in fact a slightly larger flexed and tensed arm girth for white water kayakers (1.67%). Taken alone, this measurement can be misleading, especially when compared to the relaxed arm girth measurement that is available for the white water kayaking sample in this doctoral work (Table 3.3). The measurement for relaxed arm girth is 31.53cm, larger than the flexed and tensed girth at 30.61cm. The position for measuring the arm girth flexed and tensed was described by Stewart et al. (2011, p. 79), they stated that the arm should be raised "anteriorly to the horizontal with the forearm supinated and flexed at 90^{o} to the arm." When describing the methods for taking girth measurements they are clear to identify that there should be no indentation of the skin by the tape, whilst minimising any gaps which may appear between tape and skin (Stewart et al., 2011). Utilising this method would result in any increased subcutaneous adipose tissue to also be included in this flexed and tensed arm girth, and from the considerably larger sum of 8 skinfolds measurement recorded for white water kayakers compared to slalom kayakers, which includes a skinfold at both bicep and triceps, it would be expected that this measure for female white water kayakers is masked by the increased fat at this location.

Two other measures which stand out for slalom kayakers when comparing them to white water kayakers is the biacromial breadth, measured between the acromion processes on each shoulder; and the Anterior-Posterior chest depth, measuring the depth of the thorax between the spine and the sternum in line with the centre of the 4th rib. These show large increases for both male and female slalom kayakers (biacromial: m=-10.05%; f=-10.67%; chest depth: m=-16.46%; f=-15.22%). It could be suggested that these measures indicate the 'morphological optimisation' of slalom kayakers as stated by Norton et al. (1996, p. 289), especially when the biacromial breadth is compared to Pheasant's (1996) normal population data (Table 2.2) which indicates that slalom kayakers are larger than the normal population for both males (2.91%) and females (3.74%). Unfortunately the comparable data for the chest depth is not available for the normal population as it was not a measurement presented in Pheasant's (1996) work. This evidence of morphological optimisation for slalom paddlers can also be seen in the smaller standard deviations of the data presented by Ridge et al. (2007) when compared to those seen for white water kayakers collected in this doctoral work. Interestingly, the large standard deviations presented for white water kayakers in this study are not seen in the data presented for female white water kayakers by Broomfield and Lauder (2015) although the sample there was considerably smaller at just six.

As discussed in chapter 2 (p. 43), there was evidence in Bily et al. (2011) that slalom kayakers were more reflective of the general population than their sprint kayaking colleagues. As white water kayaking is a recreational, lifestyle sport (Wheaton, 2004) attracting a wider variety of participants, it was expected that white water kayakers would be even more reflective of the general population than slalom kayakers. This has been seen as being the case when it came to stature and arm span (Table 3.6) however this is where the similarity ends. Body mass remains higher for the white water kayakers than the general population for both males (8.4%) and females (10.76%), however it is less different to the body mass of slalom kayakers (Ridge et al., 2007). This constant higher body mass for white water kayakers compared to other populations must show morphological optimisation of white water kayakers similar to the lower sitting height, however there would be no biomechanical advantage to an increase in body mass. In fact Gomes et al. (2015a) stated that an increase in paddler mass will in turn increase passive drag on the hull thus making direction changes required in white water kayaking more difficult. Therefore, there must be another reason for this increase in body mass, and the environment is the obvious place to start; Whiting and Varette (2004) identify that kayaking can take place in both warm and cold conditions. In Europe the white water season is in the summer when the sun has melted the snow in the mountains, filling the rivers; however in Britain the white water season is in the winter when rainfall has increased and this in turn fills the river. Being that most British white water kayakers will take part in the winter season in inclement weather conditions they need to be aware that cold can reduce both energy and enjoyment of white water kayaking (Whiting & Varette, 2004), this may be why they are seen to have an increase of body mass. Keatinge, Khartchenko, Lando and Lioutov (2001) discovered that swimmers in water temperatures of 9.4-11.0^{o}C required both increased mass and skinfold thickness in order to swim for longer durations. When looking at how these water temperatures compare to the British winter time, the Met Office (2017) provided a temperature average for the UK winter from 1981-2010, this largely remained below 5^{o}C and spent the majority of winter between 3^{o}C and 4^{o}C. Therefore British kayakers are spending a number of hours (Schoen & Stano, 2002) out of doors in inclement weather in temperatures lower than the swimmers investigated by Keatinge et al. (2001), providing a clear reason why they may present larger body masses, as well as skinfolds, when compared to other kayaking populations (Ridge et al., 2007) and body mass when compared to the general population (Pheasant, 1996).

As well as body mass being higher for white water kayakers, biacromial breadth is smaller when compared to the normal population (m=-8.49%; f=-7.19%) this is lower than the difference found with slalom paddlers (m= -10.05%; f=-10.67%) but still shows some homogeneity in smaller biacromial breadth of white water kayakers when compared to other populations. It is possible that this smaller biacromial breadth is seen in white water kayakers due to it minimising the mass of the shoulders required to be moved when rotating the body in order to utilise the bigger muscles of the back to move the paddle through the water (Reitz, 2016). What is interesting is that the arm power producers of the shoulders and the upper arm (acromiale radiale length) are both reducing in length for white water kayakers compared to slalom kayakers, shortening the lever length to produce power, therefore making the stroke more efficient whilst the forearm length is increasing, along with the brachial index. This results in the overall length of the reach being minimally different, particularly when looking at arm span which takes the shoulders into account (m=-1.0%; f=-2.6%). Therefore the reach is very similar, whilst the power producing lever is shorter.

This smaller biacromial breadth has also been seen in climbers and was compared to the ape index in order to understand further what this means to the athletes (Watts, Joubert, Lish, Mast & Wilkins, 2003). The ape index is described by Watts et al. (2003) as the arm span relative to stature; climbers consider values of more than 1.00 as being of importance to their climbing ability. Looking back at the data in Table 3.5, it can be seen that both kayaking populations for males and white water kayakers for females have a larger arm span than stature, for female slalom kayakers the arm span is only 0.4cm smaller. When calculating the ape index, slalom kayakers are both 1.00 or more when rounded (m=1.03; f=1.00) and the same was found for white water kayakers (m=1.02; f=1.01). Watts et al. (2003) suggest in their paper that the smaller biacromial breadth along with the increased ape index suggests that a larger proportion of the arm span is therefore made up of arm length. This, in climbing terms, means that the athlete has a larger reach in order to be able to get to more challenging hand holds; in kayaking terms the same applies, except in this case it enables the paddle to be reached further forwards. This shoulder breadth comparable reduction for white water kayakers can also be considered a possible benefit when it comes to reducing injury. Fiore and Houston (2001) and Schoen and Stano (2002) found that the shoulder was the most common site of injury in white water kayakers, however neither paper investigated the anthropometrics of the paddlers in order to be able to associate these with the injuries reported, perhaps a future area of investigation.

In summary, white water kayakers show some morphological optimisation in three areas when comparing them to both slalom kayaking (Ridge at al., 2007) and normal (Pheasant, 1996) populations. These areas are: lower sitting height, larger body mass and skinfold measures, and smaller biacromial breadth.

In terms of sitting height, white water kayakers are shorter when compared to other kayaking (Ridge et al., 2007) and normal populations (Pheasant, 1996). However, the comparison between male and female white water kayakers shows an increased difference in their sitting height of 6.93cm, larger than both slalom kayakers (2.8cm, Ridge et al., 2007) and the normal population (6cm, Pheasant, 1996). This indicates that although white water kayakers have an optimised sitting height to maintain balance in a changeable white water environment (Ridge et al., 2007), the large difference between male and female white water kayakers means that it is harder for female white water kayakers to achieve a sitting height reflective of their male colleagues in boats designed around a male specification (Manchester, 2008). This is because comfort (Ong et al., 2005) and a representative sitting height in the boat is hard to achieve in harmony.

White water kayakers also have increased body mass than both their slalom kayaking (m=12.43%; f=16.43%) and normal population (m=8.40%; f=10.76%) counterparts and also a larger sum of 8 skinfolds than slalom kayakers (m=59.77%; f=53.36%). This has been shown to create no biomechanical advantage due to the increased passive drag it would create on the kayak hull (Gomes et al., 2015a), however environmental conditions may provide the answer. The Met Office (2017) indicates the British winter, in which white water kayaking takes place, hovers around a temperature of between 3 and 4^{o}C, this is lower than the water temperatures seen to affect the skinfolds and body mass of cold water swimmers (Keatinge et al., 2001) suggesting that this increase in body mass and subcutaneous adipose tissue may be in order to allow white water kayakers to participate without a reduction in energy or enjoyment (Whiting and Varette, 2004).

Finally white water kayakers present a smaller biacromial breadth than their slalom (m=-10.05%; f=-10.67%) and normal (m=-8.49%; f=-7.19%) population colleagues. This alone is a confusing optimisation, but when considering that arm span shows very little difference between populations (slalom m=-1.0; f=-2.6: normal m=-1.00; f=1.05), Watts et al. (2003) states that this shows that a greater proportion of the span is therefore made up by arm length, thus increasing the reach ability for paddling purposes.

There are some clear morphological optimisations seen within this sample for white water kayakers, it would be interesting to see in future data whether slalom kayakers begin to show similar adaptations, particularly around biacromial breadth and brachial index, to the white water kayakers and whether this is evidence of morphological evolution.

In terms of information important to the next chapter, the findings of this chapter identified that male and female white water kayakers were very different to each other despite being more similar as a whole population to the general population than other kayaking populations such as slalom and flat water racing were seen to be. These significant differences in 32 of the 44 measures taken indicate that kayaks designed around male specifications are going to be difficult for female kayakers to paddle efficiently and therefore will in time impact on their paddling effectiveness. This understanding of the significant differences between male and female white water kayakers has enabled the achievement of sub-aim one: to establish normative anthropometrics for the white water kayaking population. In terms of how the findings of this chapter have helped to achieve the overall thesis aim: to utilise anthropometrics, three-dimensional kinematic and kinetic analysis of technique to identify a method for determining the optimum sitting height for female white water kayakers, the particular measurement of sitting height has an important role to play in this. The difference in sitting height between male and female white water kayakers was on average 6.93cm.

This was found to be larger than that between male and female slalom kayakers and also larger than the difference between males and females in the normal population. Therefore in the later chapters in this thesis, it was important to ensure that female kayakers were provided with the opportunity to paddle with more foam than this average difference in sitting height in order to determine whether it is necessary for females to be sat at a height in the kayak which reflects the difference between themselves and their male counterparts. If this finding is realised in later chapters then it will be important for kayak manufacturers to understand this and to ensure there is enough room for adaptation built into the kayaks.

4.0 Validation of Methods

4.1 Validation of methods – Introduction

The Qualysis (Sweden) organisation indicates in its Qualysis Track Manager product information (Qualysis, 2010) that the Qualysis Oqus 7+ camera system is "highly accurate", although they do not go on to indicate how accurate this may be. However when discussing their underwater system, they suggests that this is accurate to "±2mm at 10m distance" (Qualysis, 2016). It can be assumed, therefore, that the same system when used above water, should be better than ±2mm accuracy at the same distance. However, as identified within the paper by Dabnichki, Lauder, Aritan and Tsirakos (1997), there are a number of opportunities for error to creep into these systems and therefore they need to be tested for validity in order to be able to fully trust the outputs. Angulo and Dapena (1992) investigated the impact of different capture spaces on video versus film recordings. They found that cinematography, also known as "film", had a much reduced error than the video alternative, although this was when video only provided 512 horizontal pixels in their Mocap system. This is in comparison to the current Qualysis system which provides 12 mega pixels, ~4320 horizontal pixels. Angulo and Dapena (1992) also identified that markers that fell outside of the calibrated space had considerably more error than those inside the calibrated space, particularly when using a larger field of view of around 8m. Identifying that calibration of the capture volume is important to decrease error in the data capture. This finding was also agreed with by

Allard, Blanchi & Aissaoui (1995) who stated that the most important source of error comes from measuring the calibration object.

Richards (1999) tested a number of different 3D capture systems along with one of the earlier Qualysis systems for error and found that the Qualysis ProReflex system, along with a number of other passive marker systems, had less than 2.0mm root mean squared (RMS) error. The Qualysis system, in fact measured the 500mm distance within 1mm of the known value in the 2.5m capture volume length, with a RMS error of 0.080cm; the third lowest of the nine systems measured. This method of measuring the length of a known object to assess validity was similar to that utilised by Dabnichki et al. (1997), and also has been used in later validations, such as that of the Optotrak 3020 motion analysis system by States and Pappas (2006) and therefore was the method utilised in this doctoral work.

As indicated earlier, there are a number of places error can appear in calculations and in order to be able to understand and appreciate this error, testing must take place prior to the main experiment. The foam compression is one of these areas of error because the foam added to the seats of the participants will compress under the mass of the participants and it is important to ensure this compression is uniform and within an acceptable range.

The Power Meter Pro was not assessed for reliability and validity in this instance due to its recent validation in the appropriate setting. Macdermid and Fink (2017) used a case study design to validate the Power Meter. This was first validated statically in a laboratory environment by hanging known weights from the hand location on the shaft, a method previously used to assess validity of strain gauges (Aitken and Neal, 1992; Sturm et al., 2013). The results from this test showed the Power Meter to be both reliable (coefficient of variation ranged from 0.12-1.48% for left and right sides and all 3 weights) and valid (0.12-1.4% validity reported) in measurement. With this in mind Macdermid and Fink (2017) then continued to on water testing, they were using previous rowing research which has stated that power output would be proportional to the cube of the velocity in order to calculate whether the Power Meter was valid in the field. The first field test, and most relevant to the methodology utilised in this doctoral thesis, involved a straight line sprint. This was a 17m stretch from a sitting start to a finish gate and 30 trials of varying velocities (1.4-2.5m/s). Power outputs from the Power Meter in this test ranged from 47.2- 491.5W, the results matching this power to the velocity indicate that the velocity was cubed when plotted against the mean power, again indicating validity of the device according to Macdermid and Fink (2017). Finally, a slalom test on flat water was carried out. The slalom aspect of the Power Meter device is a new addition to the Power Meter and is the first commercially available device of this nature. Again the slalom test was carried out at varying velocities (1.4-2.2m/s) and was carried out over a 3 gate course from a sitting start. The time over the course varied from 18.48-28.39s and the mean power ranged from 42.4-308.5W, again there was a strong relationship between the mean power output and the velocity cubed, indicating validity according to Macdermid and Fink (2017). However, the slalom study only looked at time versus mean power output and there were questions from the authors as to whether the difficulty of the course or the introduction of white water may impact the results (Macdermid & Fink, 2017). Therefore the Power Meter was shown to be reliable and valid and thus along with the advantage of enabling both the pull and push hands (Plagenhoef, 1979) to be recorded simultaneously, the Power Meter was utilised during the straight line recording in this doctoral methodology. Despite no assessment for reliability and validity of the Power Meter in this chapter, the appropriate methods for zeroing the Power Meter, as recommended by the manufacturers, were followed and were discussed in the methods of the chapters using them for data collection.

The purpose of this chapter in the overall delivery of the thesis aim: to utilise anthropometrics, three-dimensional kinematic and kinetic analysis of technique to identify a method for determining the optimum sitting height for female white water kayakers, was to ensure measures utilised in the pursuit of sub-aim 2: to utilise three-dimensional kinematics, and kinetics to determine female white water kayakers' paddle stroke technique and efficiency related to sitting height were providing the most reliable and valid data possible.

4.2 Validation of methods – Methodology

4.2.1 Foam Compression testing

The foam, high density closed cell polyethylene foam, was tested for compression prior to use by placing weights onto the foam layers (Figure 4.1). The foam layers were added in multiples of 10mm, which was the depth of each layer of foam. As each layer was added a measured height was taken at 0 mass added and then as mass was added in 10kg increments a new height was taken at each added mass.


Figure 4.1: Foam compression testing

4.2.2 Validation of marker sets

The markers were applied to the boat in the configuration shown in Figure 4.2. The four markers of interest were those used to measure length of the boat (stern and bow) and also the width of the boat (stern port and stern starboard) (Figure 4.3).

Figure 4.2: Boat marker configuration

The validation was split into two parts. Part one involved a laboratory test where the boat was statically placed into a number of degrees of movement starting from 0^{o} then 1^{o}, 2^{o}, 5^{o}, 10^{o} and finally 20^{o} (Table 4.1) using trigonometry to calculate the angles. Initially the boat was just moved in one plane so firstly it was moved through rolling only, then pitching only (Figure 4.4) and then yaw only. Finally it was statically placed in a range of degrees of movement in all three planes starting from 0^{o}, then 1^{o}, 2^{o} and finally 5^{o} (Table 4.1). In this instance, for example, it was placed in 5^{o} of roll, pitch and yaw at the same time.

The 8 camera three-dimensional Qualysis (Sweden) camera system was set up around the laboratory with 1 reference camera utilised. This was calibrated using an “L” frame and wand which gave an error of ±0.39mm. Each time the boat was moved, a 5 second capture of the camera system took place.

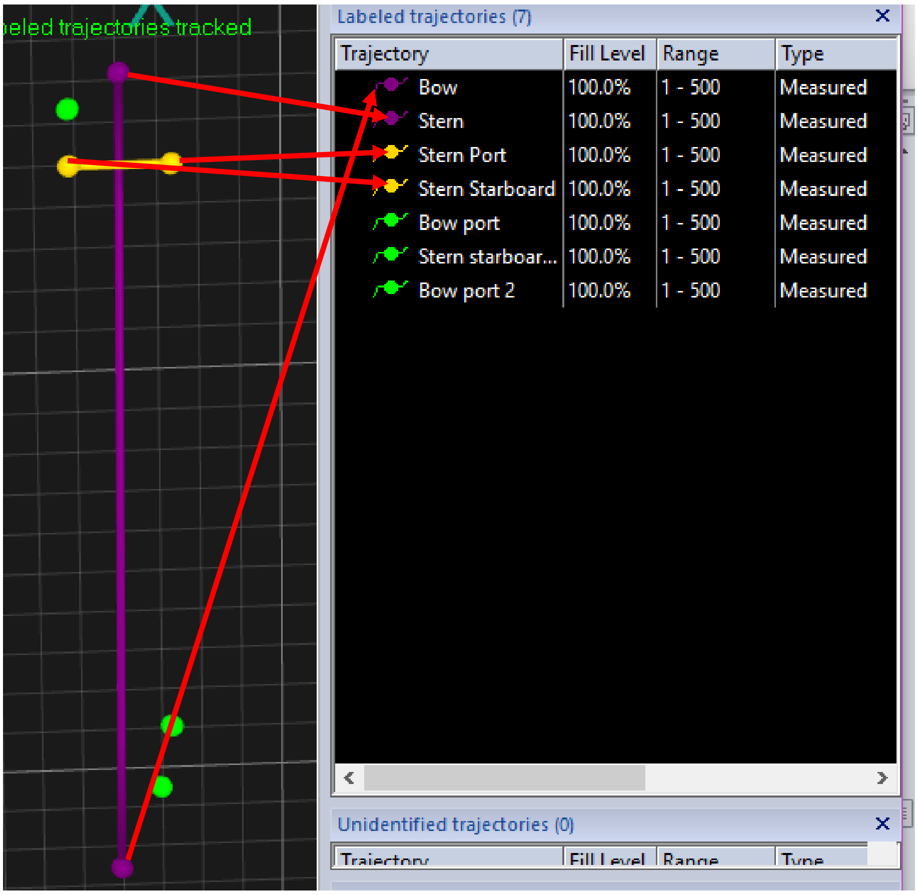


Figure 4.3: Utilised boat markers for validation analysis. Bow and stern in purple; stern port and stern starboard in yellow.

Figure 4.4: Boat statically in 20° of pitch

The second part of the validation study involved a seven camera Qualysis system with one reference camera being set up around a 25m pool. The system was calibrated with an "L" frame and wand and gave an error range of ±0.44mm to ±1.33mm. A paddler kayaked across the capture space with seven different seat raises and five trials per seat raise. In both the lab and the pool the camera systems recorded at 100Hz.

4.2.3 Analysis of results

The foam compression test data was plotted on a line graph in order to identify how much the foam was likely to compress when added into the boat with a kayaker sat in position.

The marker system validation data was analysed by applying a marker model previously set up using the Qualysis capture software (Qualysis Track Manager (QTM), V2.15) for a 7 point digitisation model (Figure 4.3). This model was applied to the unfiltered raw coordinate data for the laboratory test and then smoothed using QTM's in built method for smoothing, by fitting to a 2nd degree curve with 11 frames in the filter window, for the kayaking data.

The length and width of the boat were manually measured using a steel tape measure and measured to the centre of the two markers. Two calculations for length and width were then measured from the exported three-dimensional coordinate data across all conditions. Firstly, a one-dimensional (1D) calculation was carried out, therefore in order to measure the length of the boat, the difference between the stern and bow coordinate data in the x-direction (Figure 4.5) was calculated and averaged for each trial. For width, the difference between the stern port and stern starboard coordinate data was calculated in the y direction and averaged for each trial. Then a percentage error was calculated for each trial comparing the manually measured length or width to the measurement calculated from the Qualysis system.

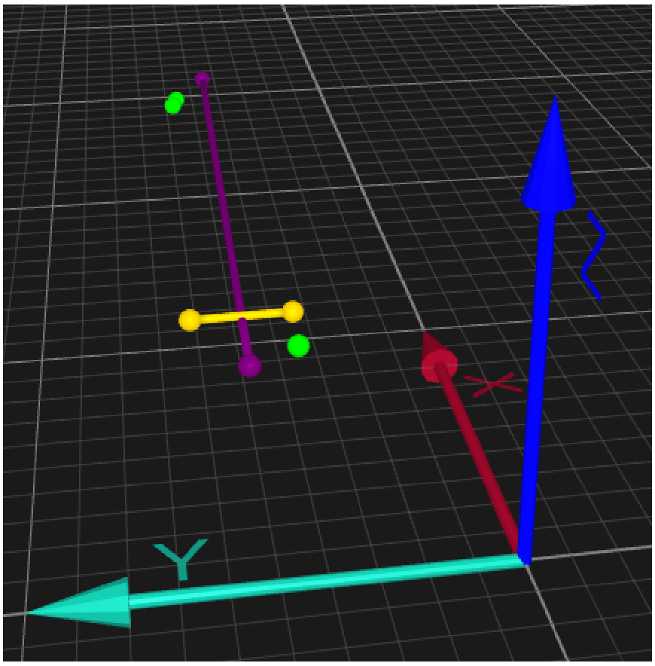


Figure 4.5: Directions of planes in the three-dimensional camera system

Secondly, the same system as above was applied, however a calculation taking into account the three-dimensional data (Equation 4.1) was used to calculate the length and width.

$$AB=\sqrt{(x_2-x_1)^2 + (y_2-y_1)^2 + (z_2-z_1)^2}$$

Equation 4.1: calculating distance using three-dimensional data

Again, the percentage error between the manually measured length and width was compared to the calculated length and width from the exported data from the three-dimensional camera system.

4.3 Validation of methods – Results

4.3.1 Results of foam compression test

The results of the foam compression test indicates that the maximum amount of compression of the foam is 6mm with both 80mm and 90mm of foam and an added mass of 70kg (Figure 4.6). This is 7.5% compression of the 80mm of foam and 6.7% of the 90mm of foam.

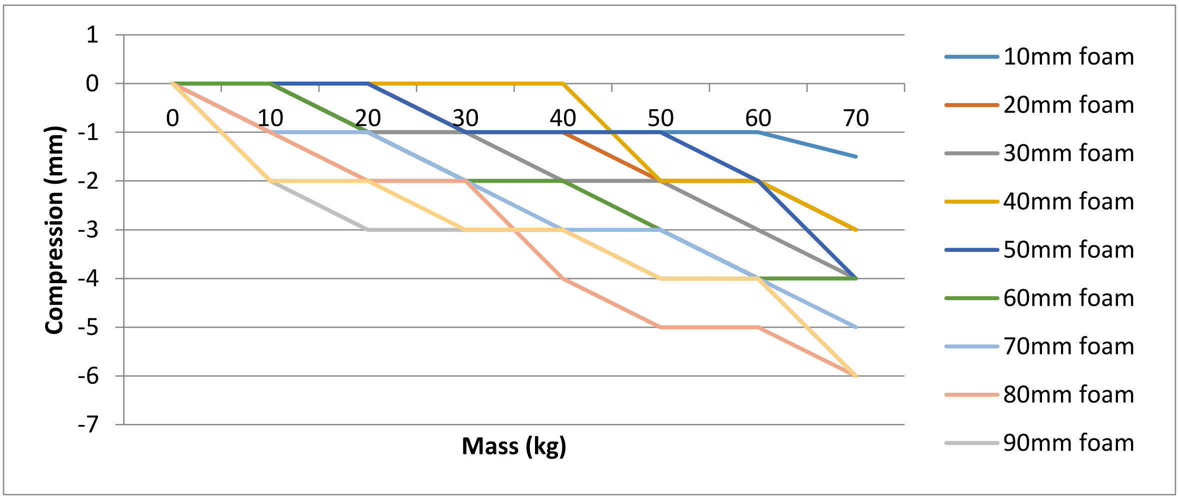


Figure 4.6: Compression testing of foam

4.3.2 Results of validation of marker set

The results of the laboratory testing of the static marker set at angles ranging from 0^{o} to 20^{o} show that using a one-dimensional calculation indicated the largest errors in the length to be at the 20^{o} position in pitch (6.10% error) and yaw (6.50% error) all other errors were below 2% (Table 4.1). The largest magnitude of these errors had a difference in length of -117.34mm from the measured 1806mm, when using the one-dimensional calculation. Table 4.2 shows these percentage errors to be reduced to no more than 0.3% across all measures when using a three-dimensional calculation, with no more than a -6mm difference in length.

Table 4.1: Percentage error from measured actual length (1806mm) for static boat position through a number of different angles in movements in 1D (pitch, roll, yaw) and 3D (multi) using a 1D calculation

	0°			1°			2°			5°			10°			20°		
	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error
Pitch length	1801.13	-4.87	0.27	1800.94	-5.06	0.28	1800.18	-5.82	0.32	1794.99	-11.01	0.61	1775.12	-30.88	1.71	1695.77	-110.23	6.10
Roll length	1800.10	-5.90	0.33	1800.30	-5.70	0.32	1800.66	-5.34	0.30	1800.67	-5.33	0.30	1800.69	-5.31	0.29	1800.40	-5.60	0.31
Yaw length	1800.80	-5.20	0.29	1800.41	-5.59	0.31	1799.38	-6.62	0.37	1793.04	-12.96	0.72	1771.43	-34.57	1.91	1688.66	-117.34	6.50
Multi length	1801.13	-4.87	0.27	1800.80	-5.20	0.29	1798.56	-7.44	0.41	1786.61	-19.39	1.07						

Table 4.2: Percentage error from measured actual length (1806mm) for static boat position through a number of different angles in movements in 1D (pitch, roll, yaw) and 3D (multi) using a 3D calculation

	0°			1°			2°			5°			10°			20°		
	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error
Pitch length	1801.42	-4.58	0.25	1801.32	-4.68	0.26	1801.32	-4.68	0.26	1801.32	-4.68	0.26	1801.26	-4.74	0.26	1801.32	-4.68	0.26
Roll length	1800.53	-5.47	0.30	1800.74	-5.26	0.29	1801.04	-4.96	0.27	1800.99	-5.01	0.28	1800.91	-5.09	0.28	1800.76	-5.24	0.29
Yaw length	1800.88	-5.12	0.28	1800.96	-5.04	0.28	1800.95	-5.05	0.28	1800.96	-5.04	0.28	1800.88	-5.12	0.28	1800.78	-5.22	0.29
Multi length	1801.26	-4.74	0.26	1801.02	-4.98	0.28	1801.13	-4.87	0.27	1801.06	-4.94	0.27						

Table 4.3: Percentage error from measured actual width (230mm) for static boat position through a number of different angles in movements in 1D (pitch, roll, yaw) and 3D (multi) using a 1D calculation

	0°			1°			2°			5°			10°			20°		
	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error
Pitch width	228.38	-1.62	0.70	228.36	-1.64	0.71	228.31	-1.69	0.73	228.23	-1.77	0.77	228.21	-1.79	0.78	227.96	-2.04	0.89
Roll width	228.37	-1.63	0.71	228.40	-1.60	0.69	228.31	-1.69	0.74	227.85	-2.15	0.93	225.84	-4.16	1.81	217.33	-12.67	5.51
Yaw width	228.25	-1.75	0.76	228.15	-1.85	0.80	228.03	-1.97	0.86	227.16	-2.84	1.23	224.43	-5.57	2.42	213.92	-16.08	6.99
Multi width	228.28	-1.72	0.75	228.28	-1.72	0.75	227.98	-2.02	0.88	226.31	-3.69	1.60						

Table 4.4: Percentage error from measured actual width (230mm) for static boat position through a number of different angles in movements in 1D (pitch, roll, yaw) and 3D (multi) using a 3D calculation

	0°			1°			2°			5°			10°			20°		
	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error
Pitch width	228.35	-1.65	0.72	228.45	-1.55	0.67	228.44	-1.56	0.68	228.39	-1.61	0.70	228.36	-1.64	0.71	228.11	-1.89	0.82
Roll width	228.39	-1.61	0.70	228.42	-1.58	0.69	228.34	-1.66	0.72	228.29	-1.71	0.74	228.33	-1.67	0.73	228.34	-1.66	0.72
Yaw width	228.31	-1.69	0.73	228.26	-1.74	0.76	228.26	-1.74	0.75	228.18	-1.82	0.79	228.18	-1.82	0.79	228.17	-1.83	0.80
Multi width	228.33	-1.67	0.73	228.30	-1.70	0.74	228.26	-1.74	0.76	228.19	-1.81	0.79						

When looking at the boat width, the one-dimentional calculation shows the largest error to be at the 20° position in both roll (5.51%) and yaw (6.99%). Errors for all other measures were below 3% (Table 4.3). The largest of these errors had a difference in width of -16.08mm from the measured 230mm, when using the one-dimensional calculation. Table 4.4 shows these percentage errors to be reduced to no more than 0.82% across all measures when using a three-dimensional calculation, with no more than -1.89mm difference in width.

When transferring these calculations to on-water trials, the one-dimensional calculation continued to show higher errors than the three-dimensional error (Tables 4.5 - 4.8). Using the one-dimensional calculation, the largest error for length was 1.62%, a difference of 29.27mm (Table 4.5). The largest error for width was 1.90%, a difference of 4.34mm when using the one-dimensional calculation (Table 4.7). When using the three-dimensional calculation the error for length reduced to ≤0.4%, a difference of just 7.17mm (Table 4.6), and the error for width reduced to -1.1% error, a difference of just -2.51mm (Table 4.8).

Table 4.5: Percentage error from measured actual length (1806mm) for a moving boat in water through 8 different seat raises and 5 trials per seat raise using a 1D calculation

	0cm			1cm			2cm			3cm			4cm			5cm			6cm			7cm		
Trial	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error
1	1789.32	16.68	0.92	1788.27	17.73	0.98	1787.76	18.24	1.01	1790.09	15.91	0.88	1788.82	17.18	0.95	1793.32	12.68	0.70	1791.72	14.28	0.79	1790.51	15.49	0.86
2	1791.08	14.92	0.83	1793.72	12.28	0.68	1793.04	12.96	0.72	1791.78	14.22	0.79	1792.80	13.20	0.73	1791.60	14.40	0.80	1790.45	15.55	0.86	1793.15	12.85	0.71
3	1793.85	12.15	0.67	1793.63	12.37	0.68	1791.96	14.04	0.78	1793.51	12.49	0.69	1787.26	18.74	1.04	1791.33	14.67	0.81	1787.45	18.55	1.03	1791.98	14.02	0.78
4	1790.92	15.08	0.83	1794.18	11.82	0.65	1782.86	23.14	1.28	1791.48	14.52	0.80	1784.89	21.11	1.17	1776.73	29.27	1.62	1789.74	16.26	0.90	1788.35	17.65	0.98
5	1788.66	17.34	0.96	1792.11	13.89	0.77	1788.13	17.87	0.99	1780.16	25.84	1.43	1794.32	11.68	0.65	1792.87	13.13	0.73	1788.66	17.34	0.96	1788.64	17.36	0.96

Table 4.6: Percentage error from measured actual length (1806mm) for a moving boat in water through 8 different seat raises and 5 trials per seat raise using a 3D calculation

	0cm			1cm			2cm			3cm			4cm			5cm			6cm			7cm		
Trial	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error
1	1799.74	6.26	0.35	1799.94	6.06	0.34	1799.43	6.57	0.36	1799.35	6.65	0.37	1799.56	6.44	0.36	1800.49	5.51	0.30	1798.92	7.08	0.39	1799.68	6.32	0.35
2	1798.92	7.08	0.39	1800.17	5.83	0.32	1799.97	6.03	0.33	1798.83	7.17	0.40	1800.43	5.57	0.31	1800.53	5.47	0.30	1799.12	6.88	0.38	1799.71	6.29	0.35
3	1799.06	6.94	0.38	1800.95	5.05	0.28	1799.68	6.32	0.35	1799.61	6.39	0.35	1799.20	6.80	0.38	1800.36	5.64	0.31	1799.36	6.64	0.37	1800.20	5.80	0.32
4	1798.88	7.12	0.39	1799.05	6.95	0.38	1800.17	5.83	0.32	1799.73	6.27	0.35	1799.69	6.31	0.35	1799.77	6.23	0.35	1798.87	7.13	0.39	1800.19	5.81	0.32
5	1798.89	7.11	0.39	1799.75	6.25	0.35	1799.95	6.05	0.33	1799.44	6.56	0.36	1800.31	5.69	0.32	1800.07	5.93	0.33	1799.62	6.38	0.35	1800.07	5.93	0.33

Table 4.7: Percentage error from measured actual width (203mm) for a moving boat in water through 8 different seat raises and 5 trials per seat raise using a 1D calculation

	0cm			1cm			2cm			3cm			4cm			5cm			6cm			7cm		
Trial	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error
1	225.44	2.91	1.27	224.92	3.42	1.50	226.22	2.13	0.93	225.22	3.13	1.37	226.59	1.75	0.77	228.76	-0.42	-0.18	225.97	2.37	1.04	226.34	2.01	0.88
2	226.37	1.98	0.87	226.68	1.66	0.73	226.39	1.95	0.85	225.50	2.84	1.24	227.32	1.02	0.45	227.91	0.43	0.19	225.61	2.73	1.20	225.28	3.06	1.34
3	225.86	2.49	1.09	224.44	3.90	1.71	226.25	2.09	0.92	226.38	1.97	0.86	226.23	2.11	0.92	227.86	0.49	0.21	224.64	3.70	1.62	224.91	3.44	1.51
4	224.97	3.37	1.48	229.12	-0.77	-0.34	226.48	1.87	0.82	225.45	2.90	1.27	226.47	1.87	0.82	225.98	2.36	1.04	224.98	3.37	1.48	224.79	3.55	1.55
5	225.97	2.37	1.04	228.48	-0.13	-0.06	225.83	2.52	1.10	224.43	3.92	1.72	227.31	1.04	0.45	228.04	0.31	0.13	224.00	4.34	1.90	224.68	3.67	1.61

Table 4.8: Percentage error from measured actual width (203mm) for a moving boat in water through 8 different seat raises and 5 trials per seat raise using a 3D calculation

	0cm			1cm			2cm			3cm			4cm			5cm			6cm			7cm		
Trial	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error	Measured (mm)	Difference from actual	%error
1	227.59	0.75	0.33	228.19	0.15	0.07	228.40	-0.06	-0.03	226.88	1.47	0.64	228.74	-0.39	-0.17	230.85	-2.51	-1.10	227.72	0.63	0.27	228.04	0.30	0.13
2	228.53	-0.19	-0.08	228.26	0.08	0.04	228.14	0.20	0.09	227.02	1.33	0.58	229.22	-0.88	-0.38	230.13	-1.79	-0.78	227.92	0.43	0.19	226.94	1.41	0.62
3	227.73	0.61	0.27	227.13	1.21	0.53	227.63	0.71	0.31	227.75	0.59	0.26	228.78	-0.44	-0.19	230.11	-1.77	-0.77	227.56	0.79	0.34	226.93	1.41	0.62
4	226.96	1.39	0.61	230.67	-2.32	-1.02	228.98	-0.63	-0.28	227.23	1.12	0.49	229.11	-0.77	-0.34	229.59	-1.24	-0.55	227.49	0.86	0.38	227.05	1.30	0.57
5	227.93	0.41	0.18	230.29	-1.94	-0.85	228.21	0.13	0.06	227.33	1.01	0.44	229.29	-0.95	-0.42	229.92	-1.57	-0.69	226.49	1.85	0.81	226.74	1.60	0.70

4.4 Validation of methods - Discussion

The results of the foam test indicate that the foam compresses more as more weight was applied but that this was in small increments of millimetres. In general the maximum amount of compression increased with the increase in layers of foam as would be expected. The foam used, high density closed cell polyethylene foam, was sourced as the foam with the least compression available on the market without resorting to solid materials which would not conform to the shaped seats in the kayaks. The important finding here to understand for later chapters was that the participants in chapter 6 only utilised a maximum of 70mm of foam in their kayaks. In this study this amount of foam compressed by 5mm at 70kg weight. This gives a compression of 3.5% for 70mm of foam and therefore was acceptably within the 5% error.

In agreement with the findings identified by Dabnichki et al. (1997) there was error in the Qualysis system. However, even when only using a one-dimensional calculation the largest error was 6.99%. An acceptable level of error would be 5%, the only time the one-dimensional calculations returned an error of above 5% was when measuring either the length or width statically with the boat at 20°. This is a large angle, as demonstrated in Figure 4.4, which the boat will very rarely reach when paddling on flat water, as used in this doctoral work, and boats would only reach this angle on white water if the gradient of the river was high.

When looking at the on-water trials, even the one-dimensional calculation did not go above 2% error, suggesting that the amount of movement on water was small enough to only result in small errors, the laboratory exaggerated these movements to identify how much error would be introduced when the boat was going through larger degrees of movement.

Despite the fact that the boat is unlikely to reach these larger angles produced in the laboratory data collection, the larger errors returned by the one-dimensional calculation when compared to the three-dimensional calculation (maximum of 6.99% 1D compared to -1.1% 3D), suggests that the three-dimensional calculation should be employed when calculating lengths and widths of the boat to use in trigonometry for the final study. This will result in a reduction in the already small errors on water to make them even more reliable.

This chapter has ensured that the measures collected in pursuit of sub-aim 2: to utilise three-dimensional kinematics, and kinetics to determine female white water kayakers' paddle stroke technique and efficiency related to sitting height, were reliable and valid. In order to ensure this takes place the following learning has taken place from this chapter. Firstly, the Power Meter Pro, previously identified by Macdermid & Fink (2017) as reliable and valid was required to undergo a zeroing process as recommended by the manufacturers and this was presented in the methodology of Chapters 5 and 6. Secondly, the foam compressed by 3.5% when the maximum foam raise of 70mm used by participants in Chapter 6 was loaded with 70kg of direct mass. This is acceptable compression for the foam at its end range in Chapter 6. Finally, the calculation utilised to measure boat length and width in order to put into further calculations for angles of movement, was the 3D calculation presented within this chapter. Although the error of the 1D calculation was small (mostly below 5% with a maximum of 6.99%), the error was improved to a maximum of -1.1% with the 3D calculation, and therefore this calculation was utilised throughout later chapters.

5.0 Observational model of white water kayaking boat kinematics

5.1 Observational model of white water kayaking boat kinematics – Introduction

Kayaking technique, particularly in terms of sprint kayaking, has been researched and discussed for a number of years. During these years there have been many equipment changes which have impacted upon the technique used. Plagenhoef (1979) initiated discussions around equipment when he investigated technique patterns when athletes were using drag blades, similar to those used by white water kayakers today. Since the change of paddles used in sprint kayaking to winged blades in circa 1986 (Jackson, 1995), the technique of sprint kayaking has changed considerably.

McDonnell et al. (2012) combined previous articles around kayaking technique and proposed an observational model of sprint kayaking technique. This observational model is important both within research and within the sport itself. It helps to ensure that everyone is breaking down the technique in the same way, and thus providing feedback in the same way, regardless of whether in a research or a coaching context. Utilising the same language and terminology to discuss the technique of sprint kayaking, as suggested by McDonnell et al. (2012), has provided opportunities for research to be both more comparable in terms of findings and applied more easily to practice. Finally, when using an observational model, communication is improved due to the understanding of the terminology (McDonnell et al., 2012). This observational model of sprint kayaking however, does not fully translate into white water kayaking, largely due to the different crafts and paddles used by white water kayakers. Therefore, a similar observational model for white water kayaking is required, which is why this doctoral thesis has attempted to create one for boat movements and force application in a white water boat.

The first comment McDonnell et al. (2012) makes in their observational model is that kayaking should be described in terms of single strokes, so for example, left paddle entry through to right paddle entry, and that if a double stroke is required then it should be displayed as 2 consecutive strokes. This is important in order to understand why the observational model presented in this thesis is shown in terms of individual strokes.

When looking at kayaking technique observations, McDonnell et al. (2012) have split this, at level one, into 2 sections; water and aerial. At level two, the water section can then be further split into entry, pull and exit to allow a more in-depth analysis of stroke. For this observational model of boat movements, level one analysis of describing the movement in water and aerial phases was used. This allowed the impact of the paddle being in contact with the water on the boat path to be determined.

McDonnell et al. (2013) also produced a deterministic model to accompany their observational model. They used average kayak velocity as the overall measure; this is possible in sprint kayaking, in which the maximum average velocity of the boat is the goal of the sport. This is different to the sport of white water kayaking in which the aim is to navigate rivers and descend rapids (BCU, 2014b) and therefore speed is not of paramount importance to achieve the goal of white water kayaking. The deterministic model that McDonnell et al. (2013) presented was of kinematic variables mainly focusing on the paddle due to stroke displacement and stroke time being deterministic of the overall kayak average velocity. Without a clear aim such as average kayak velocity, it is not possible to create a deterministic model for white water kayaking, in which the factors contained within a level should wholly determine the factors present in the level above. Therefore this thesis presents an observational model of kinematic boat movements present when kayaking a white water kayak.

Michael et al. (2009) also tried to group all determinants of flat water kayaking performance. Similar to McDonnell et al.'s (2013) later paper, they also looked at the input of the paddle into achieving the outcome of speed, identifying drag resistance as an opposing factor as well as discussing the forces the kayaker applies to the foot rest and the seat in order to transfer paddle force to the boat. They also looked at the kinetic input of the paddle, identifying that with a drag paddle as used in white water kayaking propulsion takes place when drag forces are created, hence the paddles apt name. In flat water sprint kayaking, a winged paddle is used and lift forces are more often used to cause propulsion rather than drag. Although a reasonable amount is known about forces applied via the paddle to a sprint kayak, white water kayaking is underrepresented within the literature which is why a force profile applied to white water kayaking is presented within this observational model for this thesis. It is also important to note that the force profiles of sprint kayaking are limited in their presentation in the literature and those shown do not all agree. For example, Aitken and Neal (1992) present a curve with a single peak at around 45% of the normalised paddle stroke for both left and right. However, Baker (1998) presented both a double peak, with the first peak coming quite early in the paddle stroke, and a single peak, stating that the single peak is the more desirable profile for sprint kayaking due to its indication of a smooth application of the force which also suggests efficiency. It is therefore important that it is understood what a “normal” force profile for a kayaker in a white water craft would look like. This is especially pertinent with the availability of the Power Meter Pro utilised within this study due to the ability to measure both the bottom pulling hand and top pushing hand. This is data which has not been presented in previous papers because they tended to focus on just the bottom pulling hand due to the limitations of strain gauges. This has provided novel data in the thesis in terms of combined force data for drag blades in white water kayaking.

In accompaniment of the kinetic analysis of kayaking, Michael et al. (2009) also investigated the kinematic movements observed. Along with looking into the paddle and paddler movement, they also dedicated a section to discussing the movement of the kayak itself. Much of this discussion was had in relation to rowing, due to the fact that unwanted boat movement in kayaking had been overlooked within the literature (Michael et al., 2009). It was identified within the article that Loschner et al. (2000) and Wagner et al. (1993) had discovered that yaw and roll had a greater impact on the boat movement than pitch. However it was also stated that when these movements around the craft’s axes were increased, the surface in contact with the water also increased and thus the hydrodynamic drag increased. A reduction in these unwanted movements and therefore an improved balance of the boat around all axes would result in hydrodynamic drag reduction leading to increased efficiency of paddle strokes. The paper by Loschner et al, (2000) presents a set of graphs of the rowing boat movement presented as a percentage of time, similar to this thesis for the kayak movement. The participants used for Loschner et al.'s (2000) study were scullers and therefore an oar was presented to the water on each side of the rowing boat simultaneously. In a kayak, where a paddle is only presented on one side at a time, and therefore paddle force is only applied on one side at a time, it can be hypothesised that the impact one paddle stroke will have on the boat movements would be greater. This is why this observational model presents the three movements of pitch, roll and yaw in similar graphs to Loschner et al. (2000) along with heave or bobbing as Michael et al. (2009) describe it. This addition of heave is important as Michael et al. (2009) states that this movement is neglected in the literature and its creation of waves results in lost energy which again can reduce efficiency.

The aim of this chapter, therefore, is to present normalised force profiles alongside the normalised pattern of boat movements in terms of heave, pitch, roll and yaw for a white water kayak over one single stroke.

In terms of the overall aim and sub aims of the thesis, this chapter intends to help towards delivery of sub-aim 2: to utilise three-dimensional kinematics, and kinetics to determine female white water kayakers' paddle stroke technique and efficiency related to sitting height. This observational model of boat movements and force profiles of the forwards paddle stroke is utilised in chapter 6 in order to establish true forwards paddling techniques.

5.2 Observational model of white water kayaking boat kinematics – Methodology

5.2.1 Sample

With institutional ethical clearance by the University of Chichester, seven female participants (mean 38.86 years, SD 9.70) for the force data and nine female participants (mean 37.78 years, SD 8.69) for the boat movements were recruited via conferences and talks to kayakers, social media requests and a snowball sampling strategy (Jones, 2015). The participants all had a minimum of 2 years experience of white water kayaking on a variety of rivers and were all right handed. All participants were from the United Kingdom and were predominantly based in the south of the country.

5.2.2 Procedure

Prior to the participants' arrival at the test centre the Qualysis (Sweden) camera system was set up around the 25m swimming pool. An 8 camera system with 1 reference camera was utilised (Figure 5.1a, b and c).

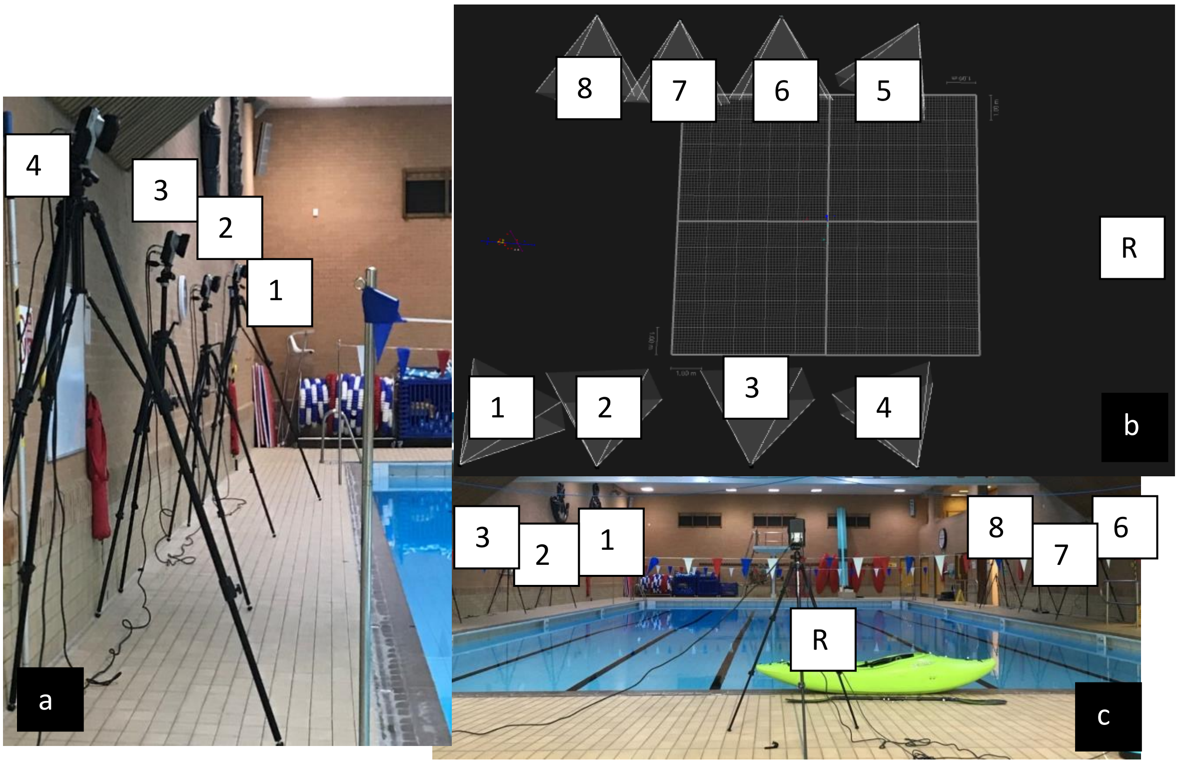


Figure 5.1a, b and c: Camera layout (cameras 1-8 and R indicating reference) around swimming pool

A marker model had previously been set up in a laboratory using the Qualysis capture software (QTM, V2.15) for a 9 point digitisation model with 7 markers on the boat (Figure 4.2) and 1 on each forearm.

Calibration of the Qualysis system using an "L" frame and a wand gave an error range of 0.44mm to 2.47mm.

Upon arrival at the testing venue participants were provided with a participant information sheet (Appendix C) and asked to sign their consent (Appendix D). The participant then chose the size of the kayak available (Dagger mamba in sizes 7.6 or 8.1

see Table 5.1 for specifications) based on their body mass and the boat they currently paddle.

The Power Meter Pro was then selected based on the length of shaft and size of blade which the participant was used to paddling with, and the Power Meter Pro was then set up to match their own current paddle, in terms of length of shaft and feather of the blades, this was accomplished by putting the two paddles together and adjusting to match. Three Power Meter Pros' were available with Adventure Technology (AT, USA) blades attached (Table 5.2). The Power Meter Pros' then underwent a zero offset procedure as recommended by the manufacturer (One Giant Leap, 2019). This involved laying the Power Meter on the floor with no force applied directly to either paddle. On the capture software the "calibrate" button was then clicked which then indicated success and a zero offset had been completed.

Table 5.1: Specifications of the boats used (Dagger Kayaks, 2018)

	Mamba 7.6	Mamba 8.1
Length	7' 7" / 231cm	8'1" / 246cm
Cockpit length	34"/ 86cm	34" / 86cm
Deck height	14" / 36cm	15" / 38cm
Volume	64gal / 242L	77gal / 292L
Width	25.5" / 65cm	26.75" / 68cm
Cockpit width	19" / 48cm	19" / 48cm
Boat mass	44lbs / 20kg	47lbs / 21kg
Paddler mass range	120-170lbs / 54-77kg	150-220lbs / 68-100kg

Table 5.2: Shaft length and paddle sizes available on Power Meter Pros

Paddle number	Blade type and size	Shaft length (mm)
86	Hercules 700cm^2	1900- 1950
87	Geronimo 725cm^2	1900- 1950
88	Geronimo 725cm^2	1950- 2000

Before data collection commenced, the body, boat and paddle markers were applied in the locations identified in Figures 4.2. as well as the forearms. The paddlers wore minimal clothing on their upper body such as a swimming costume with no spray deck, no buoyancy aid or helmet. The participant was given time to adjust the boat set up to fit them for comfort and to achieve the fit most similar to their own boat. Then a static trial was collected by the participant sitting in the floating boat with their arms outstretched in the anatomical position with the paddle rested across the cockpit. The paddler then got into the boat in the swimming pool and were given as much time as required in order to get comfortable with paddling the boat and the paddle. Once they had determined that they were happy with the boat they then paddled from one end of the swimming pool towards the capture area at a self-selected comfortable speed. The capture length for Qualysis was set to 18 seconds at 100Hz and the Power Metre Pro was recording at 50Hz throughout the duration of the capture. They paddled a minimum of 24 times across the capture space with up to 8 different seat raises reflecting a larger proportion of the female white water kayaking population.

5.2.3 Analysis

The Power Meter Pro paddle data was analysed using the One Giant Leap Analysis software (2016). Each paddle stroke raw force data was exported to Excel (2010) and the push force from the top hand was added to the pull force of the bottom hand to provide a combined force and time was then normalised to 100%. The number of strokes analysed per trial varied between 3 and 6 per side dependent on the participant with a total of 1154 left and 1142 right strokes analysed. The mean force was calculated for all strokes. These were then presented as graphs for both left and right paddle strokes drawn using MatLab (V: r2017b) to show the expected force pattern for paddling a white water kayak.

Qualysis Track Manager (V2.15) was used to analyse the Qualysis data. The 47 point digitisation model was applied to the marker data and the capture time cropped to include the visible paddle stroke data, not including the final stroke. The filtered raw coordinate data in three dimensions were exported for all five trials for each sitting height. The data was smoothed using QTM's in built method for smoothing, by fitting to a 2nd degree curve with 11 frames in the filter window and gap filled. The number of strokes analysed per trial varied between 4 and 7 dependent on the participant and the clarity of the data as the boat entered the capture area. An average of 747.3 strokes on the left and 773.75 strokes on the right were analysed across the boat movements.

Each stroke from every trial was exported into Excel (2010) and the time was normalised to 100%. The mean was calculated for all strokes. Then graphs of each stroke for left to right and right to left were created using MatLab (V: r2017b) to show the expected pattern for each of the boat movements; heave, pitch, roll and yaw.

5.3 Observational model of white water kayaking boat kinematics – Results

5.3.1 Force

As Figure 5.2 indicates the large amount of data collected has combined to give an overall force profile which is similar left to right, although the maximum mean force for the right is slightly higher (144.62N) than the left (135.06N). The recording period is for the time the paddle is in contact with the water and force is being applied. There is one large force peak as propulsion is applied for both left and right paddle strokes.

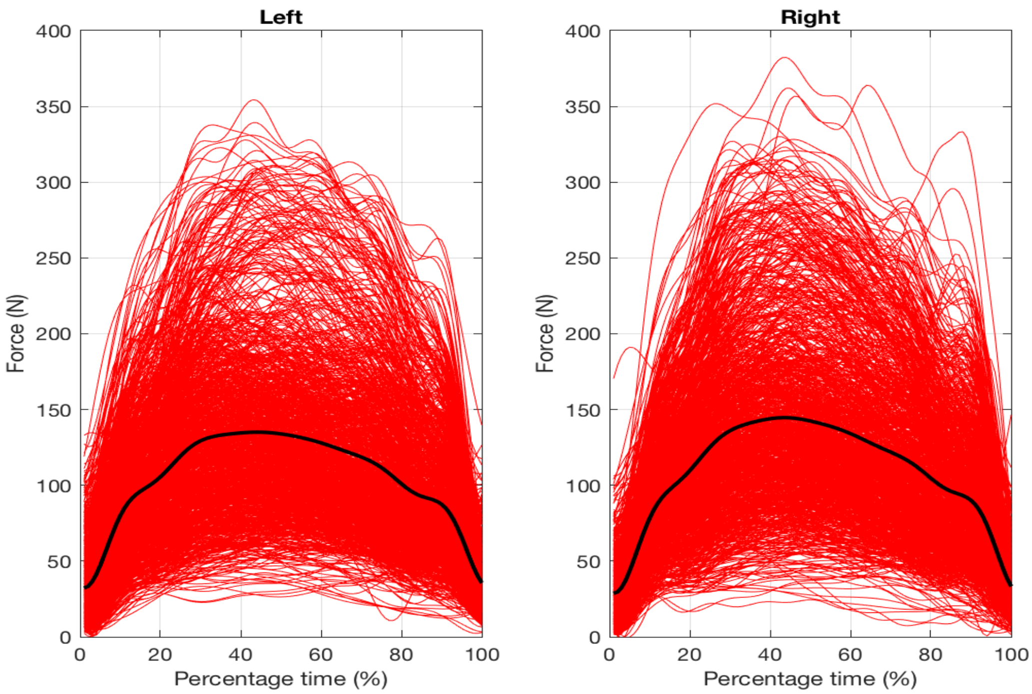


Figure 5.2: Time normalised force data for the left and right paddle strokes for all participants and all trials. The black line is the mean force profile.

5.3.2 Boat Movements

Figure 5.3a and b shows the profile of heave over a single stroke with the initiation of the stroke at 0% through to the following stroke which is initiated at 100%. Figure 5.3a, for example, shows left paddle entry through to right paddle entry. The heave of the kayak displays a small sinking of the centre of the boat as the paddle is entered into the water at 0% before the centre rises as the water phase of the stroke is initiated. This then decreases again, showing the boat sinks lower into the water towards the end of the stroke and the next stroke being initiated at 100%. The amount of movement is limited with only 14.56mm difference between peak and trough for the left paddle stroke and similarly only 14.62mm for the right paddle stroke. Figure 5.7a and b show the profile of heave more clearly with the average point of paddle exit marked to allow the water and air phase to be clearly seen.

The pitch of the kayak (Figure 5.4a and b) shows the initiation of the stroke at 0%. This causes the bow to dip before rising again as the paddle stroke is undertaken, finally another dip in the bow is seen as the kayaker prepares to put the next paddle in the water at 100%. The difference between the mean peak and trough is, similar to heave, slightly larger for the right paddle stroke in Figure 5.4b at 1.69^{o} compared to 1.61^{o} for the left paddle stroke. Figure 5.7c and d show the profile of pitch more clearly with the average point of paddle exit marked to allow the water and air phase to be clearly seen.

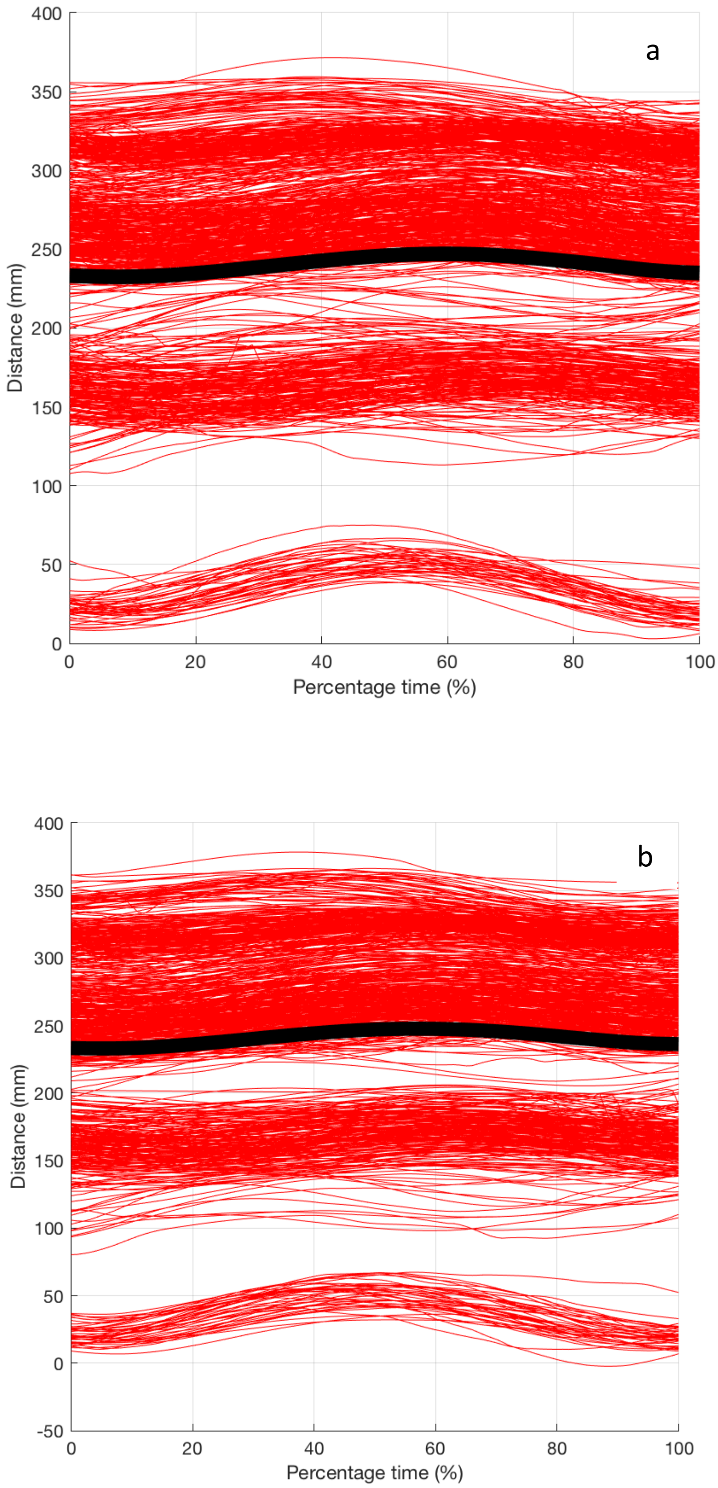


Figure 5.3a and b: Time normalised heave data for the left (a) and right (b) paddle strokes for all participants and all trials. The black line is the mean heave profile.

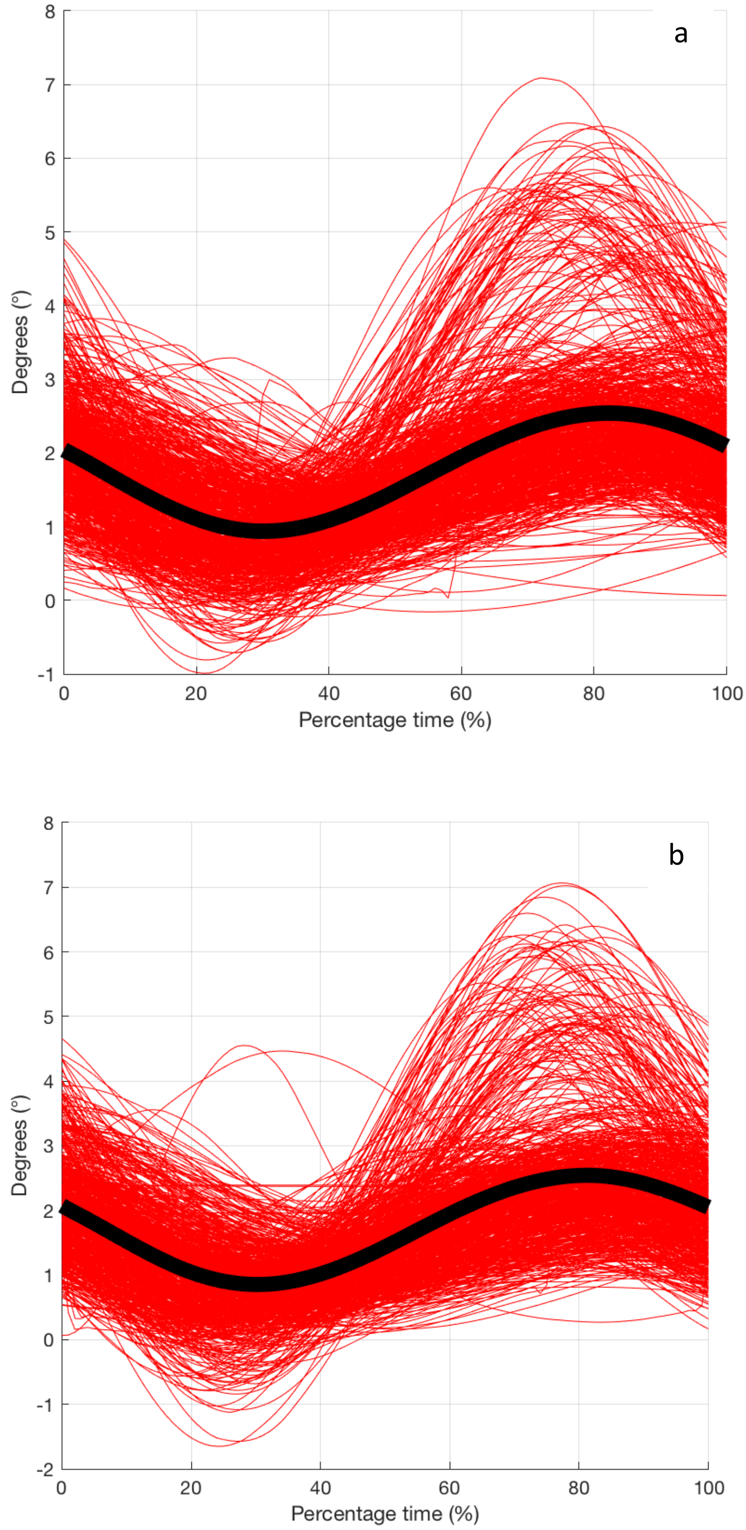


Figure 5.4a and b: Time normalised pitch data for the left (a) and right (b) paddle strokes for all participants and all trials. The black line is the mean pitch profile.

The roll of the boat (Figure 5.5a and b) shows that with the paddle entry at 0% and the initiation of the paddle stroke the kayak first rolls towards the side the paddle has been entered on, this roll then returns to flat and continues to roll towards the opposite side as the paddler prepares to put that paddle in the water at 100%. The maximum amount of roll movement within the left paddle stroke is 6.25^{o} and the maximum throughout the right paddle stroke is the same as for the left at 6.25^{o}. Figure 5.7e and f show the profile of roll more clearly with the average point of paddle exit marked to allow the water and air phase to be clearly seen.

Figure 5.6a and b show the yaw of the boat. When the paddle enters at 0% it can be seen that the boat continues to move slightly towards the paddle which is in the water, before the boat then turns away from the in-water paddle and continues to do so up until entry of the opposite paddle at 100% and then follows the same pattern as the next paddle stroke happens. The maximum amount of yaw during the left paddle stroke is 9.17^{o} and the maximum throughout the right paddle stroke is lower at 8.69^{o}. Figure 5.7g and h show the profile of yaw more clearly with the average point of paddle exit marked to allow the water and air phase to be clearly seen.

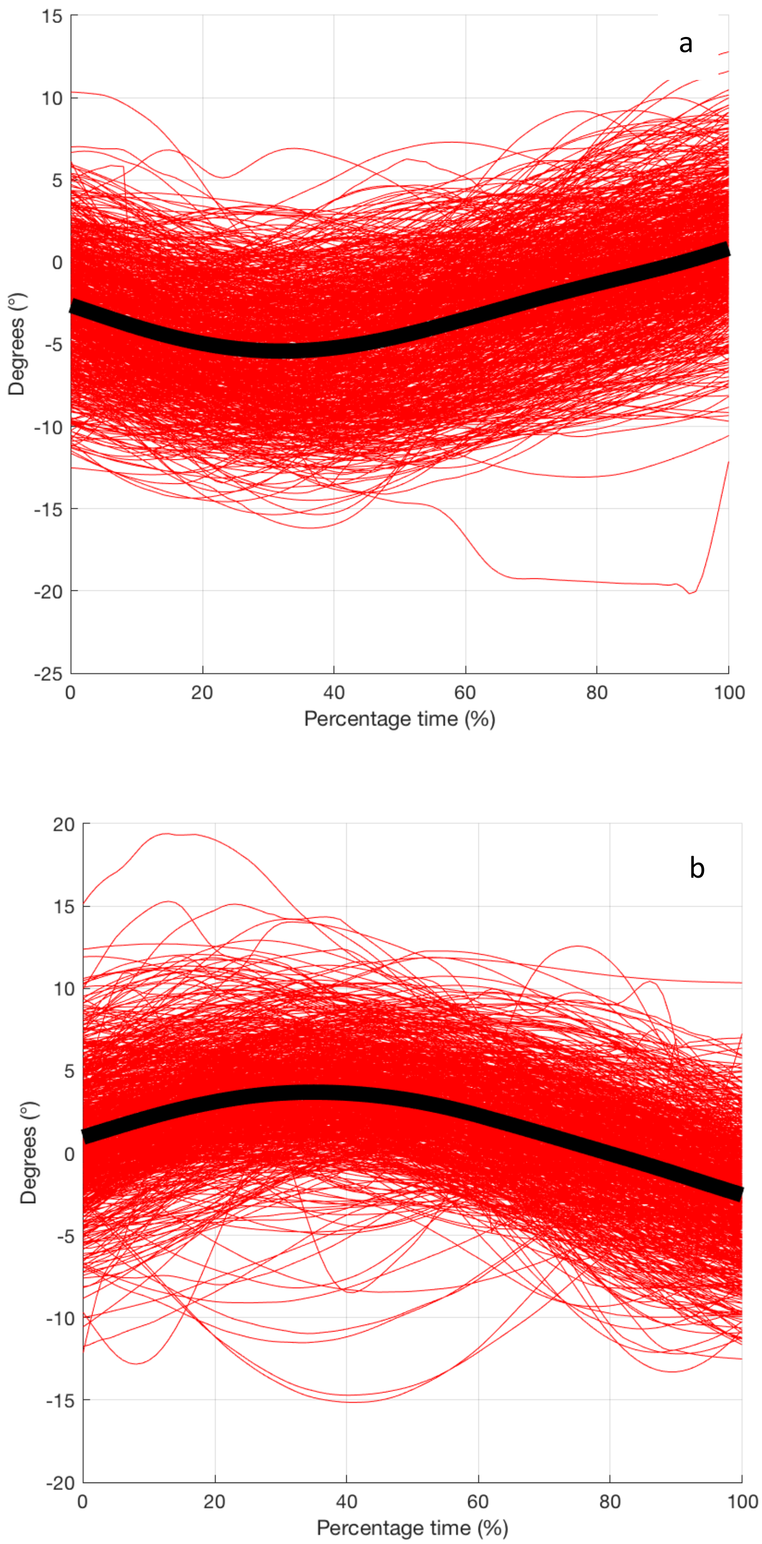
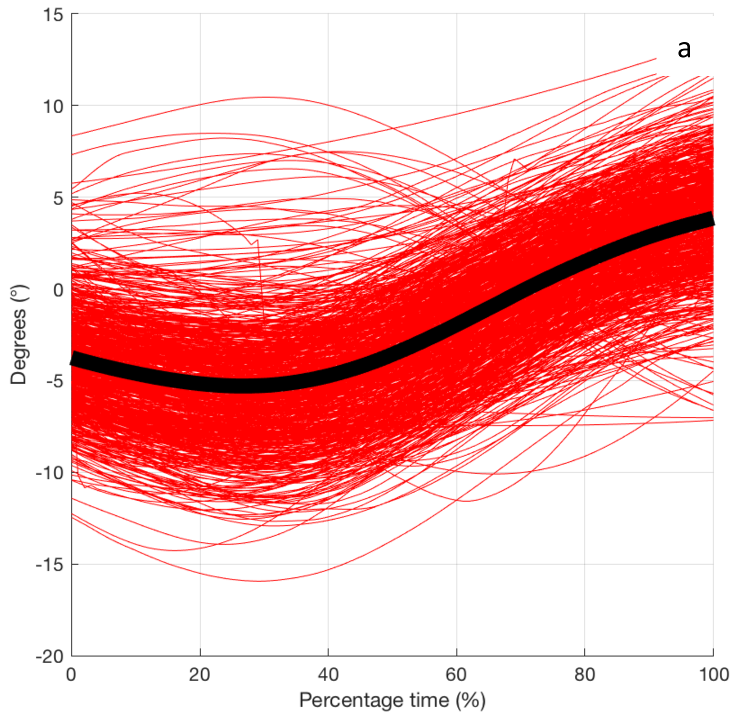


Figure 5.5a and b: Time normalised roll data for the left (a) and right (b) paddle strokes for all participants and all trials. The black line is the mean roll profile.



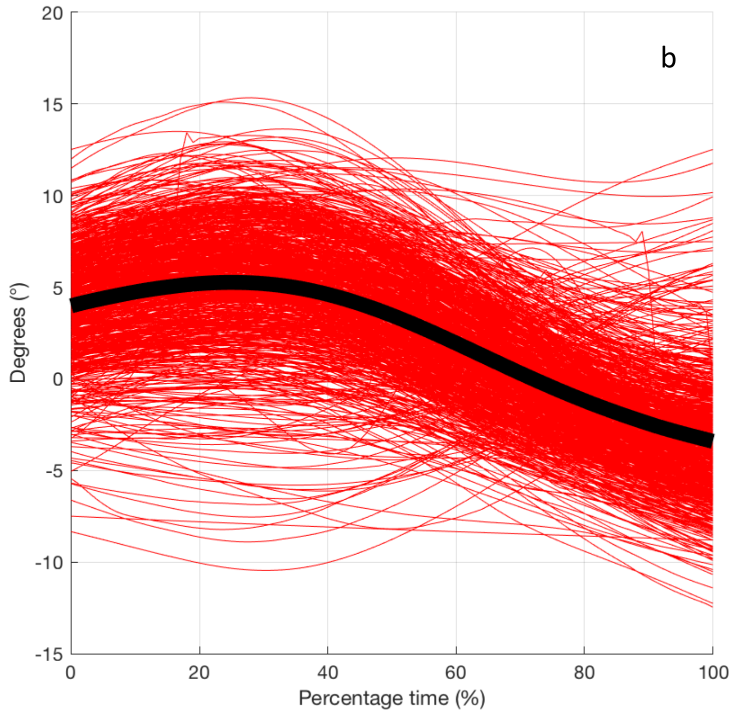


Figure 5.6a and b: Time normalised yaw data for the left (a) and right (b) paddle strokes for all participants and all trials. The black line is the mean roll profile.

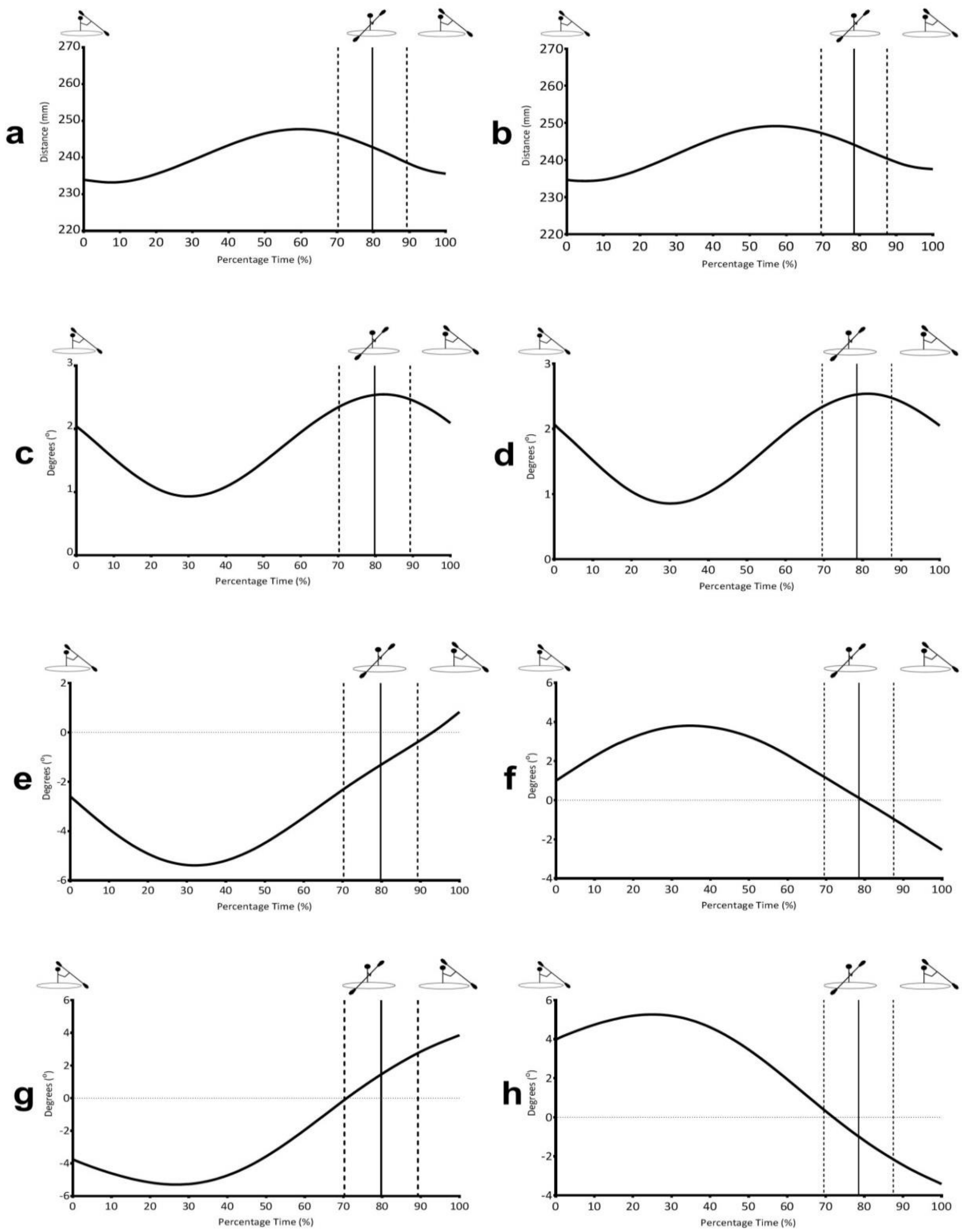


Figure 5.7: Mean profiles for each of the boat movements: heave for left paddle entry to right paddle entry (a) and right paddle entry to left paddle entry (b), pitch for left to right paddle entry (c) and right to left paddle entry (d), roll for left to right paddle entry (e) and right to left paddle entry (f), yaw for left to right paddle entry (g) and right to left paddle entry (h). The solid vertical black line indicates the mean percentage time of paddle exit to indicate the water and air phases. The dotted lines indicate 1 standard deviation either side of the mean.

The results presented within this section are of course subject to error from the 3D camera set up. As recognised within chapter 4 this error can creep into a system (Dabnichki et al., 1997) so cannot be ignored. Although the magnitude of the angles seen in this section are small, the magnitude is not the important point within an observational model which is instead looking at the shape of how the boat reacts in response to a stimulus, in this case a paddle stroke. However, as there is a known error of a maximum of 2.47mm within the system, indicated by the calibration data in section 5.2, it is important to note how much of these numbers could be due to error and how much are true measurement. Therefore using basic trigonometry, the distance that the boat would have travelled in millimetres if it had passed through the number of degrees measured was calculated. Table 5.3 shows that despite a maximum error of 2.47mm the number of millimetres the boat moved through was much larger than this indicating that although the error must be accounted for, even when the error was calculated at its maximum magnitude, these measurements are not wholly consumed by the error. Therefore they are true measures of movement and not a manifestation of system error. This should be considered especially when taking into account the fact that the magnitude is not important in this observational model, which is being utilised as a method of identifying a normal forwards paddling stroke pattern similar to a normal walking or running pattern is identified when looking at force plate data.

Table 5.3: Amount of movement of the boat in degrees and millimetres as well as the amount of movement in millimetres accounted for in the 2.47mm 3d camera system error.

	Number of degrees moved through		Number of mm moved through		% of mm accounted for by 2.47mm error	
	L	R	L	R	L	R
Heave			14.56	14.62	16.96	16.89
Pitch	1.61	1.69	50.74	53.26	4.87	4.64
Roll	6.25	6.25	25.04	25.04	9.86	9.86
Yaw	9.17	8.69	287.81	272.87	0.86	0.91

5.4 Observational model of white water kayaking boat kinematics – Discussion

The mean force profile for white water kayaking shown in Figure 5.2 has a single peak for both left and right paddle strokes at 44% of the way through the paddle stroke. This is similar to that identified by Aitken and Neal (1992) who normalised the strokes of a single paddler during a training session for sprint kayaking and also showed a uni-modal force curve reaching its maximum at around 45%. Aitken and Neal (1992) also showed similar patterns for the left and right strokes with the right stroke producing a higher output than the left, which is reflective of the findings of this study. The main difference in terms of the magnitude of the force produced was that the sprint paddler in Aitken and Neal's (1992) article produced peak forces of between 200N and 215N (dependent on hand used), it is assumed that this was with a winged paddle due to the diagrams within the paper although this is not specifically stated. However, the maximum force in the mean profile of the white water kayakers paddling with drag paddles was between 135N and 145N. Jackson (1995) calculated that the change between drag blades and wing blades would increase the efficiency from 74% to 89%. Consequently, it would be an unfair comparison to expect that the paddlers with the drag blades in this study would be able to produce the same forces as the paddler with winged blades who is also paddling a sprint boat that is designed to travel in a straight line. In comparison white water kayaks are shorter so that they can change direction more quickly (Ford, 1995; Whiting & Varette, 2004; Rosen, 2008) and therefore paddling them in a straight line is going to be less efficient. Another reason the magnitude of force production between the papers is an unfair comparison, is that all the paddlers in this doctoral thesis were female and in Aitken and Neal's (1992) paper it is unclear what gender the paddler is, although due to the largely male samples in most kayaking papers it is assumed that this paddler is also male. Finally, it is important to note that despite the figures presented here being smaller, on average, than those indicated in the Aitken and Neal (1992) work, some of the profiles presented in this thesis were much larger, with figures in excess of 350N for both left and right hands. Considering the afore mentioned points in terms of gender, boat size, and wing versus drag blades, it would be prudent to consider why there are some athletes producing forces some 150N more than those in the Aitken and Neal (1992) paper. This is due to novel work within this thesis. As stated within section 5.2, the bottom pull hand, which is the force data presented within Aitken and Neal's (1992) paper, was added to the top push hand to provide combined force data, something not possible in previous papers due to the limitations of using strain gauges as a data collection method. This combined data was presented in terms of time normalised to 100% utilising the bottom pull hand time. It is for this reason that on average neither hand start at 0N, the left hand starts at 32.21N on average and right starts on average at 28.74N indicating that the push hand is already active prior to the pull hand activating. This is novel in terms of understanding the interactions of the two hands when kayaking, due to the fact that previous papers have presented only the data for the bottom pull hand and therefore it was unknown how the two hands interacted previously.

In Baker's (1998) article it is suggested that there are two typical force profiles, either the more desirable uni-modal curve as seen in the mean force profiles of the white water kayakers or a bi-modal curve. He suggests that when seeing a bi-modal profile it is either due to flexion at the elbows or due to having an aggressive catch that the paddler cannot maintain. When kayaking with winged paddles the paddler tends to keep very straight arms so flexion at the elbow would reduce the force on the paddle. In the white water kayakers' mean force profile (Figure 5.2), it is clear that the curve has a small dip in it on the way up to the peak and also on the way down, although this is not by any means a bi-modal force curve, these changes in force could be as the paddle changes towards being vertical and then going past vertical. When paddling with drag blades in a white water kayak, the kayaker tries to get the paddle to travel as close to the boat as possible in order to reduce turning motions (Tipper, 2008) and the longer the paddle spends at vertical the more time the optimal force is generated for (Aitken & Neal, 1992; Mann & Kearney, 1980). Plagenhoef (1979) identified that with drag blades the paddle reached vertical between 20% and 26% of the way through the paddle stroke, similar to the area of the dip in the force in the white water kayakers' profile. Mann and Kearney (1980) had similar findings, identifying 23% of the way through the paddle stroke was the point the paddle reached vertical.

Baker (1998) stated that out of the two typical force profiles the uni-modal profile is the preferred curve. When looking at this single peak force curve in more detail, it was suggested that having a wider period across the top of the curve is preferable to a sharper peak as this indicates that the paddler is maintaining peak force for longer. Both of the examples provided by Baker (1998) show curves with considerably sharper peaks than that of the white water kayakers force profile, even the more desirable example presented. This suggests that the white water paddlers, although not necessarily producing the magnitude of force the sprint kayakers are producing, they are maintaining their peak force for longer.

The boat movement patterns identified also showed some interesting findings even once the error of the 3D camera system had been taken into account. When looking at the pitch of the kayak (Figure 5.7c and d) it is likely that the movement of the paddler's centre of gravity is what is causing the change in pitch. This is similar to the findings of Loschner et al. (2000) who indicated the change in pitch of a sculling boat was due to the athlete's weight transfer. The amount of movement in a sculling boat was found to be limited, with the mean at 0.2^{o} (Loschner et al., 2000). There was a wider range of motion in the mean pitch of the white water kayak which was found to be 1.62^{o} for the left paddle stroke and 1.69^{o} for the right paddle stroke. This is likely to be due to the fact that in a sculling boat the oars are simultaneously applying force to the water and the seat the rower is on slides in the boat whereas the kayak seat is fixed meaning the kayaker leans forwards when planting the paddle in the water. However the most likely reason for the difference in the pitch magnitudes between kayaking and rowing is due to the length of a sculling boat which is on average 8.2m (World Rowing, 2018), compared to the 2.31m-2.46m of the length of the white water kayak (Dagger Kayaks, 2018). This shorter length in the white water kayak will mean that the movement of the paddler's weight when planting the paddle and then during the stroke, will have a much larger impact on the boats pitch.

The roll seen within Loschner et al.'s (2000) paper was the largest of the three measurements taken in the sculling boats. The mean amount of roll was measured at 1.7^{o}. This was still considerably smaller than the mean roll witnessed within the white water kayaks, which was measured at 6.23^{o} during the left paddle stroke and 6.35^{o} in the right stroke. Loschner et al. (2000) reported that the roll started just post the catch of the oars in the scullers but did not give reasoning as to what caused this. In the kayak it is much clearer why the roll is so high as the kayaker puts the blades into the water unilaterally, meaning that the kayakers centre of gravity will not only move forwards, as we saw during the pitch, but also to the side the paddle is being placed into.

The yaw of the scullers was found to be very small with the average reported as 0.5^{o} (Loschner et al., 2000). This is very different to the white water kayakers whose mean yaw was 9.17^{o} on the left and 8.69^{o} on the right paddle stroke. With the scullers putting the oars in the water simultaneously on opposite sides of the boat, you would expect the yaw to be very little in these boats. It would have been interesting to identify whether there was a direction yaw was larger in and whether this was related to the favoured hand of the rowers, but this was not investigated in Loschner et al.'s (2000) paper. Loschner et al. (2000) equated the 0.5^{o} of movement in the yaw of the scullers to being 2.5cm of movement, in the kayak the 9.17^{o} of movement on the left paddle stroke equates to

38cm of movement at the bow or stern, and on the right stroke 8.69° of movement corresponds to 36cm. It is clear that the yaw of the kayak is much larger than the scullers. The main reasons for this are the unilateral paddle entry on the kayak promoting a turning motion, the much shorter length (Dagger Kayaks, 2018; World Rowing, 2018), and the hull shape of the kayak being designed to promote ease of change of direction (Ford, 1995; Whiting & Varette, 2004; Rosen, 2008).

The final boat movement measured in this observational model was heave. This was not a measurement taken by Loschner et al. (2000) which is interesting due to the fact that the waves created by this could result in lost energy and therefore reduced efficiency (Michael et al., 2009). Michael et al. (2009) emphasised its importance within kayaking research. The movement is small in the mean heave measurement taken within this kayaking study, indicating that the boats centre only moves up and down between 14.55mm and 14.81mm dependent on the hand used. This is considerably smaller than the distance moved within the pitch which was 67mm to 69mm dependent on the hand used. This indicates that the ends of the boat in kayaking are likely to have a larger movement than the centre of the boat due to the paddlers weight transfer when placing the paddle in the water.

The difference seen between mean left and right paddle strokes for the white water kayakers in this study was very little; 0.26mm for heave, 0.07° for pitch, 0.12° for roll and 0.48° for yaw. All the paddlers in the study were right handed and heave, pitch and roll all showed larger movements when paddling on the right side. This may be because of confidence the paddlers had in that side of the body when it came to reaching forwards and rotating the body (Tipper, 2008) thus increasing all three of these movements. However yaw was larger on the left, indicating that the kayakers may have had more control at minimising the most visual of all of these boat movements to the kayaker (Timms, 2008).

Due to this, some of the strokes the paddlers took within the study may have been strokes which were designed to control the turning motion or sweep strokes as they are known (Timms, 2006) and thus were not true forwards paddling strokes. If this were the case then they would exhibit a different boat movement pattern to that identified within this observational model, therefore it is important that these strokes are removed from an analysis only looking at the forwards paddling strokes. Hence, in the following chapter, the results presented have utilised the patterns obtained from this observational model in order to remove any strokes which did not follow the observed pattern of movements identified in this study.

This chapter intended to aid in the achievement of sub-aim 2: to utilise three-dimensional kinematics, and kinetics to determine female white water kayakers' paddle stroke technique and efficiency related to sitting height. It has done this by creating an observational model of both top and bottom hand combined force profiles as well as patterns of boat movements for the forwards paddle stroke. The learning from this chapter was taken into chapter 6 and aided the analysis of the results by allowing removal of all paddle strokes which did not follow a normal observational model.

6.0 Determining optimum sitting height

6.1 Determining optimum sitting height – Introduction

The history of the sport of kayaking explains why it remains a male dominated sport (Winning, 2002). Early male Inuits used kayaks to hunt in the arctic waters (Mattos, 2009) and then Rob Roy popularised kayaking as a recreational activity during Victorian times (Winning, 2002). This male dominated history has resulted in kayaks being made around male specifications in the present (Levesque, 2008a &b; Manchester, 2008). This means that in order to paddle these kayaks built for men, females adapt their boats in order to improve comfort (Manchester, 2008) and this sometimes also leads to an improvement in efficiency in terms of improving connectivity and therefore reducing unwanted movements of the craft, despite the fact that this is often not the goal of the adaptations (Ong et al., 2005). However, the difference between male and female anthropometrics is quite large, in fact even within females, differing populations have been found to be diverse. For example, Broomfield and Lauder (2015) identified that the female white water kayakers in their sample had a smaller sitting height than their female slalom counterparts. They went on to identify that this difference between female white water kayakers and female slalom kayakers indicated a much bigger difference between female and male white water paddlers. This can be also be assumed from the slalom paddlers in Ong et al.’s (2005) paper which showed further differences between female and male slalom paddlers, specifically males were taller and heavier than their female counterparts. This would also suggest that male white water kayakers would have further differences, when compared to female white water kayakers, than the female slalom kayakers; evidenced by the results presented within chapter 3 of this thesis which support the postulations that male white water kayakers exhibit different anthropometrics to female white water kayakers.

This large difference in males and females has meant that females are required to adapt their boats to fit them better, due to them being made based on male specifications (Levesque, 2008a & b; Manchester, 2008). The boats that females paddle are often too large for their smaller frames (Levesque, 2008a). This becomes a disadvantage meaning that in order to achieve full connectivity with the boats at the lumbar back, gluteal region, hips, thighs, knees and toes (Whiting & Varette, 2004) females need to adapt the boats otherwise they are not connected and thus have less control over the boat. This lack of connectivity means the female paddlers lose ability to change direction at speed as well as to apply propulsive forces to the boat (Ong et al., 2005). This means that efficiency is reduced due to excessive unwanted boat movements, resulting in less effective paddle strokes once the kayaker has tired due to this lack of efficiency.

One such suggestion of adapting the boat to improve connectivity and control is to introduce a seat raise into the kayak (Manchester, 2008) in order to enable the sitting height of the female paddlers to be more similar to male kayaker measurements (Ridge et al., 2007). This advice was investigated by Broomfield and Lauder (2015). They introduced a seat raise into the kayak based on a percentage (3.5%) of sitting height. This required sitting height was based on advice from Manchester (2008) that females should add in "one to one and a half inches" of seat raise. This then was calculated as a percentage of the average sitting height of the closest reference population of female slalom kayakers at 89.7cm (Ridge et al., 2007), 3.5% of 89.7cm was 3.14cm or 1.24inches, a value within Manchester's (2008) recommendations. So the seat raises introduced were 3.5% to the nearest 0.5cm of the sitting height of the participant.

Broomfield and Lauder (2015) went on to measure improvements in efficiency that this thesis has been adapted from, specifically looking at boat centre bouncing (heave), boat end bouncing (pitch), boat rocking (rolling), boat snaking (yaw). Their findings suggested that the introduction of a seat raise did show improvements, but that these differed for individuals. They suggested that this may be to do with an insufficient seat raise being used for some participants based on their anthropometrics. Chapter 3 of this doctoral work supports Broomfield and Lauder's (2015) postulations due to the findings that the average sitting height of the female white water kayakers was 75.82cm. When calculating 3.5% of this sitting height rather than the average slalom sitting height (the previously closest reference population) it only provides 2.65cm or 1.04inches of sitting height. This value is only just inside Manchester's (2008) recommendations. This learning from chapter 3 is why several different raises were introduced within this doctoral study to identify a method that would determine the most beneficial seat raise for technique.

In other studies looking into efficiency of equipment, timed efforts over a representative course has been utilised. For example, in the paper by Mason et al. (2012) a number of different wheelchair cambers were investigated in order to determine the best camber for mobility performance. In order to assess this, a number of tests were undertaken at each camber, these tests included a 20m sprint to assess initial acceleration as well as sprinting performance; a linear mobility test to assess acceleration, breaking and backwards pulling performance; and finally a maneuverability test which included an initial sprint, followed by a sharp turn and then a series of slalom movements. This maneuverability test was incorporated into the efficiency measures taken within this doctoral thesis in the way of the slalom test, in which sprinting, 90^o turns in both directions, as well as 360^o turns in both directions were incorporated. Both directions being included was important as Mason et al. (2012) indicated by them doing 2 tests in their wheelchair study, one with a right turn and one with a left turn and then averaged the times, indicating that some people may be better at turning in one direction than another.

The efficiency measures identified as being pertinent to this study included: surge or fluctuations in boat speed (Broomfield& Lauder, 2015; Barbosa et al., 2012); boat movements, specifically heave (Broomfield& Lauder, 2015; Lauder & Kemecsey, 1999), roll (Broomfield& Lauder, 2015; Kemecsey & Lauder, 1998; Loschner et al., 2000), pitch (Broomfield& Lauder, 2015; Lauder & Kemecsey, 1999) and yaw (Broomfield& Lauder, 2015; Lauder & Kemecsey, 1999); paddle reach (Broomfield& Lauder, 2015; Plagenhoef, 1979); stroke length (Broomfield& Lauder, 2015; Plagenhoef, 1979); force applied through the paddle to produce a consistent velocity of boat movement across trials (Gomes et al. 2015; Mononen & Viitasalo, 1995); slalom trials (Mason et al., 2012; Sterzing et al., 2009). In most instances a reduction in these measures would indicate an improvement in efficiency, however when looking at paddle reach and stroke length, an increase in these would show improved efficiency.

These measures of efficiency have not been investigated in previous works to identify whether any of these have a bigger impact on efficiency than the others. However, it was suggested within sculls rowing that yaw and roll have more of an impact on boat movements than pitch (Loschner et al., 2000; Wagner et al., 1993). This is a very different situation to kayaking due to the fact that when sculling both oars are presented to the water simultaneously, unlike in kayaking when each paddle is presented alone. This simultaneous presentation of oars in sculling will mean that rolling should be reduced, but if there is roll on the sculler then the oars will not contact the water simultaneously which will of course impact on the efficiency of the sculler. Due to this considerable difference in sculling to white water kayaking, it is not possible to carry this information forwards into this new sport and therefore, similarly to Loschner et al. (2000), all measures will initially be treated equally until known otherwise. Therefore overall it was difficult to determine whether any or some of these measures should be viewed as more important when creating a method for establishing the most beneficial seat height to be used and how much more important they should be seen as, indicating that until further information is available, all should be treated equally in white water kayaking. Alongside this lack of ability to weight measures is the fact that as a recreational sport, white water kayaking has no performance measure such as average velocity, which is a performance measure of other kayaking racing disciplines such as slalom and flat water kayaking and therefore the methodology required participants to travel at a constant boat speed. White water kayaking has been defined in this thesis as navigating rivers and descending white water rapids and therefore there is no speed factor involved in this. Instead, it is about the skill of achieving these goals safely and enjoyably, enabling the paddler to continue for long periods of time with little fatigue, achieved by paddling efficiently, ensuring that the kayaker is then able to deliver effective strokes when the environment requires. With no performance measure and no way of weighting the efficiency measures identified from previous literature all measures were treated equally in terms of their contribution to overall efficiency this means that the use of regression analysis and functional data analysis was rejected as discussed in section 2.6.

The work of Grehaigne et al. (1997) was therefore used as a method to look into the position or rank of the seat raises overall. Grehaigne et al. (1997) identified methods of assessing an individual's performance within a team sport setting. Their goal was to enable educators and coaches within sports to be better able to assess and develop individual athletes. Grehaigne et al. (1997) went through a process broadly used within the data analysis for this thesis using first a frequency count, followed by rating scales, followed by assessing both positive and negative actions and how they linked. There were differences between the work of Grehaigne et al (1997) and how this was utilised within this work, particularly around this interaction of positive and negative actions, due to there being no identified negative actions as such in this work. Instead it was identified that reduction of negative actions such as yaw and pitch (Kemecsey & Lauder, 1998; Broomfield and Lauder, 2015) is seen to indicate an improvement in efficiency for that seat raise. Thus, knowing how much of an impact on the efficiency this seat raise has had is important to being able to fully identify the seat raise which has had the biggest improvement in efficiency for all measures. Therefore the method of calculating the percentage difference was created in this doctoral work. From here novel ground was broached and the further methods identified extended the work of Grehaigne et al. (1997). Utilising these methods enabled efficiency measures to be identified for each participant and enabled them to be investigated holistically.

Therefore the aim of this chapter was to identify whether there were specific measures of efficiency which could be used to determine a method for establishing the most beneficial seat height to use.

In terms of the overall aim and sub aims of the thesis, this chapter intended to help towards delivery of sub-aim 2: to utilise three-dimensional kinematics, and kinetics to determine female white water kayakers' paddle stroke technique and efficiency related to sitting height. As well as deliver sub-aim 3: To identify the best method of determining optimum sitting height for female white water kayakers. This knowledge can then in turn be utilised to deliver the aim of the thesis: To utilise anthropometrics, three-dimensional kinematic and kinetic analysis of technique to identify a method for determining the optimum sitting height for female white water kayakers.

6.2 Determining optimum sitting height – Methodology

6.2.1 Sample

With institutional ethical approval by the University of Chichester, seven female participants (mean 38.86 years, SD 9.70) were recruited via conferences and talks to kayakers, social media requests and a snowball sampling strategy (Jones, 2015). The participants all had a minimum of 2 years' experience of white water kayaking on a variety of rivers and were all right handed. All participants were from the United Kingdom and were predominantly based in the south of the country.

6.2.2 Procedure

Prior to the participants' arrival at the test centre the Qualysis (Sweden) camera system was set up around the 25m swimming pool. An 8 camera system with 1 reference camera was utilised (Figure 5.1a, b and c).

A marker model had previously been set up in a laboratory using the Qualysis capture software (Qualysis Track Manager, V2.15) for a 9 point digitisation model with 7 markers on the boat (Figure 4.2) and a marker on each forearm.

Calibration of the Qualysis system using an "L" frame and a wand gave an error range of 1.34mm to 2.47mm.

Upon arrival at the testing venue participants were provided with a participant information sheet (Appendix C) and asked to sign their consent (Appendix D). After collecting demographic information, a part ISAK profile of 31 measures was collected by a Level 2 accredited ISAK anthropometrist. Measurements included were similar to those collected by Ridge et al. (2007): Body mass, stretch stature, sitting height, arm span, 8 skinfolds (triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh, medial calf), 7 girth measurements (arm flexed and tensed, chest, waist, gluteal, thigh (1cm distal from the gluteal line), thigh (mid trocanterion- tibale lateral), calf), 6 length measurements (upper arm, forearm, leg (to illiospinale), leg (to trochanterion), upper leg, lower leg) and 6 breadth measurements (shoulder, hip, chest (transverse), chest (anterior- posterior), humerus, femur). As with chapter 3, two measurements were taken on the right hand side of the body, the same Level 2 accredited ISAK anthropometrist collected the data and the TEMs were reported to be 1.99% for skinfolds and 0.17% for all other measurements, again within the acceptable error. The equipment utilised was the same as that for chapter 3 and ISAK protocols were followed throughout (Stewart et al., 2011).

The participant then chose the size of the kayak available (Dagger mamba in sizes 7.6 or 8.1 see Table 5.1 for specifications) based on their body mass and the boat they currently paddle.

The Power Meter Pro was then selected based on the length of shaft and size of blade which the participant was used to paddling with, and the Power Meter Pro was then set up to match their own current paddle, in terms of length of shaft and feather of the blades, this was accomplished by putting the two paddles together and adjusting to match. Three Power Meter Pros' were available with Adventure Technology (AT, USA) blades attached (Table 5.2). The Power Meter Pros' then underwent a zero offset procedure as recommended by the manufacturer (One Giant Leap, 2019). This involved laying the Power Meter on the floor with no force applied directly to either paddle. On the capture software the "calibrate" button was then clicked which then indicated success and a zero offset had been completed.

Participants then self-selected their maximum seat raise, determined by the amount of foam that could be fitted within the boat comfortably. The seat raises were then randomly selected as to the order of seat raise introduction. Each participant paddled with no seat raise (0cm) up to their maximum selected seat raise, at 1cm increments in a random order. The seat raises were made of high density closed cell polyethylene foam (Figure 6.1).

Figure 6.1: Foam seat raises used to raise the participant in the boat

These seat raises were selected due to a combination of reasons; Manchester (2008) suggested raising sitting height by 1-1.5inches or 2.54-3.81cm, therefore the measured seat raises fully incorporate this range of heights, however Broomfield and Lauder (2015) found that for the tallest participant in their sample, there was limited improvement seen when using a seat raise which had been determined by Manchester's (2008) suggestions, Broomfield and Lauder (2015) postulated that this was due to the seat raise being too much, therefore the measured seat raises in this doctoral study also included lower seat raises such as no seat raise, 1cm and 2cm. Finally in Broomfield and Lauder's (2015) study the shortest participant in the sample also showed limited improvement, the reasoning given behind this finding was that the seat raise was not enough to be fully representative of a male sitting height in the kayak. This can be seen when looking at Ridge et al.'s (2007) data, the difference between male and female slalom kayaker average sitting heights were 92.5cm and 89.7cm respectively, this is only a difference of 2.8cm indicating that the raise used in the study by Broomfield and Lauder (2015) should have been sufficient, but when looking to the range of heights in Ridge et al.'s (2007) data the lower end is 90.1cm for males and 84.7cm for females, a difference of 5.4cm. This indicates that the 1-1.5" or 2.54-3.81cm seat raise recommended by Manchester (2008) and used as a guide for the Broomfield and Lauder (2015) study may have not been a sufficient addition. Therefore there is a clear argument for a larger range of seat heights to have been introduced in this doctoral study when compared to previous work in order to account for shorter female paddlers.

Before data collection commenced, the body, boat and paddle markers were applied in the locations identified in Figures 4.2 and the forearms of the participant. The paddlers wore minimal clothing on their upper body such as a swimming costume with no spray deck, no buoyancy aid or helmet. The participant was given time to adjust the boat set up to fit them for comfort and to achieve the fit most similar to their own boat. Then a static trial was collected with 0cm seat raise by the participant sitting in the floating boat with their arms outstretched in the anatomical position with the paddle rested across the cockpit. The paddler then got into the boat and were given as much time as required in order to get comfortable with paddling the boat and the paddle. Once they had determined that they were happy with the boat, the first seat raise was installed and they then paddled from one end of the swimming pool towards the capture area at a self-selected comfortable speed, ending at the swimming pool flags which gave them a run-off. The capture length for Qualysis was set to 18 seconds at 100Hz and the Power Metre Pro was recording at 50Hz throughout the duration of the capture. The Power Metre Pro and the Qualysis system were not synced, however they were started at approximately the same time. Due to the force not being linked to individual strokes visible on the Qualysis system during analysis, syncing was not necessary. Five trials were recorded for each sitting height capturing a maximum of 8 paddle strokes. Once the five trials were completed the participant got out of the boat, a new seat raise was installed according to the random order selected at the beginning of testing and they were allowed to again adjust the boat set up and were given a self-selected habituation period. They then repeated the process for all seat raises.

6.2.2.1 Slalom test

In order to assess the different types of motion seen in white water kayaking a slalom course was also part of the assessment of efficiency, similar to previous studies assessing equipment efficiency in sports with changes in direction (Mason et al., 2012; Sterzing et al., 2009). Therefore, on a separate day of testing to ensure full recovery, each participant was timed, using a stop watch accurate to 100th of a second (Garmin, Kansas, USA), over a slalom course of approximately 100m (Figure 6.2). They did 3 trials at each seat raise introduced in the same random order and up to the self-selected maximum from the previous testing session. The slalom course included acceleration, deceleration, left and right hand turns, and full 360° turns in each direction. These are moves which are executed whilst paddling white water on a regular basis. The participants were given as much recovery time as needed between trials and indicated when they were ready to undertake the next trial.

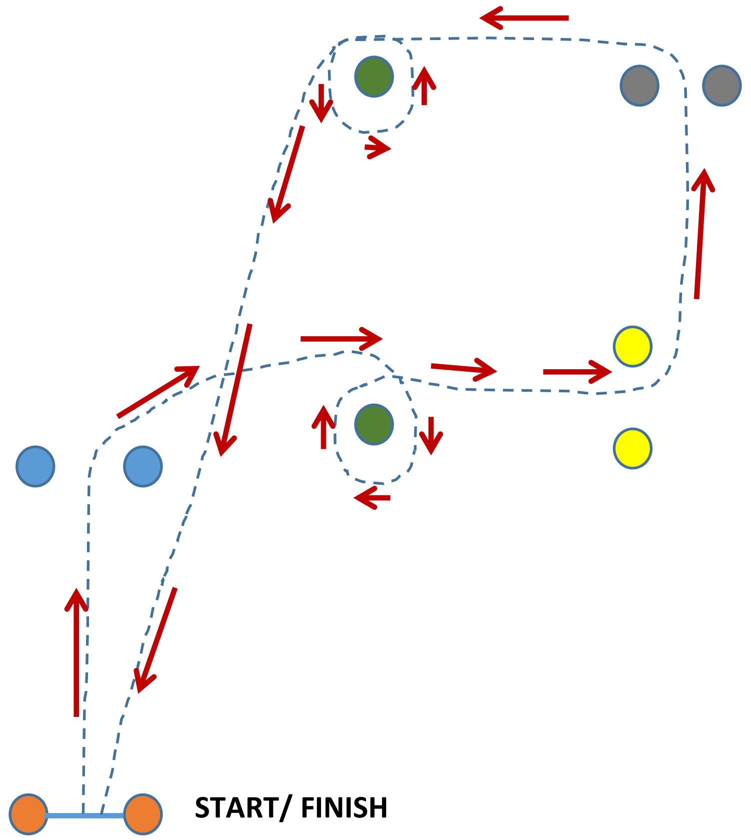


Figure 6.2: Slalom course

6.2.3 Analysis

Qualysis Track Manager (V2.17) was used to analyse the Qualysis data. The 47 point digitisation model was applied to the marker data and the capture time cropped to include the visible paddle stroke data. The filtered raw coordinate data in three dimensions were exported for all five trials for each sitting height. The data was smoothed using QTM's in built method for smoothing, by fitting to a 2nd degree curve with 11 frames in the filter window and gap filled. The number of strokes analysed per trial varied between 4 and 8 dependent on the participant and the clarity of the data as the boat entered the capture area.

The average velocity of the boat during each trial was calculated and these were checked to be within 5% of the overall average velocity for the individual as well as for the average velocity of the individual at that particular seat raise, any trials which did not meet these conditions were removed, there were a total of 2 trials removed for all participants at all seat raises. Each paddle stroke for each seat raise per participant was normalised to percentage of time and then they were compared to the observational model of a typical stroke for the boat movements identified in chapter 5. A visual inspection of the data allowed irregularities in the paddle strokes to be identified and removed, ensuring that the paddle strokes included in the method to determine the optimum sitting height were true forwards paddling strokes.

The measures then taken were as follows:

6.2.3.1 Technique measures

- The reach was measured by identifying the paddle when at its furthest point forward and measured between the forearm marker and the marker on the stern of the boat.
- Stroke length was calculated using the method identified by Sanders and Kendal (1992a) and McDonnell et al. (2013) by measuring the distance travelled by the

centre of the boat between entry of paddle one, through to entry of paddle two utilising the forearm marker.

- Consistency of boat velocity was calculated using the difference between the peak of velocity and trough of velocity during each paddle stroke.

6.2.3.2 Boat movements

The following boat movements were calculated in a manner adapted from Broomfield and Lauder (2015):

- Heave (centre bouncing) – at each time point throughout the sample, the vertical movement at the bow was added to the vertical movement at the stern, to provide the total boat movement in the vertical direction. A line graph of the results was plotted and a regression line added. The distance from the peak to the regression line was then added to the distance from the trough to the regression line for each heave.
- Pitch (end bouncing) – the angle of end bouncing was calculated by taking the bow position in the Z-direction (vertical plane) away from the stern position in the Z-direction, dividing this difference by the boat length. The inverse sine of this was then calculated. The difference between peak and trough in degrees was then calculated for each bounce, giving a total angle for the maximum deflection for each pitch phase.
- Roll (rocking) – The vertical movement (Z-direction) of the stern port marker minus the vertical movement of the stern starboard marker was calculated and

then divided by the boat width. The inverse sine of this was then calculated. The difference between peak and trough in degrees was then calculated for each roll, giving a total angle for the maximum deflection for each roll phase.

- Yaw (snaking) – this angle was calculated in a similar way to pitch except this time the movement at the bow and stern was in the Y-direction which was the lateral movement of the boat.

This information was added to the slalom data and the paddle force data. Then the most efficient measure for each of the factors was identified. These were identified by the lowest figures in the consistent velocity measure, force, slalom and the boat movements and the largest figures in reach and stroke length whilst considering the amount of variability seen by also measuring the standard deviation. Once the most efficient measures had been identified for each factor, a number of different methods were utilised to explore the data in order to determine whether a single or combination of efficiency measures could determine the most beneficial seat raise across all individuals. The individualistic nature of the data collected ascertained that no further statistical testing methods could be utilised. Instead, the focus was on identifying a method which could be used by kayakers to establish the most beneficial seat raise for their technique.

6.3 Determining optimum sitting height – Results

Each participant had a total of 13 efficiency measures taken; heave, pitch, rolling left , rolling right, yaw, consistency of boat velocity, slalom, reach left, reach right, stroke length left to right, stroke length right to left and average force of the left and right. All raw data and efficiency measure graphs can be found for all seven participants in Appendix E. As can be seen in these graphs and tables, there is a wide variety of sitting heights seen to be the most efficient across the measures taken.

The measures for each participant were first investigated at the individual level in order to see whether there were any clear measurements which were not contributing to the overall efficiency of the kayak movement and therefore could be removed from further analysis. However, the variety in the measures at the level indicated that none should be removed at this point. An example of this can be seen by looking at a comparison of participant 4 and 5, specifically for pitch (Figure 6.3).

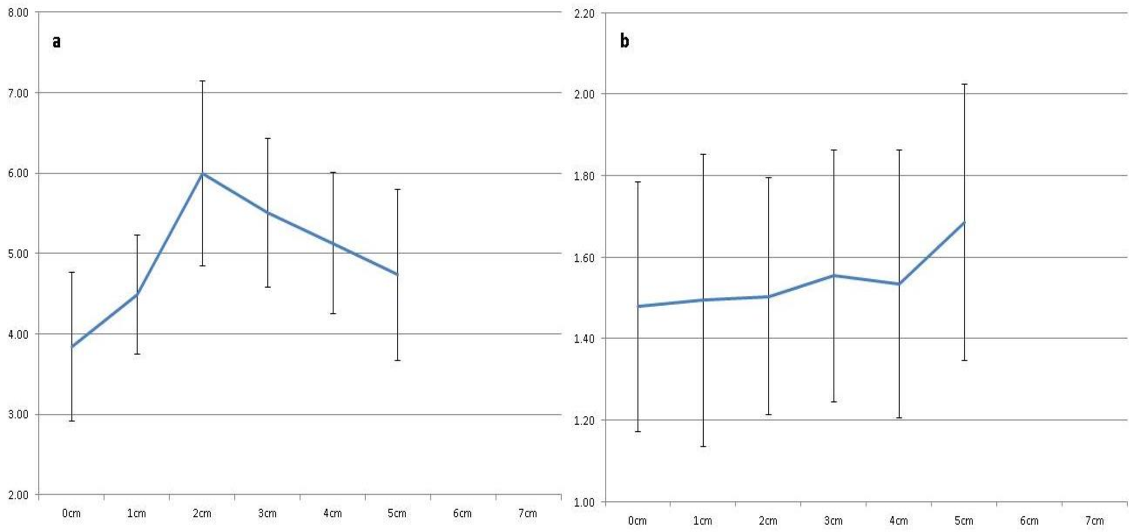


Figure 6.3: Graphs to show pitch for participant 4 (a) and participant 5 (b)

Figure 6.3 shows that pitch for participant 4 indicated that seat raise 0cm was most efficient, showing that pitch could have a clear contribution to boat movement efficiency. However, participant 5 showed no clear seat raise improvement for the same measure.

Another example comes when looking at heave comparing participants 6 and 7. Figure 6.4 shows that participant 6 showed limited differentiation in the seat raises when investigating heave. However participant 7 showed 3cm to be the most efficient seat raise with clear differentiation between the seat raises.

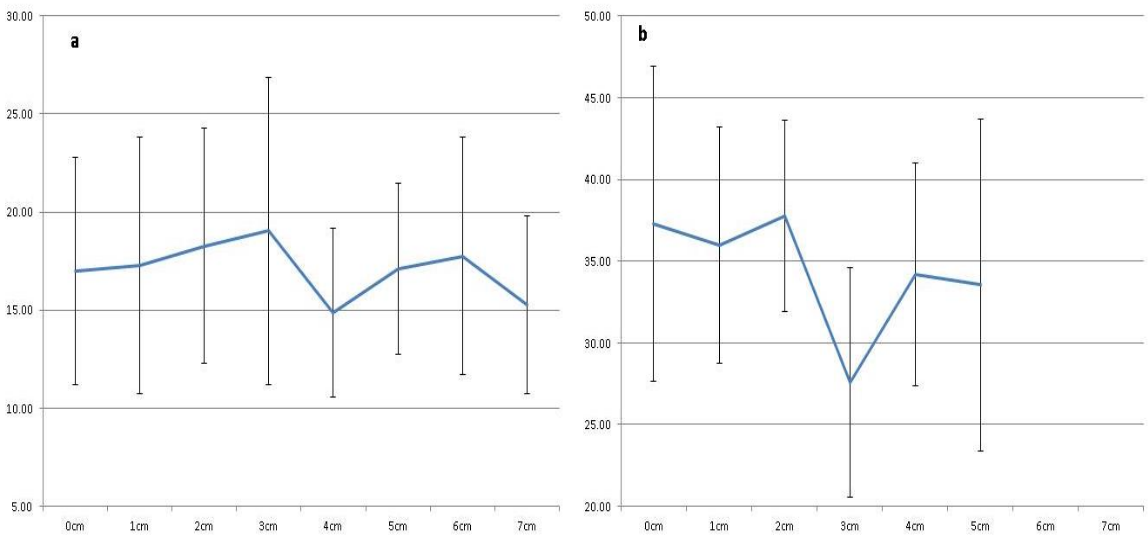


Figure 6.4: Graphs to show heave for participant 6 (a) and participant 7 (b)

As it is therefore clear that no efficiency measure alone is a strong predictor of which seat raise a kayaker should use. Thus when attempting to identify the most efficient seat raise for an individual it was important to consider all measures together rather than to remove any measures at this point. Once the individual's most beneficial seat raise has been identified, it is then important to then identify what individual anthropometrics may predict the most efficient seat raise, before finally working backwards to see if there are some efficiency measures which are more likely to predict the seat raise than others in order to reduce the number of efficiency measures used in future studies and to make the method created more accessible to kayakers and kayak clubs.

6.3.1 Identifying the most efficient seat raise

Initially, several methods have been investigated in order to determine which seat raise provided the most efficient outcome overall for each participant, these methods have been adapted from the discussion in the paper by Grehaigne, Godbout and Bouthier (1997), initially following the appropriate methods used and then extending these to include other measures more suited to this particular investigation.

In the first instance a simple frequency count was carried out for each seat raise which was ranked as most efficient for each measure (Table 6.1). For example, if for participant 1 in the heave measure seat raise 0cm was most efficient, 0cm was given a count of 1.

Table 6.1: Frequency of 1st ranked seat raise in each efficiency measure. X denotes a seat raise not attempted by this participant.

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
0cm	2	1	3	3	3	4	3
1cm	5	2	1	1	3	1	3
2cm	2	4	3	3	1	1	2
3cm	3	1	1	3	3	1	1
4cm	0	1	1	1	1	3	4
5cm	2	2	4	2	2	1	0
6cm	0	2	X	X	X	0	X
7cm	0	X	X	X	X	2	X
	1cm	2cm	5cm	0,2,3cm	0,1,3cm	0cm	4cm

Table 6.1 shows that there was limited detail within this frequency count method resulting in large numbers of seat raises recording the same number. Therefore the next step was to look at carrying out a frequency count of the first two ranked seat raises in each efficiency measure (Table 6.2). As can be seen from the numbers in Appendix E, there were negligible differences between some of the seat raises for some measures. Therefore ranking the top two seat raises could provide more differentiation between the seat raises when only small differences were seen overall, and was expected to give a more comprehensive result. An example in this case was, if for participant 1 in the heave measure 0cm was most efficient and 5cm was second most efficient, both 0cm and 5cm were given a count of 1.

Table 6.2: Frequency of 1st and 2nd ranked seat raise in each efficiency measure. X denotes a seat raise not attempted by this participant.

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
0cm	6	2	4	4	4	5	3
1cm	5	6	4	6	6	5	5
2cm	4	4	5	5	3	1	4
3cm	6	4	7	5	4	3	4
4cm	0	2	1	3	5	4	6
5cm	4	5	5	3	4	1	4
6cm	0	3	X	X	X	2	X
7cm	1	X	X	X	X	5	X
	0,3cm	1cm	3cm	1cm	1cm	0,1,7cm	4cm

The method presented in Table 6.2 still resulted in multiple sitting heights being ranked the same, furthermore for participants 1 and 6 multiple sitting heights were ranked as the most efficient. It was concluded that the frequency count method did not provide enough detail, so therefore a ranking system similar to team scoring in a sports event such as a cross-country race was created which included all seat raises across all efficiency measures. The scoring system gave each seat raise in each efficiency measure a score based on their position; the most efficient seat raise was scored as 1 and the second most efficient was scored 2 and so on and so forth. So for participant 1 in the heave measure, seat raise 0cm was given 1 point and seat raise 5cm was given 2 points and seat raise 7cm was given 3 points and so on until each seat raise was given a score. Then all the scores in each seat raise were added up and the lowest result indicated the most efficient seat raise (Table 6.3).

Table 6.3: Ranking scores for all seat raises in each efficiency measure. X denotes a seat raise not attempted by this participant.

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
0cm	51	53	44	42	47	44	43
1cm	49	35	54	39	39	55	42
2cm	59	51	41	47	46	76	47
3cm	50	52	39	47	45	68	54
4cm	69	66	57	51	42	48	42
5cm	54	51	38	47	52	67	45
6cm	73	51	X	X	X	64	X
7cm	63	X	X	X	X	46	X
	1cm	1cm	5cm	1cm	1cm	0cm	1,4cm

The method shown in Table 6.3 provides much greater detail in terms of determining the most efficient sitting height for each participant. Only participant 7 had more than one highest ranked seat raise and there was a reduction in the number of seat raises which were ranked equally. However, this method didn’t account for the earlier mentioned proximity of seat raises to each other within the measures. Therefore in Table 6.4 a percentage difference from the 1st place ranked sitting height for each subsequent sitting height was calculated and then all added together. For example, for participant 1 in the heave measure, seat raise 0cm was most efficient and given a score of 0, seat raise 5cm was 5.85% different so was given a score of 5.85 and seat raise 7cm was 14.71% different so was given this score. In this case the lowest score indicated the most efficient seat raise.

Table 6.4: Percentage difference score from the most efficient seat raise in each efficiency measure. X denotes a seat raise not attempted by this participant.

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
0cm	111.15	148.93	168.28	133.87	174.40	109.70	196.59
1cm	127.81	58.30	241.64	178.82	74.51	106.48	208.96
2cm	203.03	181.09	190.07	213.63	115.61	145.28	140.78
3cm	159.81	150.30	168.12	172.48	163.47	169.08	259.62
4cm	241.91	168.40	225.92	209.30	128.47	81.26	178.47
5cm	212.56	89.47	161.45	188.83	154.68	153.98	137.49
6cm	257.21	84.63	X	X	X	124.55	X
7cm	171.81	X	X	X	X	60.82	X
	0cm	1cm	5cm	0cm	1cm	7cm	5cm

Table 6.4 clearly shows greater differentiation between the seat raises with no two seat raises being ranked the same and in all cases the lowest scored seat raise shows considerable difference to the next best with the closest being for participant 7 with a difference of 3.29%. Despite the fact that this percentage difference method shows improvement, some of the efficiency measures have contributed more to the overall score than others. For example, for participant 1 arm reach on the right gives a maximum percentage difference of only 5.46%, whereas rolling to the right gives a maximum

percentage difference of 71.11% (Appendix F). In order to even up the contribution to the overall score, a percentile distribution method was used, by calculating the spread of the results across the whole of the range for each measure. Therefore the most efficient measure was still given 0, but the most inefficient measure was given 100 and the others were distributed between these two. For the participant 1 example in the heave measure, seat raise 0cm was most efficient and given a score of 0, seat raise 5cm was 8.26% along the range of the data spread and so was given a score of 8.26 and seat raise 7cm was 21.76% along the range and so was given this score. In this case the lowest score indicated the most efficient seat raise.

Table 6.5: The distribution of values across the total range, in the form of a percentile, from the most efficient seat raise in each efficiency measure. X denotes a seat raise not attempted by this participant.

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
0cm	512.83	611.89	655.11	678.80	695.91	481.58	570.59
1cm	479.33	356.03	838.42	639.74	482.23	644.01	606.76
2cm	619.08	620.89	634.62	683.81	608.40	925.92	682.38
3cm	450.65	710.60	546.99	676.08	564.64	809.55	861.00
4cm	781.88	855.05	956.02	823.09	633.56	454.85	668.39
5cm	608.90	596.96	568.92	701.05	740.58	787.90	649.66
6cm	830.77	663.76	X	X	X	728.24	X
7cm	726.73	X	X	X	X	450.98	X
	3cm	1cm	3cm	1cm	1cm	7cm	0cm

Similar to the percentage difference method, all of the participants in the percentile method had only one seat raise identified as the most efficient raise and there were still clear differences between all of the seat raises. All of the methods used up until now have not included the standard deviation in the calculation so there is no indication of the spread of the data from the mean calculated for each efficiency measure. Therefore the coefficient of variation (CoV) was calculated for each seat raise as this indicates the variability in relation to the sample mean. The lowest number indicated less variability and therefore was identified as the most efficient seat raise (Table 6.6).

Table 6.6: The coefficient of variation for all seat raises in each efficiency measure. X denotes a seat raise not attempted by this participant.

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
0cm	180.33	243.19	158.88	216.95	242.02	192.86	213.39
1cm	217.98	225.67	190.47	213.76	235.79	209.49	274.66
2cm	169.88	224.92	175.97	234.82	253.17	190.46	347.40
3cm	198.17	224.57	199.47	551.62	321.42	210.06	338.24
4cm	153.87	252.05	229.84	255.74	198.82	191.39	279.72
5cm	161.23	241.25	251.72	184.62	255.62	183.91	400.20
6cm	188.13	252.68	X	X	X	214.42	X
7cm	206.74	X	X	X	X	240.95	X
	4cm	3cm	0cm	5cm	4cm	5cm	0cm

Table 6.6 shows that the CoV has also given individual seat raises as the most efficient seat raise for each participant, similar to the percentage difference and percentile methods. However, the results give a different most efficient seat raise for all participants when compared to all of the previous methods, except for participant 7 which gave the same result as for the percentile method.

Due to this lack of consistency, another calculation utilising the mean was introduced. The standard error of the mean (SEM) identifies how far the mean of the sample deviates from the mean of the population. This method was calculated and displayed in Table 6.7, in this case a smaller deviation indicates a more efficient seat raise.

Table 6.7: The standard error of the mean for all seat raises in each efficiency measure. X denotes a seat raise not attempted by this participant.

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
0cm	89.05	87.33	147.14	125.95	86.36	93.71	139.14
1cm	145.93	83.34	156.43	110.68	85.94	91.39	133.24
2cm	68.66	114.94	135.08	98.91	96.67	65.98	163.73
3cm	165.39	100.08	237.55	227.84	86.86	108.66	181.52
4cm	88.91	115.76	303.66	125.01	82.93	76.04	244.12
5cm	93.79	95.98	210.23	97.58	69.88	82.16	171.27
6cm	159.64	102.00	X	X	X	102.71	X
7cm	97.38	X	X	X	X	95.66	X
	2cm	1cm	2cm	5cm	5cm	2cm	1cm

Table 6.7 shows again, one most efficient seat raise identified for each individual, however all except for participant 4 had a different most efficient seat raise when compared to the CoV. Interestingly, for the SEM method participants 2 and 7 had a most efficient seat raise that had been identified in the previous methods compared to only one participant for the CoV method.

The evolution of the most efficient seat raise for each method by participant can be seen in Table 6.8. All participants, except participants 1 and 6, have results which have stabilised over the 7 methods utilised. It is clear from the lack of stabilisation, particularly with participant 6 which has identified two very different seat raises as most efficient, that these methods, based on all the efficiency measures, have not given a full answer as to the most efficient seat raise. Therefore the first thing to reinvestigate is the efficiency measures used.

Table 6.8: Evolution of the most efficient seat height by participant for each method utilised

	Frequency of 1st ranked	Frequency of 1st or 2nd ranked	Ranking score	Percentage difference	Percentile	CoV	SEM	
PP1	1cm	0,3cm	1cm	0cm	3cm	4cm	2cm	**0,1,3**
PP2	2cm	1cm	1cm	1cm	1cm	3cm	1cm	**1**
PP3	5cm	3cm	5cm	5cm	3cm	0cm	2cm	**5**
PP4	0,2,3cm	1cm	1cm	0cm	1cm	5cm	5cm	**1**
PP5	0,1,3cm	1cm	1cm	1cm	1cm	4cm	5cm	**1**
PP6	0cm	0,1,7cm	0cm	7cm	7cm	5cm	2cm	**0,7**
PP7	4cm	4cm	1,4cm	5cm	0cm	0cm	1cm	**4**

The boat movements measured here have largely come from the flat water racing research in kayaking. Yaw, heave and pitch all clearly apply to the white water kayaking environment, in that an increase in any of these movements would result in increased hydrodynamic drag due to more hull exposure to the water and thus a reduction in efficiency. Roll however is a slightly different situation from the flat water racing world due to hull shape. A flat water racing kayak has a “U” shaped hull (Mackereth, 2008), the white water kayaks utilised in this doctoral study had planing hulls, which are flat. In a flat water racing kayak, a rolling movement means that the hull is not evenly exposed to the water, with one side in further than the other. However, in a white water kayak, a rolling movement actually creates a “U” shaped hull and can aid the boat with tracking in a straight line better (Figure 6.5). Therefore it is difficult to tell when the white water kayakers are rolling due to lack of control over the boat, or choosing to roll due to control over the boat and thus enabling a more “U” shaped hull and better straight line tracking. Therefore rolling has been removed from the results in this instance.

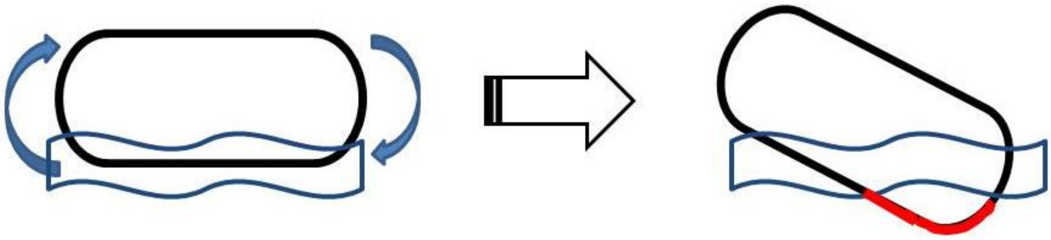


Figure 6.5: Indication of how a planing hulled white water kayak can create a "U" shaped hull whilst rolling

Table 6.9-6.15 have repeated the methods used previously, having rolling removed, with all of the results present that have been displayed in Tables 6.1-6.7. Table 6.9 and 6.10 have given more results for the most efficient seat raise for some participants when rolling has been removed. However similarly to when rolling was included in the results, by the time the percentage difference method is employed (Table 6.12) only one seat raise is indicated as being the most efficient for each participant.

Table 6.16 shows the evolution of the resulting most efficient seat raise for all participants. All participants, except participant 5, have results which have stabilised over the 7 methods utilised, this is an improvement on 2 participants who did not stabilise in the results which included rolling. It is clear that the 2 methods which most predict the resultant most efficient seat raise are the percentile measure and the ranking score method (Table 6.16), however the percentile method provides an individual seat raise for each individual rather than several which is found for some participants in the ranking score method. Therefore the percentile method is seen to be the best method to determine the most efficient seat raise.

Table 6.9: Frequency of 1st ranked seat raise in each efficiency measure except roll

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
0cm	1	1	2	3	3	3	3
1cm	4	0	1	0	2	1	3
2cm	2	4	3	2	1	0	1
3cm	3	1	1	3	3	1	1
4cm	0	1	1	1	0	3	3
5cm	1	2	3	2	2	1	0
6cm	0	2	X	X	X	0	X
7cm	0	X	X	X	X	2	X
	1cm	2cm	2,5cm	0,3cm	0,3cm	0,4cm	0,1,4cm

Table 6.10: Frequency of 1st and 2nd ranked seat raise in each efficiency measure except roll

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
0cm	5	2	3	4	4	4	3
1cm	4	4	3	5	4	4	4
2cm	3	4	4	4	2	0	3
3cm	5	4	7	4	4	3	4
4cm	0	1	1	3	4	4	5
5cm	4	4	4	2	4	1	3
6cm	0	3	X	X	X	2	X
7cm	1	X	X	X	X	4	X
	0,3cm	1,2,3,5 cm	3cm	1cm	0,1,3,4,5 cm	0,1,4,7 cm	4cm

Table 6.11: Ranking scores for all seat raises in each efficiency measure except roll

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
0cm	46	43	37	34	38	38	35
1cm	42	33	46	32	36	49	36
2cm	50	38	34	42	41	67	41
3cm	40	42	32	40	36	58	42
4cm	60	60	48	42	35	38	38
5cm	42	42	34	41	43	57	39
6cm	60	45	X	X	X	54	X
7cm	56	X	X	X	X	38	X
	3cm	1cm	3cm	1cm	4cm	0,4,7cm	0cm

Table 6.12: Percentage difference score from the most efficient seat raise in each efficiency measure except roll

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
0cm	68.75	87.27	100.82	91.69	69.47	59.55	80.15
1cm	76.73	58.30	132.86	149.67	44.61	72.19	113.15
2cm	131.85	92.13	83.01	194.05	64.80	106.75	91.03
3cm	78.14	91.40	71.57	137.24	65.63	123.18	99.87
4cm	166.09	141.57	118.76	164.79	49.41	32.45	100.77
5cm	92.38	58.16	116.60	170.10	65.13	106.26	92.62
6cm	146.98	57.52	X	X	X	67.19	X
7cm	104.09	X	X	X	X	34.74	X
	0cm	6cm	3cm	0cm	1cm	4cm	0cm

Table 6.13: The distribution of values across the total range, in the form of a percentile, from the most efficient seat raise in each efficiency measure except roll

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
0cm	455.52	488.60	555.11	554.57	573.67	381.58	452.41
1cm	417.15	356.03	700.70	539.74	455.61	577.78	518.85
2cm	520.17	423.06	498.33	635.36	560.86	822.22	606.65
3cm	338.77	581.07	433.58	581.53	466.04	706.49	661.00
4cm	679.77	805.58	823.30	698.96	533.56	349.46	603.44
5cm	440.13	493.62	522.30	646.05	652.04	688.65	586.75
6cm	676.13	600.13	X	X	X	610.91	X
7cm	646.53	X	X	X	X	382.86	X
	3cm	1cm	3cm	1cm	1cm	4cm	0cm

Table 6.14: The coefficient of variation for all seat raises in each efficiency measure except roll

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
0cm	130.75	160.24	119.71	171.94	131.31	156.20	140.64
1cm	157.79	165.43	129.19	161.52	143.53	168.26	129.65
2cm	114.84	158.27	139.40	164.87	131.33	155.32	153.79
3cm	148.26	166.51	155.83	485.37	226.89	155.50	167.30
4cm	100.84	188.57	196.71	172.02	121.98	151.50	119.39
5cm	117.98	197.69	154.71	127.67	128.03	146.72	134.98
6cm	126.44	170.64	X	X	X	171.70	X
7cm	119.91	X	X	X	X	178.27	X
	4cm	2cm	0cm	5cm	4cm	5cm	4cm

Table 6.15: The standard error of the mean for all seat raises in each efficiency measure except roll

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
0cm	88.52	85.49	146.06	125.02	85.28	92.88	138.00
1cm	145.21	82.48	154.00	109.49	85.22	90.51	131.22
2cm	67.82	113.60	133.67	97.20	95.78	65.32	162.03
3cm	164.64	98.87	236.18	226.67	85.62	107.43	178.50
4cm	88.15	114.71	302.46	122.86	81.97	75.17	241.89
5cm	93.00	95.35	207.87	96.42	68.73	81.26	168.96
6cm	158.72	100.78	X	X	X	101.67	X
7cm	96.41	X	X	X	X	94.30	X
	2cm	1cm	2cm	5cm	5cm	2cm	1cm

Table 6.16: Evolution of the most efficient seat height by participant for each method utilised except roll

	Frequency of 1st ranked	Frequency of 1st or 2nd ranked	Ranking score	Percentage difference	Percentile	CoV	SEM	result
PP1	1cm	0,3cm	3cm	0cm	3cm	4cm	2cm	**3**
PP2	2cm	1,2,3,5cm	1cm	6cm	1cm	2cm	1cm	**1**
PP3	2,5cm	3cm	3cm	3cm	3cm	0cm	2cm	**3**
PP4	0,3cm	1cm	1cm	0cm	1cm	5cm	5cm	**1**
PP5	0,3cm	0,1,3,4,5cm	4cm	1cm	1cm	4cm	5cm	**1,4**
PP6	0,4cm	0,1,4,7cm	0,4,7cm	4cm	4cm	5cm	2cm	**4**
PP7	0,1,4cm	4cm	0cm	0cm	0cm	4cm	1cm	**0**

As the percentile method most closely matches the resultant most efficient seat raise for each participant, it is suggested that this is the method utilised for calculating which is the most efficient seat raise.

6.3.2 Identifying the individual anthropometrics that predict the seat raise

Table 6.17 shows the anthropometric measures taken for each participant along with their most efficient seat raise as identified in section 6.3.1 above and using the percentile method. Looking initially at height, or stretch stature, the identified seat raises do not make much sense, participant 2, the shortest participant standing at 156.75cm, has one of the lowest recommended seat raise of 1cm. Participant 4 the second tallest participant standing at 167.90cm, however, has the same recommended seat raise. This pattern of results are similar when looking at sitting height alone as well, with participant 1 having the smallest sitting height and participant 4 this time having the tallest and yet still the same recommended seat raise.

Table 6.17: Anthropometrics of the seven participants and their recommended seat raise

		PP1	PP2	PP3	PP4	PP5	PP6	PP7
Most efficient seat raise		3cm	1cm	3cm	1cm	1 cm	4cm	0cm
Body mass	kg	45.85	65.3	89.75	64.55	60.35	57.6	89.5
Stretch stature	cm	163.35	156.75	158.15	167.9	163.5	161.95	169.6
Sitting height	cm	76.4	73.05	77.3	82.9	77.7	76.2	79.25
Arm Span	cm	163.3	161.4	153.4	165.7	163.5	162.45	172.55
Triceps sf	mm	10.9	22.6	35.2	20.2	20.4	12.2	27.8
Subscapular sf	mm	6.7	25.2	34.2	9.9	10.1	8.3	33.0
Biceps sf	mm	3.9	16.2	30.7	14.8	16.7	7.6	15.6
Iliac Crest sf	mm	7.8	36.4	25.0	12.4	15.1	12.4	24.6
Supraspinale sf	mm	4.8	18.6	24.9	8.1	7.1	7.0	22.4
Abdominal sf	mm	9.5	33.7	34.1	18.8	12.2	11.5	27.8
Front Thigh sf	mm	16.6	36.1	46.0	23.7	40.4	21.4	37.9
Medial Calf sf	mm	9.6	23.7	41.5	14.8	20.0	14.0	28.4
Sum of 6 SF	mm	58.0	159.9	215.9	95.3	110.0	74.4	177.2
Sum of 8 SF	mm	69.6	212.5	271.5	122.4	141.7	94.4	217.4
Arm girth relaxed	cm	23.0	31.6	37.6	29.5	29.4	27.9	36.3
Corrected arm girth	cm	19.6	24.5	26.5	23.2	23.0	24.1	27.5
Arm girth flexed and tensed	mm	23.6	30.2	36.5	29.2	29.8	28.3	34.2
Chest girth (mesosternale)	mm	78.6	95.6	101.9	88.8	85.2	84.9	109.4
Waist girth (min.)	mm	63.9	82.2	92.7	70.2	72.6	68.7	90.5
Gluteal girth (max.)	mm	87.2	103.8	119.0	101.4	98.5	95.3	114.1
Thigh girth (1 cm dist. glut. line)	mm	48.3	60.1	71.0	59.8	56.0	53.6	69.5
Thigh girth (mid tro-tib lat)	mm	42.4	52.5	66.3	53.1	50.9	48.9	62.0
Calf girth (max.)	mm	31.6	37.7	44.2	37.3	36.6	37.4	39.8
Corrected calf girth (max.)	cm	28.6	30.2	31.2	32.7	30.3	33.0	30.9
Acromiale-radiale	cm	30.5	30.1	28.3	30.5	31.4	30.4	32.7
Radiale-stylion	cm	24.8	23.1	21.5	25.0	23.3	23.9	24.4
Iliospinale height	cm	101.7	97.6	99.2	102.4	100.0	100.1	106.0
Trochanterion height	cm	91.6	87.6	86.6	94.3	89.9	92.7	96.8
Trochanterion-tibiale laterale	cm	38.1	34.6	37.1	41.2	36.2	40.0	42.8
Tibiale laterale height	cm	44.8	43.5	39.7	43.2	44.6	43.1	44.8
Biacromial breadth	cm	29.3	32.1	33.3	32.7	33.0	31.9	35.0
Biiliocristal breadth	cm	23.3	23.5	28.5	24.2	23.5	24.7	26.0
Transverse chest breadth	cm	20.5	22.4	26.1	22.5	21.0	20.5	27.6
A-P Chest depth	cm	9.3	12.4	15.5	12.3	13.5	11.5	15.7
Humerus breadth (biepicondylar)	cm	5.6	6.0	6.5	6.2	6.4	6.0	6.1
Femur breadth (biepicondylar)	cm	8.1	8.8	9.4	8.7	9.2	8.8	9.7

When looking at the ratio of sitting height to height (Table 6.18), this doesn't provide any further answer with participants 1,2,6,7 all having a ratio of 0.47, the same as the overall white water sample seen in chapter 2, and participant 5 having 0.48 and participants 3 and 4 having 0.49 suggesting a very slightly longer torso in relation to leg length than the other participants.

It would be expected that participant 2, a shorter participant with shorter sitting height, would be recommended a larger seat raise in order to be more reflective of their male peers, whom the boat is designed around. However a larger seat raise is most likely to impact upon paddle reach in terms of the technique measures taken as well as overall control in the boat movement measures, however if the arms already allow a longer reach then it is possible that a higher seat raise is not required. Therefore as height provides little in the way of explanation as to why these are the most efficient seat raises, other anthropometric measures may provide more answers. Coupled with the need to be able to reach the water and the artificial seat raise meaning the arms are further away from the water, the next aspect to investigate was arm length.

Table 6.18: Ratio of sitting height to height for each participant

		PP1	PP2	PP3	PP4	PP5	PP6	PP7
Stretch stature	cm	163.35	156.75	158.15	167.9	163.5	161.95	170
Sitting height	cm	76.4	73.05	77.3	82.9	77.7	76.2	79.3
ratio sitting height:height		0.47	0.47	0.49	0.49	0.48	0.47	0.47

Looking at arm span alone, this is reflective of the previous findings with height, with participant 2 having the second smallest arm span and participant 4 having the second largest. However the results of the upper arm measurements (acromiale-radiale) show a difference; participant 2 continues to have the second smallest upper arm length measurement of the participants, however participant 4 is now the equal 3rd longest, with very minimal differences between the 2 participants with only 0.4cm between them. However, when looking at the forearm length (radiale-stylion) participant 4 has returned to being the longest with participant 2 back to their original position of 2nd shortest. The similarities between the participants upper arm length, suggests that further investigation into the differences in the participants arm distribution is warranted. Therefore the first aspect to be investigated was the brachial index (ratio of the length of forearm to length of upper arm). This shows that participant 2 now has the fourth highest brachial index (76.74%) of the seven participants but participant 4 remains with the largest (Table 6.19).

Table 6.19: Investigation of arm measures for all seven participants

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
brachial index	81.31	76.74	75.97	81.97	74.20	78.62	74.62
ape index	1.00	1.03	0.97	0.99	1.00	1.00	1.02
actual arm length with hand	67.00	64.65	60.05	66.50	65.25	65.28	68.78
actual arm length no hand	55.3	53.2	49.8	55.5	54.7	54.3	57.1
actual arm length with hand: sitting height	87.70	88.50	77.68	80.22	83.98	85.66	86.78
actual arm length no hand: sitting height	72.38	72.83	64.42	66.95	70.40	71.26	72.05

Ape index was the next measure to be taken (Table 6.19) and this measure shows some interesting results with participant 2 having the largest arm span to height measure (1.03) of the seven participants and participant 4 in 6^{th} place (0.99). This provides a greater indication that arm length may be more of a factor than height alone in the efficiency measures recorded. This ape index was then further investigated to calculate actual arm length, this was done in two ways; firstly the following equation was used:

$$\text{Actual arm length with hand} = \frac{\text{arm span} - \text{biacromial breadth}}{2}$$

This allowed the hand measure to be included within the arm measurement, the second method simply added the upper and forearm measures together, but therefore removed the hand from the result. Both arm length measures gave similar results (Table 6.19), participant 2 had the second smallest arm length measures whereas participant 4 had the second or third longest arm length measure dependent on the measurement used. This was similar to the findings of the unadjusted height and arm length measures seen in Table 6.17 and therefore was as expected, however in order to identify how much of an impact this would have on ability to reach the water, a ratio of actual arm length to sitting height was calculated, using both the with hand result and without hand result, due to the hand only being partially included in the arm length when gripping a paddle. This now shows a big change between participants 2 and 4 with participant 2 having the largest ratio (88.50%) whereas participant 4 had the second smallest ratio (80.22%). This is also reflected in the ratio with no hand included. The indication from these two participants, with the same recommended seat raise, is that height or sitting height alone are not anthropometric predictors of recommended seat raise and that arm length to height or sitting height should also be included in the calculations. This also may indicate why in section 6.3.3 it can be seen that left arm reach is an efficiency measure that appears to predict seat raise.

The next area to investigate was why participant 1 and participant 3 are recommended the same seat raise of 3cm when anthropometrically they are very different (Table 6.17). Especially when looking at the arm measurements (Table 6.19), it is clear that participant 3 has smaller measurements than the other participants and therefore required a larger seat raise in order to allow an increase in reach. It should also be noted that her body mass is almost double that of participant 1 (Table 6.17) and therefore she will be sitting lower in the water. This indicates that body mass may also be a consideration when looking at the anthropometrics which may predict seat raise.

Beyond this there are many questions that are unable to be answered from these results such as why has participant 6 been recommended a seat raise of 4cm when her anthropometrics are not in the extremes and are moderate for most measurements (Table 6.17, 6.18, 6.19) and yet has the largest recommended seat raise. Despite interrogation of the anthropometric data in a number of ways, no patterns could be found which could explain the seat raise recommendations for all participants. Therefore, it must be concluded that anthropometrics alone cannot predict a seat raise recommendation. Although it can be understood from these results, that arm length and body mass as well as height and sitting height may have a part to play; these are not the only factors impacting upon a seat raise recommendation. The answer could possibly come from technique changes, which is out of scope for this doctoral study, but this postulation has been further discussed in section 6.4.

6.3.3 Predicting the seat raise from efficiency measures

In order to determine whether the seat raise recommended for each individual could be predicted from less efficiency measures, the efficiency measures were further interrogated in order to identify common measures that may predict the seat raise. Due to the individualistic nature of the data set it was not possible to use a regression analysis in this instance. Therefore, the previously identified percentile method was used to calculate the recommended seat raise for each participant, for each efficiency measure (except the previously removed rolling) as can be seen in Table 6.20. The percentiles for each efficiency measure were then added up and divided by the number of participants in order to calculate the mean percentile for each efficiency measure.

The measures that were worse than the 50th percentile were removed, this included heave, right arm reach and stroke length right to left. Then the percentile was recalculated for all seat raises for each individual to determine whether the remaining efficiency measures would still recommend the same seat raise as with all measures included. The remaining measures accurately predicted 100% of the seat raises which were recommended by all of the measures (Table 6.21).

Table 6.20: The percentiles for each participant for each efficiency measure for the recommended seat raise, utilised to calculate the overall percentile for each efficiency measure in order to use as few measures as possible to predict the seat raise.

	recommended seat raise	heave (mm)	Yaw (degrees)	Pitch (degrees)	velocity change	Slalom	Ave force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L	stroke length L-R
PP1	3cm	33.54	55.52	61.87	60.37	0	83.91	0	11.80	4.80	0	26.97
PP2	1cm	97.79	16.71	25.66	13.50	62.29	17.24	34.75	17.12	25.77	17.47	27.73
PP3	3cm	51.79	24.43	28.56	47.56	19.09	2.73	17.38	85.81	56.23	100	0
PP4	1cm	47.40	71.03	30.17	82.75	82.80	44.52	13.34	44.48	3.53	66.49	53.23
PP5	1cm	100	61.89	7.33	0	17.64	74.79	0	78.42	0.73	45.85	68.96
PP6	4cm	0	43.15	14.05	36.38	25.29	0	0	47.77	64.16	70.35	48.31
PP7	0cm	95.26	42.25	0	0	0	67.68	37.79	72.56	56.83	53.63	26.42
Total		425.77	314.97	167.64	240.56	207.11	290.88	103.27	357.95	212.05	353.79	251.61
mean percentile		60.82	45.00	23.95	34.37	29.59	41.55	14.75	51.14	30.29	50.54	35.94

Table 6.21: Seat raise prediction from percentiles for efficiency measures with rolling, heave, right arm reach and stroke length right to left removed; all above 50th percentile.

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
0cm	320.36	355.03	353.42	403.90	460.29	297.89	230.96
1cm	285.00	223.66	556.62	381.36	231.34	410.40	384.65
2cm	448.57	291.93	251.03	499.90	383.03	540.51	383.61
3cm	293.44	313.27	195.98	425.13	365.03	552.67	543.70
4cm	506.42	641.27	686.65	519.75	391.36	231.35	462.55
5cm	325.77	321.02	384.98	446.05	542.63	589.69	413.31
6cm	551.72	397.56				421.25	
7cm	444.11					289.03	

With 100% of the seat raises predicted by removing all measures over the 50th percentile, it was then decided to see if the number of measures needed to be recorded could be further reduced. Therefore, all measures which were above the 33rd percentile were included as this was the top third of the measures. Table 6.22 shows that participants 2 and 3 had now changed their predicted seat raises by 1cm, and therefore 71.43% of the participants have correctly predicted seat raises from just 4 measures: pitch, slalom, force left and left arm reach. Due to the reduction in the ability to predict the correct seat raises, it was decided to go between these two indicators of 50th and 33rd percentiles and therefore all measures above the 40th percentile were included (Table 6.23). This was now calculated from 6 measures: pitch, velocity change, slalom, force left, left arm reach and stroke length left-right. It is only participant 2 now who displays an incorrect prediction albeit by 2cm this time. This gives a correct predicted seat raise for 85.71% of the sample population.

Table 6.22: Seat raise prediction from percentiles for efficiency measures with rolling, heave, velocity change, force right, right arm reach, stroke length left to right and stroke length right to left removed; all above 33rd percentile.

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
0cm	140.91	199.40	105.09	214.70	90.96	164.21	94.62
1cm	185.00	148.47	203.23	129.84	25.70	193.10	224.37
2cm	205.23	121.45	100.08	248.27	84.28	224.78	209.19
3cm	66.67	123.03	121.26	177.46	214.90	253.76	245.23
4cm	255.66	340.85	371.74	285.45	121.65	103.51	203.69
5cm	223.74	196.18	183.96	243.14	388.36	252.93	240.98
6cm	330.17	260.03				261.01	
7cm	262.04					175.32	

Table 6.23: Seat raise prediction from percentiles for efficiency measures with rolling, heave, force right, right arm reach and stroke length right to left removed; all above 40th percentile.

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
0cm	228.21	215.36	199.13	377.41	286.44	210.57	121.04
1cm	285.00	189.71	356.62	265.82	94.66	234.09	316.65
2cm	248.57	214.43	188.26	377.78	262.61	375.64	339.86
3cm	154.01	158.94	168.82	277.46	299.02	384.46	427.80
4cm	349.42	485.81	523.90	426.71	277.31	188.20	362.55
5cm	231.03	239.05	299.61	338.16	519.03	413.26	321.31
6cm	376.83	364.26				364.56	
7cm	368.51					263.00	

The two measures not used in the 40th percentile measure which are in the 50th percentile are yaw and force right, it was decided to add back in force right because when instrumenting a paddle to measure the force on the left, the force on the right is no more difficult to collect and therefore there is no gain in leaving it out. Table 6.24 shows that with force right back in, 100% of the sample have their correct seat raise predicted again.

Table 6.24: Seat raise prediction from percentiles for efficiency measures with rolling, heave, right arm reach and stroke length right to left removed; all above 40th percentile plus force right.

	PP1	PP2	PP3	PP4	PP5	PP6	PP7
0cm	252.27	284.53	288.44	377.41	360.29	221.72	188.71
1cm	285.00	206.95	456.62	310.33	169.45	330.95	319.93
2cm	348.57	214.43	188.26	477.78	362.61	475.64	383.61
3cm	237.92	258.94	171.56	325.13	365.03	452.67	527.80
4cm	443.92	541.27	611.58	519.75	328.94	188.20	362.55
5cm	265.56	253.22	384.98	384.21	519.03	493.18	395.36
6cm	452.76	397.56				410.70	
7cm	406.10					289.03	

6.4 Determining optimum sitting height – Discussion

The results presented within chapter 3 of this doctoral work confirmed that the seat raises utilised in the chapter 6 study provided a good range of available seat raises which encompassed the mean sitting height difference seen within chapter 3. This difference ranged from 7.9cm between the smallest male and female to 8.7cm between the tallest male and female with the difference between the average male sitting height and average female sitting height at 6.93cm. This was far more than the difference seen in previous work, such as between male and female slalom kayakers sitting height (Ridge et al., 2007), which was on average 2.8cm different. It was also more than was seen between male and female normal population statistics which Pheasant (1996) reported to be 6cm different. This suggests that prior to collecting this important population data, boat manufacturers may have underestimated the sitting height adjustments required by female kayakers within a boat. This amount of adjustment is difficult in current boats as can be seen in the choice of the self-selected maximum sitting heights for the participants in this chapter, which ranged from 50mm to 70mm, a mean of 57.14mm (SD 9.57). This mean self-selected maximum seat raise did not reach the average difference in sitting heights of 69.3mm between male and female white water kayakers. The self-selected seat raises were chosen on the basis of the ability to fit the participant's legs into the boat comfortably, a method which Ong et al. (2005) identified many kayakers use to set up their boats with. Therefore, if it is uncomfortable, or in some cases not possible, to raise the seat higher, then regardless of any efficiency improvements which may be seen, kayakers will choose comfort over efficiency, especially in white water kayaking where the aim is to navigate rivers (BCU, 2014b). This navigation may take several hours (Schoen & Stano, 2002) and therefore comfort is a necessity rather than a luxury. Despite the fact that the sample in this chapter was not able to achieve an average sitting height of that suggested in chapter 3, none of the participants had their largest seat raise recommended to them as most efficient (Table 6.16), indicating that there were sufficient seat raises to go past efficiency and into inefficiency in their data. This was not the case however when the rolling data was included in the calculations (Table 6.8); participant 6 was recommended both her lowest and highest seat raise showing that the methods were not appropriate in their current format. This was why the impact of rolling on the results was considered a key finding of this chapter.

The literature regarding the boat movement reductions comes largely from the rowing and flat water kayaking literature (Kemecsey & Lauder, 1998; Lauder & Kemecsey, 1999; Loschner et al., 2000; Wagner et al., 1993). This has not been transferred into white water kayaking previously, where boats have a flat planing hull in comparison to the “U” shaped hulls in these sports. Loschner et al. (2000) and Wagner et al. (1993) identified yaw and roll as having more of an impact on boat movements than pitch. This is an interesting finding as it contradicts the findings of this doctoral research. Loschner et al. (2000), particularly, studied sculling in rowing where both oars are placed into the water simultaneously, and thus rolling movement should be reduced by this action. However, rolling movement in general would have an impact on the oars reaching the water simultaneously and therefore the impact of rolling in sculling would be large as Loschner et al. (2000) rightly acknowledged. The reason for these “U” shaped hulls in rowing and flat water kayaking is that having a “U” shaped hull aids with straight line tracking along with their additional length (Mackereth, 2008). The aim of these sports is travelling in a straight line either fast or for long periods of time so the boats have been designed to achieve this. However, a white water kayak which is designed to navigate rivers and descend white water rapids is required to be able to change direction at speed, hence its flat hull (Mackereth, 2008). However, when asked to paddle their white water kayak in a straight line and on flat water, the paddler may choose to roll the boat more in order to change their flat hull into more of a “U” shaped hull (Figure 6.5). Paddling in a straight line on flat water between rapids is a common exercise in white water kayaking and therefore this would not be an unusual decision for the kayakers. However, this is why it became difficult to identify those paddlers who were so connected and in control of the boat that they were able to choose to put their boat on edge, rolling, in order to help create a hull which was more able to track in a straight line, versus those who were not in control of the boat and therefore were rolling because they were unable to maintain a flat hull. From the data collected in this study, it is not possible to distinguish between these two types of rolls and therefore rolling was removed from the results giving a more consistent response for the participants, going from two participants who had more than one “most efficient” seat raise identified, to only one once rolling was removed.

Another key finding was that the anthropometrics of the participants were unable to predict the seat raise recommended alone, despite there being suggestions that both sitting height and arm length, as well as body mass may have had a part to play. The data that was collected and analysed gave clear recommendations of one seat raise which was most efficient, or optimum, for each participant, with participant 5 being the most unclear with even recommendations of 2 seat raises across the methods employed. The expectation was that the seat raise recommendations would be linked to height, or more likely sitting height, due the fact that this was the main anthropometric measure which was being manipulated by adding an artificial seat raise in to the kayak. After the chapter 3 results, this was further cemented as an expectation due to the much larger difference seen between the sitting height of male and female white water kayakers when compared to slalom kayakers (Ridge et al., 2007) and the normal population (Pheasant, 1996). Interestingly, the initial investigation of the participant anthropometry showed no link between the height alone and the seat raise recommended, with participant 2 being the shortest in terms of both height and sitting height and yet having one of the lowest recommended seat raises.

This lead to the investigation progressing from height to the arms, this was due to the findings of Broomfield and Lauder (2015) which suggested that the introduction of an artificial seat raise would move the naturally shorter female arm further away from the water. Therefore in order to reach the water, the kayaker would have to 'lean' further, impacting upon the movements of the kayak, specifically rolling. This investigation showed that Broomfield and Lauder (2015) were correct in their postulations and that arm length may have a large part to play in the identification of the most efficient seat raise for an individual, although not necessarily due to its impact on rolling. On first investigation of Table 6.17, the arm length measurements (acromiale- radiale and radiale-stylion) showed no real indication of them playing any larger part than height in the seat raise recommendation. However when looking into the brachial index (Table 6.19), which Norton et al. (1996) have suggested is advantageous for longer stroke lengths, there is an immediate indication that there may be more to the arm length being important to identifying an efficient seat raise for a kayaker. Participant 2 moved from having the second shortest arm span, upper arm and forearm measures to having the third longest brachial index. However the relationship between height and arm length is also important to investigate as seen with climbers, where having a larger ape index (arm span relative to stature; Watts et al., 2003) is important to their overall climbing ability due to the increased reach this provides. The results for the ape index in this doctoral research were also seen to suggest that this arm length and height relationship is important when determining the most efficient seat raise for kayakers, with participant 2 showing the largest ape index of all participants, perhaps providing an indication as to why their seat raise recommendation was so low despite being the shortest participant in the group. Watts et al. (2003) also suggested that when looking to the arm span that the amount made up by the shoulder breadth or biacromial breadth was also important, a smaller biacromial breadth to arm span would mean that more of the arm span was made up of arm length and therefore increasing reach. This therefore lead to the actual arm length being calculated for the participants of this study by removing the biacromial breadth from the arm span and then dividing by two to give one single arm length. As can be seen for participant 2 in Table 6.19, despite the largest ape index, they still had the second smallest actual arm length. However, the ape index is relative to height as Watts et al. (2003) see this as being important within the sport of climbing to increase reach, therefore for kayakers the calculated actual arm length from the arm span, was then presented as a ratio of sitting height. This is because instead of overall arm span relative to overall stature being important as it is in climbing, in kayaking the equivalent would be actual arm length relative to sitting height because it is the reach of one arm only that is important and the kayaker is sitting down. When looking at the findings for this particular measure, participant 2 had one of the smallest recommended seat raise and had the largest actual arm length relative to sitting height despite being the shortest participant in terms of sitting height overall. However, participant 6 had the largest recommended seat raise and, as with the other measures, she is very much moderate in her arm length relative to sitting height, not being in either extreme. This means that although there is clear indication that arm length, particularly in relation to sitting height, could give some insight into what seat raise should be recommended over and above the sitting height alone, there is no coherent pattern that can be followed in this instance.

Drag can also be impacted upon by body mass as identified by Gomes et al. (2015a) who recognised that regardless of the size of kayak a paddler is kayaking; the larger the mass of the kayaker causes an increase in passive drag on the hull. It is interesting when looking at the mass of the participants (Table 6.17) that the two lighter participants (1 and 6) are recommended the larger seat raises. This would indicate that less of the hull is engaged in the water already for these participants and that they are already, therefore sitting higher in the water, furthermore meaning that passive drag is reduced when compared to the other participants. This suggested that body mass may have a part to play when using anthropometrics to predict the seat raise, although its exact contribution cannot be described empirically. This is due to the fact that participant 1 the lightest participant, has been recommended a seat raise of 3cm which is the same as participant 3, the heaviest participant. This means that although there are patterns beginning to emerge, it is not anthropometrics alone that are able to predict the seat raise for an individual and therefore technique differences beyond the stroke technique may have a part to play alongside the anthropometrics, but this is outside of the scope of this doctoral study and is a potential area for future investigation.

The final finding from this study was that the thirteen efficiency measures identified at the start of this thesis; fluctuations in boat speed (Barbosa et al., 2012); boat movements, specifically heave (Lauder & Kemecsey, 1999), roll to left and right (Kemecsey & Lauder, 1998; Loschner et al., 2000), pitch (Lauder & Kemecsey, 1999) and yaw (Lauder & Kemecsey, 1999); paddle reach on the left and right (Plagenhoef, 1979); stroke length right to left and left to right (Plagenhoef, 1979); force applied through the paddle on the left and right to produce a consistent velocity of boat movement across trials (Gomes et al. 2015; Mononen & Viitasalo, 1995); and slalom trials (Mason et al., 2012; Sterzing et al., 2009) could be reduced. The results indicated that just seven efficiency measures were able to predict the recommended seat raise for all participants in the sample; pitch, velocity change, slalom, force for both left and right, left arm reach, and stroke length left to right. This finding contradicts the rowing literature which stated that yaw and roll had a bigger impact on boat movement than pitch (Loschner et al., 2000; Wagner et al., 1993). Pitch has been identified here as being more important than both yaw and roll in terms of identifying the optimum seat raise.

It is not surprising that slalom has been found to be a measure that should be included to aid prediction of the most efficient seat raise as this has been used as a measure of efficiency for other sports where change of direction is paramount such as Mason et al.'s (2012) study into wheelchair cambers.

The velocity change, or surge in sailing terms (Fossati, 2009), has been shown to be important in swimming (Barbosa et al., 2012). This is also a cyclical watersport which was shown to have similarities in terms of participant anthropometrics to kayaking as discussed in section 2.3, so it is not surprising that it has been identified as important for kayaking too. Similar to swimming, Kendal and Sanders (1992) discussed a lag in application of force between one paddle leaving the water and the next entering it, resulting in a deceleration in the boat. This also links to why force is important in predicting the optimum seat height, the application of force and subsequent lag is what is causing the surge, but Mononen and Viitasalo (1995) found that there was a high correlation between mean velocity and mean paddle force, indicating why force would be included in the seven predicting measures along with velocity change. Aitken and Neal (1992) and Sturm et al. (2010) found there was a disparity in the force between left and right strokes showing the importance of looking at a full stroke cycle when identifying force characteristics, hence why both left and right average force have been identified as being included in the seven efficiency measures to predict optimum seat height. The most surprising finding in the seven measures was that it was left arm reach and stroke length left to right that have been identified as being predictors rather than the right side. This is surprising due to the fact that all participants were right handed and it would be interesting to determine whether the importance of the non-dominant out strips the dominant hand in a sample of mixed handed kayakers, or whether a similar finding would be found in other cyclical water sports such as swimming.

The findings in this chapter have enabled successful completion of sub-aim 2: To utilise three-dimensional kinematics, and kinetics to determine female white water kayakers' paddle stroke technique and efficiency related to sitting height, by establishing the most efficient seat raise for each participant by identifying a combined reduction in unwanted movements around the 6 degrees of freedom of the craft. Alongside this delivery of sub-aim 3 was achieved: To identify the best method of determining optimum sitting height for female white water kayakers. The findings have also made a large contribution to achieving the aim of this doctoral study, along with those from chapters 3, 4 and 5. The achievement of the overall aim will be discussed in chapter 7.

7.0 Discussion

7.1 General Discussion

The aim of this doctoral thesis was to utilise anthropometrics, three-dimensional kinematic and kinetic analysis of technique to identify a method for determining the optimum sitting height for female white water kayakers. The methods to determine the most efficient seat raise used in this work, have not been previously achieved in published works. This is due to the limited empirical investigations into efficiency outcomes caused by equipment changes which have been attempted within this work.

Lauder (2008) identified that little analysis of white water kayaking has taken place. This lack of previous work had meant that it was not possible to identify whether the female paddlers strokes in chapter 6 followed a normal pattern for forwards paddling. Therefore chapter 5 collated a large number of strokes and identified the normal pattern of movement for force and each of the boat movements. This has not been attempted before for white water kayaking, and most kayaking research in general has looked at the body positions whilst kayaking (Brown, 2009; Mann & Kearney, 1980; Plagenhoef, 1979), but has not taken this to the next step of identifying how the body movements impact upon the boat movements. This ensured that all strokes included within the numbers used to identify the optimum sitting height had resulted in a normal pattern of boat movement and therefore were a normal forwards paddling stroke rather than a turning or other stroke.

Due to a lack of previous works in the area, similar efficiency investigations in other fields were sought in order to determine the best methods to use. Previous studies looking into efficiencies of systems have used panels of experts in order for their subjective opinion to be used to determine whether one system is more efficient than another (Sherman, 1984; Triantafillou, Pomportsis & Demetriadis, 2003). In this case a subjective opinion would not result in the deeper understanding of the impact the individual efficiency measures had on the overall recommendation of the optimum seat raise and therefore it was decided to look into the position or rank of the seat raises overall. The methods used, initially, followed a broadly similar pattern to the discussion had by Grehaigne et al. (1997) when identifying methods of assessing an individual's performance within a team sport setting. Their goal was to enable educators and coaches within sports to be better able to assess and develop individual athletes. Grehaigne et al. (1997) identified that frequency measures were used, albeit more often by coaches than teachers, in order to record how many times an athlete carried out a specific event such as how many times a shot was taken (Grehaigne et al., 1997). Therefore in this doctoral work a frequency count of the number of times a seat raise was the most efficient in each measure was taken and then the same again with the first and second most efficient seat raises due to the negligible differences between some of the efficiency measures (Tables 6.9 and 6.10, Appendix F). As was identified by Grehaigne et al. (1997), this frequency count did not provide enough detail. In Grehaigne et al.'s (1997) paper they identified that a frequency count of events in a sports match did not give any detail as to whether they were a result of technique or tactics or a combination of the two and therefore more detailed methods of individual assessment were required. Although in a different field, it was clear that detail was lacking in the results of the frequency method in this doctoral work. A large number of seat raises were given the same efficiency position suggesting that more detailed assessment needed to be carried out.

Grehaigne et al. (1997) went on to discuss how Pinheiro (1994) produced a method of using rating scales to assess the quality of motor skills in a variety of environments including sports. This was the next method adopted within this doctoral work. The ranking method utilised, followed a similar process to scoring team positions in sports events, such as cross-country races. This provided a more detailed result in terms of identifying the most efficient seat raise, but as ranking only provided ordinal data, it did not take into account the within-efficiency measure situation. This means that there was no indication of the gaps between the ranks and whether some efficiency measures were very similar within their ranks and the numbers were close together, whereas others gave a wider spread of data and therefore the gaps between the ranking positions were larger. This leads onto the next area of investigation of the efficiency measures, however the discussion in the Grehaigne et al. (1997) paper begins to differ at this point, they were interested in the impact positive and negative actions had on an overall efficiency score by dividing the results of the positive actions such as a successful shot by the results of the negative actions such as lost balls. However, this type of scoring method is not possible with the efficiency measures in this study, due to there being no identified negative actions as such. Identifying the reduction of the negative actions such as yaw and pitch (Kemecsey & Lauder, 1998) is seen to indicate an improvement in efficiency for that seat raise. Thus, knowing how much of an impact on the efficiency this seat raise has had is important to being able to fully identify the seat raise which has had the biggest improvement in efficiency for all measures. This was why the method of calculating the percentage difference was created (Table 6.12, Appendix F). This method presented a larger differentiation in the results for the seat raises and gave a clear overall most efficient seat raise recommendation for each participant.

This is where the methods employed leave the Grehaigne et al. (1997) paper and move into areas not previously explored. It was clear from the percentage difference method that this was an improvement on the previous frequency and ranking scores employed, however some efficiency measures were more heavily weighted upon the results than others. For example, slalom contributed a maximum score in the single figures for all participants, to the sum of all the percentage differences for all measures at each seat raise (Appendix F). However, heave was quite comfortably within the double figures for all participants, and had a score of up to 53.5% different to the optimum seat raise for some participants for some seat raises. This shows that not all efficiency measures were equally contributing to the overall score and with no indication of which measures should contribute more to the overall measures due to the novelty of this doctoral study, it was decided they should all contribute equally at this point. Therefore a percentile method was utilised (Table 6.13), where the most efficient seat raise for each efficiency measure was awarded a score of 0 and the most inefficient seat raise was scored 100 and all others were distributed equally along this scale according to how far away they were from the 0 rated measure (Field, 2013, Appendix F). This method was used by Emery and Tyreman

(2009) in order to identify the distribution of sports injuries across the body mass index percentiles of their sample. They used the percentile method to identify how the sample was distributed equally across the range of body mass indexes, in the same way this method has been utilised within this study, to give a spread of the data equally across 100 for each efficiency measure. This also gave a clear one answer response for each participant, four of these had not changed from the previous percentage difference method, however three showed some considerably different responses (Table 6.16).

An aspect not considered in any of the previous methods was the spread of the data, a larger standard deviation from the mean indicates that the data has a larger spread within each measure. The percentile method accounted for the spread of the data as a whole, but not the standard deviations, therefore the CoV was measured. This indicates the variability in relation to the sample mean and allows comparisons of the spread of the data between data sets even though the means are different. This gave a set of individual recommended seat raises for each participant but they were very different to those which had been recommended previously. And therefore another measure of SEM was calculated, this also incorporates the spread of the data but identifies how far the mean of the sample deviates from the mean of the population (Field, 2013). This gave different results again, although these were closer to the percentile method than the CoV. Finally, the recommended seat raise across all of the methods utilised were collated in Table 6.16. It was clear from this collation, that the percentile method was the method that provided this most commonly recommended seat raise. Therefore it was recommended that when measuring efficiency across different equipment adaptations, in this case determining the optimum sitting height, that use of the percentile method would be the best way of calculating the most efficient adaptation when faced with a number of different possible adaptations.

This method was then taken further and utilised to identify whether less efficiency measures could be used to predict the recommended seat raise. At the start of this thesis, there were 13 recognised methods of measuring efficiency in kayaking: fluctuations in boat speed (Barbosa et al., 2012; Janura et al., 2005)); boat movements, specifically heave (Lauder & Kemecsey, 1999), roll to the left and to the right (Kemecsey & Lauder, 1998; Loschner et al., 2000), pitch (Lauder & Kemecsey, 1999) and yaw (Lauder & Kemecsey, 1999); paddle reach on the left and right (Plagenhoef, 1979); stroke length left to right and right to left (Plagenhoef, 1979); magnitude of force on the left and right applied through the paddle to produce a consistent velocity of boat movement across trials (Gomes et al. 2015; Mononen & Viitasalo, 1995); slalom trials (Mason et al., 2012; Sterzing et al., 2009). In section 6.4 it was discussed that reduction in rolling was not a comprehensive measure of efficiency and therefore it should be removed from the measures. This was due to the fact that the information that indicated rolling, along with yaw, was more impactful on boat movements than pitch (Loschner et al., 2000; Wagner et al., 1993), came from rowing data, particularly sculling. In rowing, the boat hulls are "U" shaped and the oars are inserted into the water simultaneously. This is contrary to white water kayaking where the boats have planing hulls and paddles are inserted consecutively. And therefore, it was determined rolling could be both a sign of lack of control of the boat, or of control over the boat. Choosing to roll when in control would achieve more of a “U” shaped hull, similar to that seen in rowing and flat water kayak racing in which the kayak is designed to track in a straight line. Therefore when determining the optimum sitting height for female white water kayakers, rolling should not be included as one of the efficiency measures.

In chapter 6 it was also identified that the number of efficiency measures required to be able to predict the optimum seat raise could be reduced to just 7 measures; pitch, velocity change, slalom, force left, force right, left arm reach and stroke length left to right. When it comes to identifying a method to determine the optimum sitting height, this finding was both key and also useful in terms of enabling participants’ of the sport to be able to replicate the findings. The methods used in this study were investigated and discussed in chapter 4 and they included the use of a 3D camera system as being key to the overall study. However, in a coaching environment and in a water environment in general, there is rarely access to a 3D camera system or the appropriate environment for this to be used in. This is evidenced by the very few 3D camera studies in kayaking that have been published (Baker et al., 1999; Brown, 2009; Broomfield & Lauder, 2015), the majority of studies have been carried out using 2D kinematics (Kendal & Sanders, 1992; Mann & Kearney, 1980; Plagenhoef, 1979; Sanders & Kendal, 1992a; Sanders & Kendal, 1992b). This is important because the four kinematic efficiency measures that have been identified as predicting the optimum sitting height can all be measured in two-dimensions. This means that the utilisation of the discovered method will be far more accessible to kayakers and coaches alike. The kinetic measurements required will be an additional cost, however, this is minimal in comparison to a 3D camera system. If the one calibrated 2D camera is placed on the kayaker's left hand side, all measures will be visible, with the exception of the right paddle entry to calculate the stroke length, so a second, non-calibrated camera may be needed for this. These can be synced by the left paddle entry as long as they are filming in the same frame rate. Markers will need to be placed on the bow and stern as they were in chapter 5 and 6 as well as markers on the kayakers forearms. All calculations will be possible from these marker and camera positions.

The anthropometrics identified in chapter 3 were interesting in terms of identifying that the difference between sitting height of the male and female white water kayakers in the sample was larger than both the slalom kayakers (Ridge et al., 2007) and the population norms (Pheasant, 1996). Linking this finding to the maximum seat raises, which the participants in chapter 6 self-selected, they were unable to reach the average difference between the chapter 3 males and females of 69.3mm, selecting an average of just 57.14 (SD= 9.51) for their largest seat raise. This is an important point for boat manufacturers to note when designing boats to allow maximum adaptability within the cockpit. However, it was clear from chapter 6, that despite the sitting height difference being 6.93cm between the male and female white water kayakers in chapter 3, there appears to be no need for the females to reflect this in their seat raise. This was because no participant in chapter 6 was recommended their most efficient seat raise as their largest raise, indicating that they reached efficiency and then efficiency was lost with a loss of balance due to their centre of mass being too high and therefore difficulty to maintain its location over the centre of buoyancy (Mackereth, 2008).

Although it was found in chapter 6 that it was not possible to predict the optimum seat raise from the anthropometrics of the female white water kayaking participants, there were clear indications of the aspects of the anthropometrics that were influencing the seat raises that were calculated as most efficient. Arm length as a ratio to sitting height was evident as being as important to kayaking as the ape index is to climbing (Watts et al., 2003). It was also clear that body mass is important due to the drag experienced on the kayak due to more of the hull being exposed to the water with heavier masses (Gomes et al., 2015a). A potential area of further research would be to investigate this further by adding in further technique measures alongside the anthropometrics to identify whether the technique differences between the participants are also impacting upon the selected optimum sitting height.

7.2 Implications of the research

This is a novel area of investigation in many ways. White water kayaking in general has been subjected to very little analysis (Lauder, 2008). And therefore any research into this particular area is going to be novel in its own right, however there are findings here which have greater impact both within white water kayaking and in kayaking in general.

Taking the information around body positioning during a stroke (Brown, 2009; Mann & Kearney, 1980; Plagenhoef, 1979) to the next level of identifying how the stroke impacts upon the boat movement has been a novel way of investigating what a normal forwards paddle stroke looks like. This has also meant it has been possible to remove paddle strokes from the analysis if they do not follow this pattern, suggesting that they may be an adjustment, turning or other stroke. This information could prove useful not only in white water kayaking, but also in other kayaking disciplines when it is required to identify a particular stroke used, perhaps breaking down in flat water racing the number of pure forwards strokes used.

The method identified within this doctoral work to help discover the optimum sitting height for a female white water kayaker has reduced the number of efficiency measures down to just seven; pitch, velocity change, slalom, force right and left, left arm reach, stroke length left to right. These can be measured with just one calibrated 2D camera and a second non-calibrated camera to identify right paddle entry. From these cameras and markers on the bow, stern and the kayaker's forearms, all events for the four kinematic measures can be collected. Of the other measures; the slalom course requires a similar course utilised here to be set up and then a stop watch to time the kayaker. The kinetic data can be collected through the use of a Power Meter as used in this doctoral work, these are available to all kayakers to purchase and require no other specialised equipment. This ease of the data collection method has resulted in the identification of the optimum sitting height for female white water kayakers as being possible both for clubs and kayakers themselves.

7.3 Limitations of the research

The main limitation of this research was the lack of application to a white water environment. There is still application within this work due to the time white water kayakers spend forwards paddling and also the fact that they paddle flat water regularly between the rapids they descend. However, being able to identify the impact white water has on their control of the boat would have been a useful addition. This was not possible due to the fact that the mechanics of the water would be required to be exactly the same under each seat raise change and the kayaker would therefore have had to paddle exactly the same course within millimetre accuracy to ensure that this dependant variable was controlled. As this was not possible to achieve, the slalom course which included changes in direction as well as accelerations were deemed to be the next best available option.

The lack of in-depth statistical testing in chapter 6 of the thesis could be seen as a limitation of the work, but due to the individual analysis required by the data coupled with a small number of participants (n=7) due to the vast quantities of data collected for each individual, further statistical testing would not have been reliable. This was an acceptable limitation in this doctoral work due to the focus being on identifying an appropriate method for determining the most beneficial seat raise for an efficient technique. A clear method was identified, and despite the lack of statistical validation of this method, the aims and sub-aims have been fully met.

7.4 Recommendations for future research

The current research has identified that seven of the thirteen initial efficiency measures can be used to predict the optimum seat raise. However this was determined using the percentile method identified within this doctoral thesis as being the best predictor of optimum sitting height. In order to progress this further, it would be useful to reduce the sitting heights used by the participants, due to the identification by this thesis that less were required. Then a repetition of the study could be carried out with enough participants to be able to carry out a regression analysis to determine which measures predict the optimum seat raise. This would enable validation of the method identified within this doctoral work.

Further to this, it was clear that there were links between anthropometrics and the seat raise selected, but the patterns between these were not clear with this sample, again it may be useful to investigate with a larger sample, but also including additional technique measures such as those utilised by Brown (2009), in his analysis of flat water racing technique. This would make it possible to see whether the anthropometrics and technique combined were able to predict the optimum sitting height.

Finally it would be useful to identify whether the patterns of boat movement caused by the paddle stroke, were the same for male white water kayakers and what the patterns were for other stroke types. It would also be interesting to clarify whether other kayaking disciplines have similar patterns. This way it would be possible to use boat movement to categorise strokes.

8.0 Conclusion

The aim of this doctoral thesis was to utilise anthropometrics, three-dimensional kinematic and kinetic analysis of technique to identify a method for determining the optimum sitting height for female white water kayakers.

The Sub-Aims were:

- To establish normative anthropometrics for the white water kayaking population.
- To utilise three-dimensional kinematics, and kinetics to determine female white water kayakers' paddle stroke technique and efficiency related to sitting height.
- To identify the best method of determining optimum sitting height for female white water kayakers.

The first sub-aim was achieved in chapter 3 where the anthropometrics of both male and female white water kayakers were obtained in the first investigation of this kind. The findings from this chapter identified that male and female white water kayakers were significantly different with 72.7% of measures resulting in a p-value of less than 0.05. When looking specifically at the difference in male and female white water kayakers sitting heights this was much larger than for either slalom paddlers or the normal population. It was also found that male and female white water kayakers had the same ratio of sitting height to height (0.47 sitting height to height ratio), meaning that they have an equally proportioned torso length to height ratio as the females. There was found to be a much larger spread of the data for white water kayakers when compared to slalom paddlers, suggesting that the population hasn't achieved the same morphological optimisation as seen in the competitive counterpart.

The second sub-aim was achieved in chapters 5 and 6. This significant contribution to knowledge, identified patterns of boat movement and force application for a normal forwards paddle stroke for female white water kayakers, as displayed in chapter 5. Most previous forwards paddling technique studies have looked at flat water racing and focused on what the body does, rather than how the boat is impacted upon by the body as carried out in this study. The impact the stroke has upon the boat movements is therefore an area of study which has not previously been carried out in other kayaking disciplines and thus is an important finding in order to identify stroke types. Chapter 6 went on to utilise this information to identify all the true forwards paddling strokes and then use these to establish the most efficient seat raise for each participant. The major finding associated with this aim was the removal of rolling data due to the fact that it is unclear whether increased rolling is inefficient or efficient due to making the hull more of a "U" shape. This was the first time these boat movements had been considered in a white water craft and therefore this finding has greatly added to knowledge. Another key finding was that even though the first sub-aim identified a difference of 6.93cm between male and female white water kayakers sitting heights, there is no need for this amount of seat raise to be added into the female kayakers to reflect this difference. The largest seat raise identified in chapter 6 as being most efficient was 4cm for participant 6. The knowledge that female sitting heights do not need to reflect male sitting heights in order to achieve efficiency is an important contribution to knowledge in order to allow improved future boat design.

Sub-aim three was achieved in chapter 6. In this chapter it was discovered that the 13 efficiency measures identified at the outset of this doctoral work could be reduced down to just seven to predict the optimum sitting height; pitch, velocity change, slalom, force on the left and right, left arm reach and stroke length left to right. This was a significant contribution to knowledge due to it being the first time any study had looked to identify a method to determine the most efficient seat raise in female white water kayaking, despite the knowledge that boats have been designed around male specifications. It was also identified that the percentile calculation was the best method of predicting from these measures the most efficient seat raise for a female white water kayaker. It was also found that the four kinematic measures here would be able to be recorded with just one calibrated 2D camera making this a much more accessible data collection method for coaches and kayakers alike. The kinetic data would require further equipment in terms of an instrumented paddle such as the Power Meter, but this is a much more achievable cost when compared to a 3D camera system. This finding regarding the use of a 2D camera system is an especially important contribution to knowledge because this thesis has been investigating a recreational population and the method discovered in this doctoral work is notably accessible to this very population. The final key finding in chapter 6 in relation to sub-aim three was that it was not possible to predict the optimum sitting height from the anthropometrics alone. Despite there being indications that arm length in relation to sitting height and body mass may all be important, this was not conclusive for all participants and therefore the consideration of further technique measures being required is an area for future investigation.

References

Ackland, T.R., Ong, K.B., Kerr, D.A., & Ridge, B. (2003). Morphological characteristics of Olympic sprint canoe and kayak paddlers. *Journal of Science and Medicine in Sport, 6,* 285-294.

Aitken, D.A., & Jenkins, D.G. (1998). Anthropometric-based selection and sprint kayak training in children. *Journal of Sports Sciences*, *16*, 539-543.

Aitken, D. A., & Neal, R. J. (1992). An on-water analysis system for quantifying stroke force characteristics during kayak events. *International Journal of Sport Biomechanics*, *8*(2), 165-173.

Akca, F., & Muniroglu, S. (2008). Anthropometric- somatotype and strength profiles and on-water performance in Turkish elite kayakers. *International Journal of Applied Sports Sciences, 20*(1), 22-34.

Alacid, F., Marfell-Jones, M., Lopez-Minarro, P.A., Martinez, I., & Muyor, J.M. (2011). Morphological characteristics of young elite paddlers. *Journal of Human Kinetics, 27,* 95-110.

Alberty, M., Potdevin, F., Dekerle, J., Pelayo, P., Gorce, P., & Sidney, M. (2008). Changes in swimming technique during time to exhaustion at freely chosen and controlled stroke rates. *Journal of Sports Sciences, 26*(11), 1191-1200.

Allard, P., Blanchi, J-P., & Aissaoui, R., (1995). Bases of three-dimensional reconstruction. In P. Allard, I.A.F. Stokes & J-P. Blanchi (Eds.), *Three-Dimensional Analysis of Human Movement* (pp. 19-40). Champaign, USA: Human Kinetics.

Angulo, R.M., & Dapena (1992). Comparison of film and video techniques for estimating three-dimension coordinates within a large field. *International Journal of Sport Biomechanics,* 8, 145-151.

Arkenford Ltd. (2013). *Watersports participation survey.* Guildford, England: Arkenford Ltd.

Baker, J. (1998). Evaluation of biomechanic performance related factors with on-water tests. In J. Vrijins (Ed.), *International Seminar on Kayak-Canoe Coaching and Science - International Seminar on Kayak-Canoe Coaching and Science* (pp. 50-66). Gent: University of Gent Press.

Baker, J. (2012). Biomechanics of paddling. *ISBS-Conference Proceedings Archive,* (Vol. 1, No. 1).

Baker, J., Rath, D., Sanders, R., & Kelly, B. (1999). A three-dimensional analysis of male and female elite sprint kayak paddlers. *International Symposium on Biomechanics in Sport*, 53-56.

Barbosa, T. M., Costa, M. J., Morais, J. E., Morouço, P., Moreira, M., Garrido, N. D., . . . & Silva, A. J. (2013). Characterization of speed fluctuation and drag force in young swimmers: A gender comparison. *Human Movement Science*, *32*(6), 1214-1225.

Barbosa, T. M., Lima, F., Portela, A., Novais, D., Machado, L., Colaço, P., . . . & Vilas-Boas, J. P. (2006). Relationships between energy cost, swimming velocity and speed fluctuation in competitive swimming strokes. *Revista Portuguesa de Ciências do Desporto*, 192-194.

Barbosa, T.M., Marinho, D.A., Costa, M.J., & Silva, A.J. (2011). Biomechanics of competitive swimming strokes. *In Tech,* 367-388.

Barbosa, T. M., Morouço, P. G. F., Jesus, S., Feitosa, W. G., Costa, M. J., Marinho, D. A., . . . & Garrido, N. D. (2012). The interaction between intra-cyclic variation of the velocity and mean swimming velocity in young competitive swimmers. *International Journal of Sports Medicine*, *34*(02), 123-130.

Barlow, M.J., Findlay, M., Gresty, K., & Cooke, C. (2014). Anthropometric variables and their relationship to performance and ability in male surfers. *European Journal of Sports Science*, 14(S1), 171-177.

Barrett, R.S., & Manning, J.M. (2004). Relationships between rigging set-up, anthropometry, physical capacity, rowing kinematics and rowing performance. *Sport Biomechanics*, *3*(2), 221-235.

Bencke, J., Damsgaard, R., Saekmose, A., Jorgensen, P., Jorgensen, K., & Klausen, K. (2002). Anaerobic power and muscle strength characteristics of 11 year old elite and non-elite boys and girls from gymnastics, team handball, tennis and swimming. *Scandinavian Journal of Medicine and Science in Sports, 12*, 171-178.

Berry, M. (2008). Reading white water. In F. Ferrero (Ed.), *British Canoe Union: canoe and kayak handbook.* 3rd ed (pp.280-292). Gwynedd, UK: Pesda Press.

Bily, M., Suss, V., & Buchtel, M. (2011). Selected somatic factors of white water canoeists. *Journal of Outdoor Activities, 5*(2), 30-42.

Bishop, D. (2000). Physiological predictors of flat-water kayak performance in women. *European Journal of Applied Physiology*, *82*, 91-97.

Bjerkefors, A., Tarassova, O., Rosén, J.S., Zakaria, P., & Arndt, A. (2018). Three-dimensional kinematic analysis and power output of elite flat-water kayakers. *Sports biomechanics*, *17*(3), 414-427.

Bourgois, J., Claessens, A.L., Janssens, M., Van Renterghem, B., Loos, R., Thomis, M., . . . & Vrijens, J. (2001). Anthropometric characteristics of elite female junior rowers. *Journal of Sports Sciences, 19,* 195-202.

Bourgois, J., Claessens, A.L., Vrijens, J., Philippaerts, R., Van Renterghem, B., Thomis, M., . . . & Lefevre, J. (2000). Anthropometric characteristics of elite male junior rowers. *British Journal of Sports Medicine, 34*, 213-217.

British Canoeing (2017). *Canoe Slalom*. Retrieved from https://www.britishcanoeing.org.uk/competition/canoe-slalom/.

British Canoe Union (2004). *BCU Long Term Paddler Development Pathway*. Nottingham, UK: BCU.

British Canoe Union (2013). *Thirty third annual report of the British Canoe Union board, 2013.* Nottingham, UK: BCU.

British Canoe Union (2014a). *Our sport*. Retrieved from http://www.bcu.org.uk/our-sport.

British Canoe Union (2014b). *White water kayaking*. Retrieved from http://www.bcu.org.uk/our-sport/white-water-kayaking-/.

Broomfield, S.A.L., & Lauder, M. (2015). Improving paddling efficiency through raising sitting height in female white water kayakers. *Journal of Sports Sciences, 33*, 1440-1446.

Brown, M.B. (2009). *Biomechanical analysis of flatwater sprint kayaking.* (Doctoral thesis, University of Chichester, UK).

Carter, J.E.L. (2002). *The Heath-Carter anthropometric somatotype: Instructor manual.* San Diego: San Diego State University.

Cengel, C. and Turner, R.H. (2012) *Fundamentals of Thermal-Fluid Sciences*. McGraw-Hill Education - Europe, 4th edition.

Chirazi, M. (2010). Methodical aspects regarding the use of recreational kayak. In *International Scientific Conference, Perspectives In Physical Education and Sport*.

Chollet, D., Chalies, S., & Chatard, J. C. (2000). A new index of coordination for the crawl: description and usefulness. *International Journal of Sports Medicine*, *21*(01), 54-59.

Coe, R. (2002). It's the effect size, stupid: What effect size is and why it is important. *Annual Conference of the British Educational Research Association,* University of Exeter, England.

Collins, L. (2008). White water kayaking. In F. Ferrero (Ed.), *British Canoe Union: canoe and kayak handbook.* 3rd ed (pp.293-304). Gwynedd, UK: Pesda Press.

Dabnichki, P., Lauder, M., Aritan, S. & Tsirakos, D. (1997). Accuracy evaluation of an online kinematic system via dynamic tests. *Journal of Medical Engineering and Technology, 21*(2), 53-66.

Dagger Kayaks (2018). Kayaks. Retrieved from https://www.dagger.com/us/kayaks?activity.

de Groot, G., & van Ingen Schenau, G.J. (1988). Fundamental mechanics applied to swimming: technique and propelling efficiency. *Swimming Science V*, *18*, 17-30.

Deschner, W. (1997). *Travels with a kayak.* Oregon: Eddie Tern Press.

Emery, C. A., & Tyreman, H. (2009). Sport participation, sport injury, risk factors and sport safety practices in Calgary and area junior high schools. *Paediatrics & child health*, *14*(7), 439-444.

Fernandes, A.A.D. (2013). *Analysis of the relationships between the anthropometric characteristics of young kayakers, the paddle set-up and the performance.* (Masters thesis, University of Coimbra, Portugal).

Field, A. (2013). *Discovering statistics using IBM SPSS statistics.* 4th ed. London, UK: Sage Publications Ltd.

Figueiredo, P., Pendergast, D. R., Vilas-Boas, J. P., & Fernandes, R. J. (2013). Interplay of biomechanical, energetic, coordinative, and muscular factors in a 200 m front crawl swim. *BioMed research international*, *2013*, 1-12.

Fillingham, P. (1974). *The complete book of canoeing and kayaking.* New York: Drake Publishers Inc.

Fiore, D. C., & Houston, J. D. (2001). Injuries in whitewater kayaking. *British Journal of Sports Medicine*, *35*(4), 235-241.

Fleming, N., Donne, B., & Mahony, N. (2007). Electromyographic and kinesiological analysis of the kayak stroke: comparison of on-water and on-ergometer data across exercise intensity. In *Proceeding of the 12th annual congress of the European college of sports sciences* (p.1744).

Ford, K. (1995). *Whitewater and sea kayaking.* Champaign: Human Kinetics Publishers Inc.

Fossati, F. (2009). *Aero-hydrodynamics and the performance of sailing yachts.* London: Adlard Coles Nautical.

Fredriks, A. M., van Buuren, S., Van Heel, W. J. M., Dijkman-Neerincx, R. H. M., Verloove-Vanhorick, S. P., & Wit, J. M. (2005). Nationwide age references for sitting height, leg length, and sitting height/height ratio, and their diagnostic value for disproportionate growth disorders. *Archives of Disease in Childhood*, *90*(8), 807-812.

Geladas, N.D., Nassis, G.P., & Pavlicevic, S. (2005). Somatic and physical traits affecting sprint swimming performance in young swimmers. *International Journal of Sports Medicine*, *26,* 139-144.

Gomes, B.B., Conceicão, F.A.V., Pendergast, D.R., Sanders, R.H., Vaz, M.A.P., & Vilas-Boas, J. P. (2015a). Is passive drag dependent on the interaction of kayak design and paddler weight in flat-water kayaking? *Sport Biomechanics, 14*(4), 394-403.

Gomes, B. B., Ramos, N. V., Conceição, F. A., Sanders, R. H., Vaz, M. A., & Vilas-Boas, J. P. (2015b). Paddling Force Profiles at Different Stroke Rates in Elite Sprint Kayaking. *Journal of Applied Biomechanics*, *31*(4), 258-263.

Grant, S., Hasler, T., Davies, C., Aitchinson, T.C., Wilson, J., & Whittaker, A. (2001). A comparison of the anthropometric, strength, endurance and flexibility characteristics of female elite and recreational climbers and non-climbers. *Journal of Sports Sciences*, *19*, 499-505.

Grant, S., Hynes, V., Whittaker, A., & Aitchinson, T. (1996). Anthropometric, strength, endurance and flexibility characteristics of elite and recreational climbers. *Journal of Sports Sciences*, *14,* 301-309.

Grehaigne, J. F., Godbout, P., & Bouthier, D. (1997). Performance assessment in team sports. *Journal of Teaching in Physical Education*, *16*(4), 500-516.

Hay, J.G. (2002). Cycle rate, length, and speed of progression in human locomotion. *Journal of Applied Biomechanics*, *18,* 257-270.

Heath, J.D., & Arima, E. (2004). *Eastern Arctic kayaks: History, design, technique.* Fairbanks: University of Alaska Press.

Heath, B.H., & Carter, J.E.L. (1967). A modified somatotype method. *American Journal of Physical Anthropology, 27,* 57-74.

Henry, J. C., Clark, R. R., McCabe, R. P., & Vanderby Jr, R. (1995). An evaluation of instrumented tank rowing for objective assessment of rowing performance. *Journal of Sports Sciences*, *13*(3), 199-206.

Jackson, P.S. (1995). Performance prediction for Olympic kayaks. *Journal of Sports Sciences*, *13*(3)*,* 239-245.

Jackson, P.S., Locke, N., & Brown, P. (1992). The hydrodynamics of paddle propulsion. *11th Australasian Fluid Mechanics Conference,* 1197-1200.

Janura, M., Kratochvíl, J., Lehnert, M., & Vaverka, F. (2005). An analysis of the forward stroke as used in a wild water kayak on flat waters. *Universitatis Palackianae Olomucensis Gymnica*, *35*(2), 113-116.

Jones, I. (2015). *Research methods for sports studies. 3rd edition.* Abingdon: Routledge.

Keatinge, W. R., Khartchenko, M., Lando, N., & Lioutov, V. (2001). Hypothermia during sports swimming in water below 11 C. *British Journal of Sports Medicine*, *35*(5), 352-353.

Kemecsey, I., & Lauder, M. (1998, December). *Kayak technique diagnosis and remedies, Part one*. Canoe Focus, pp. 16–17.

Kendal, S.J., & Sanders, R.H. (1992). The technique of elite flatwater kayak paddlers using the wing paddle. *International Journal of Sport Biomechanics, 8,* 233-250.

Knechtle, B., Baumann, B., Knechtle, P., & Rosemann, T. (2010). Speed during training and anthropometric measures in relation to race performance by male and female open-water ultra-endurance swimmers. *Perceptual and Motor Skills, 111*(2), 463-474.

Langford, K. (1980). Slalom. In B. Skilling (Ed.), *Canoeing complete: Revised edition.* (pp.115-131). London, UK: Kaye & Ward Ltd.

Lauder, M.A. (2008). Motion analysis in water sports. *Journal of Applied Biomechanics, 32*, 217-245.

Lauder, M., & Kemecsey, I. (1999, January/February). *Kayak technique diagnosis and remedies, Part two.* Canoe Focus, pp. 18–19.

Leone, M., Lariviere, G., & Comtois, A.S. (2002). Discriminant analysis of anthropometric and biomotor variables among elite adolescent female athletes in four sports. *Journal of Sports Sciences, 20*, 443-449.

Levesque, A. (2008a). In *Girls at play white water kayaking DVD* (edited by C. Emerick). USA: Watergirls at play.

Levesque, A. (2008b). Tips for women. In: K Whiting & K. Varette, *Whitewater kayaking: The ultimate guide.* 2nd ed. (pp. 237-242). Ontario: Heliconia Press.

López-Plaza, D., Alacid, F., Muyor, J. M., & López-Miñarro, P. Á. (2017). Sprint kayaking and canoeing performance prediction based on the relationship between maturity status, anthropometry and physical fitness in young elite paddlers. *Journal of sports sciences*, *35*(11), 1083-1090.

López-Plaza, D., Alacid, F., Rubio, J. Á., López-Miñarro, P. Á., Muyor, J. M., & Manonelles, P. (2018). Morphological and physical fitness profile of young female sprint kayakers. *The Journal of Strength & Conditioning Research,* publish ahead of print DOI: 10.1519/JSC.0000000000002511

Loschner, C., Smith, R., & Galloway, M. (2000). Intra-stroke boat orientation during single sculling. In *ISBS-Conference Proceedings Archive* (Vol. 1, No. 1).

Macdermid, P.W., & Fink, P.W. (2017). The validation of a paddle power meter for slalom kayaking. *Sports Medicine International Open, 2*, E50-E57.

Mackereth, G. (2008). Canoe, kayak and paddle design. In F. Ferrero (Ed.), *British Canoe Union: canoe and kayak handbook.* 3rd ed (pp.19-36). Gwynedd: Pesda Press.

Maddock, A. (2008). Slalom. In F. Ferrero (Ed.), *British Canoe Union: canoe and kayak handbook.* 3rd ed (pp.305-310). Gwynedd: Pesda Press.

Manchester, T. (2008). In *Girls at play white water kayaking DVD* (edited by C. Emerick). USA: Watergirls at play.

Mann, R., & Kearney, J.T. (1980). A biomechanical analysis of the Olympic-style flatwater kayak stroke. *Medicine and Science in Sport and Exercise*, *12*(3), 183-188.

Mason, B., van der Woude, L., Tolfrey, K., & Goosey-Tolfrey, V. (2012). The effects of rear-wheel camber on maximal effort mobility performance in wheelchair athletes. *International Journal of Sports Medicine, 33*, 199-204.

Mattos, B. (2009). *The kayaking handbook: a beginners guide.* London: Apple Press.

McDonnell, L.K., Hume, P.A., & Nolte, V. (2012). An observational model for biomechanical assessment of sprint kayaking technique. *Sports Biomechanics, 11*(4), 507-523.

McDonnell, L.K., Hume, P.A., & Nolte, V. (2013). A deterministic model based on evidence for the associations between kinematic variables and sprint kayak performance. *Sports Biomechanics, 12*(3), 205-220.

McGhee, R. (2001). *Ancient people of the Arctic.* Vancouver: University of British Columbia Press.

Met Office (2017). *Winter 2016/17.* Retrieved from http://www.metoffice.gov.uk/climate/uk/summaries/2017/winter.

Michael, J.S., Smith, R., & Rooney, K.B. (2009). Determinants of kayak paddling performance. *Sports Biomechanics, 8*(2), 167-179.

Mikulic, P. (2008). Anthropometric and physiological profiles of rowers of varying ages and ranks. *Kinesiology, 40*(1), 80-88.

Mononen, H.V., & Viitasalo, J.T. (1995). Stroke parameters and kayak speed during 200m kayaking. *Congress of the International Society of Biomechanics*, 632- 633.

Murtagh, M., Brooks, D., Sinclair, J., & Atkins, S. (2016). The lower body muscle activation of intermediate to experienced kayakers when navigating white water. *European Journal of Sport Science, 16*(8), 1130-1136.

Norton, K., Olds, T., Olive, S., & Craig, N. (1996). Anthropometry and sports performance. In K. Norton and T. Olds (Eds.), *Anthropometrica.* (pp.287-352). New South Wales: University of New South Wales Press Ltd.

One Giant Leap (2019). *Zero Offsets.* Retrieved from https://support.onegiantleap.co.nz/kayak/calibration/zero-offset

Ong, K.B., Ackland, T.R., Hume, P.A., Ridge, B., Broad, E., & Kerr, D.A. (2005). Equipment set up among Olympic Sprint and Slalom Kayak paddlers. *Sports Biomechanics,* 4, 47-58.

Ong, K., Elliott, B., Ackland, T., & Lyttle, A. (2006). Performance tolerance and boat set-up in elite sprint kayaking. *Sports Biomechanics, 5*(1), 77-94.

Páez, L. C., Díaz, I. C. M., de Hoyo Lora, M., Corrales, B. S., & Ochiana, N. (2010). Ergometric testing for top-level kayakers: validity and reliability of a discontinuous graded exercise test. *Kinesiologia Slovenica, 16*, 16-20.

Pelayo, P., Sidney, M., Kherif, T., Chollet, D., & Tourny, C. (1996). Stroking characteristics in freestyle swimming and relationships with anthropometric characteristics. *Journal of Applied Biomechanics, 12*, 197-206.

Petersen, H.C. (1985). *Ships and boats of the North, Volume 1: Skinboats of Greenland.* Denmark: The National Museum of Denmark.

Pheasant, S. (1991). *Ergonomics, work and health*. London: Macmillan academic and professional ltd.

Pheasant, S. (1996). *Bodyspace: Anthropometry, ergonomics and design.* London: Taylor and Francis.

Pinheiro, V. (1994). Diagnosing motor skills—A practical approach. *Journal of Physical Education, Recreation & Dance, 65*(2), 49-54.

Plagenhoef, S. (1979). Biomechanical analysis of Olympic flatwater kayaking and canoeing. *Research Quarterly, 50*(3), 443-459.

Qualysis (2010). *Qualysis Track Manager – QTM: Motion capture software for tracking all kind of movements*. Gothenburg: Qualysis.

Qualysis (2016). *Oqus underwater: Motion capture camera for advanced underwater measurements.* Gothenburg: Qualysis.

Reilly, T. (2010). *Ergonomics in sport and physical activity: Enhancing performance and improving safety.* Champaign: Human Kinetics.

Reitz, B. (2016). *The five immutable rules of the kayak forward stroke*. Retrieved from http://www.usawildwater.com/training/fwdstroke.html.

Richards, J.G. (1999). The measurement of human motion: A comparison of commercially available systems. *Human Movement Science,* 18, 589-602.

Richards, G., & Wade, P. (1981). *The complete book of canoeing and kayaking*. London: BT Batsford Ltd.

Ridge, B.R., Broad, E., Kerr, D.A., & Ackland, T.R. (2007). Morphological characteristics of Olympic slalom canoe and kayak paddlers. *European Journal of Sport Science, 7*(2), 107-113.

Rosen, Y. (2008). *The Evolution of the Kayak*. Retrieved from http://wavewalk.com/blog/articles-2/#KAYAK_STUFF.

Sanders, R.H., & Baker, J.D. (1998). Evolution of technique in flatwater kayaking. *Science and Practice of Canoe/Kayak,* pp. 67-81.

Sanders, R.H., & Kendal, S.J. (1992a). A description of Olympic flatwater kayak stroke technique. *The Australian Journal of Science and Medicine in Sport*, 25-30.

Sanders, R.H., & Kendal, S.J. (1992b). Quantifying lift and drag forces in flatwater kayaking. In *ISBS-Conference Proceedings Archive* (Vol. 1, No. 1).

Schoen, R. G., & Stano, M. J. (2002). Year 2000 whitewater injury survey. *Wilderness & Environmental Medicine*, *13*(2), 119-124.

Schranz, N., Tomkinson, G., Olds, T., & Daniell, N. (2010). Three-dimensional anthropometric analysis: Differences between elite Australian rowers and the general population. *Journal of Sports Sciences, 28*(5), 459-469.

Secher, N. H. (1993). Physiological and biomechanical aspects of rowing. *Sports Medicine*, *15*(1), 24-42.

Seifert, L., Toussaint, H. M., Alberty, M., Schnitzler, C., & Chollet, D. (2010). Arm coordination, power, and swim efficiency in national and regional front crawl swimmers. *Human Movement Science*, *29*(3), 426-439.

Sherman, H. D. (1984). Hospital efficiency measurement and evaluation: empirical test of a new technique. *Medical care*, 922-938.

Skilling, B., & Sutcliffe, D. (1980). Introduction to the first edition. In B. Skilling (Ed.), *Canoeing complete: Revised edition.* (pp.IX-XI). London: Kaye & Ward Ltd.

Smith, R.M., & Loschner, C. (2000). Net power production and performance at different stroke rates and abilities during pair-oar rowing. *Proceedings of the XVII^th^ International Symposium on Biomechanics in Sport.* 340-343.

Sperlich, J., & Klauck, J. (1992). Biomechanics of canoe slalom: Measuring techniques and diagnostic possibilities. In *ISBS-Conference Proceedings Archive* (Vol. 1, No. 1).

Sport England (2013). *Active People Survey results for canoeing; Period ASP2 to ASP7.* London: Sport England.

Sport England (2017). *Active Lives: Canoeing.* London: Sport England.

Stainsby, W. N., Gladden, L. B., Barclay, J. K., & Wilson, B. A. (1980). Exercise efficiency: Validity of base-line subtractions. *Journal of Applied Physiology, 48,* 518–522.

States, R. A., & Pappas, E. (2006). Precision and repeatability of the Optotrak 3020 motion measurement system. *Journal of medical engineering & technology*, *30*(1), 11-16.

Sterzing, T., Müller, C., Hennig, E.M., & Milani, T.L. (2009). Actual and perceived running performance in soccer shoes: A series of eight studies. *Footwear Science, 1*(1), 5-17.

Stewart, A., Marfell-Jones, M., Olds, T., & de Ridder, H. (2011). *International standards for anthropometric assessment*. Australia: ISAK.

Sturm, D., Yousaf, K., Brodin, L. Å., & Halvorsen, K. (2013). Wireless kayak on-water ergometry–Part 1: Paddle blade force. *Sports Technology*, *6*(1), 29-42.

Sturm, D., Yousaf, K., & Eriksson, M. (2010). A Kayak Training System for Force Measurement on-water. In *ISBS-Conference Proceedings Archive* (Vol. 1, No. 1).

Taylor, B. (2009). Coaching. In F. Ferrero (Ed.), *British Canoe Union: coaching handbook* (pp. 7-48). Gwynedd, UK: Pesda Press.

Timms, B. (2009). Coaching Novices. In F. Ferrero (Ed.), *British Canoe Union: coaching handbook* (pp. 135-152). Gwynedd, UK: Pesda Press.

Tipper, L. (2008). Foundation kayak skills. In F. Ferrero (Ed.), *British Canoe Union: canoe and kayak handbook.* 3rd ed (pp.47-68). Gwynedd, UK: Pesda Press.

Toussaint, H.M., Knops, W., De Groot, G., & Hollander, A.P. (1990). The mechanical efficiency of front crawl swimming. *Medicine and Science in Sports and Exercise*, *22*(3), 402-408.

Tran, N.M. (2008). *An introduction to theoretical properties of functional principal component analysis.* (Undergraduate thesis, University of Melbourne, Austrailia).

Triantafillou, E., Pomportsis, A., & Demetriadis, S. (2003). The design and the formative evaluation of an adaptive educational system based on cognitive styles. *Computers and Education, 41*(1), 87-104.

Ueng, S.K. D Lin, D. & Liu, C.H. (2008) A ship motion simulation system. *Virtual reality* 12 (1), 65-76.

van Someren, K.A., & Howatson, G. (2008). Prediction of flatwater kayaking performance. *International Journal of Sports Physiology and Performance, 3*, 207-218.

van Someren, K.A., & Palmer, G.S. (2003). Prediction of 200m sprint kayaking performance. *Canadian Journal of Applied Physiology*, 28(4), 505-517.

Vedat, A. (2012). Somatotypes of male whitewater canoe athletes of the Turkish national canoe team. *Educational Research and Reviews, 7*(24), 526-531.

Vilas-Boas, J. P. (1996). Speed fluctuations and energy cost of different breaststroke techniques. *Biomechanics and Medicine in Swimming VII*, 167.

Wagner. J., Bartmus, U., & de Marees, H. (1993). Three-axes gyro system quantifying the specific balance of rowing. *International Journal of Sports Medicine, 14*(1), S35-S38.

Warmenhoven, J., Cobley, S., Draper, C., Harrison, A. J., Bargary, N., & Smith, R. (2017). Assessment of propulsive pin force and oar angle time-series using functional data analysis in on-water rowing. *Scandinavian journal of medicine & science in sports*, *27*(12), 1688-1696.

Warmenhoven, J., Cobley, S., Draper, C., Harrison, A., Bargary, N., & Smith, R. (2019). Bivariate functional principal components analysis: considerations for use with multivariate movement signatures in sports biomechanics. *Sports biomechanics*, *18*(1), 10-27.

Warmenhoven, J., Cobley, S., Draper, C., Harrison, A., Bargary, N., & Smith, R. (2019a). Considerations for the use of functional principal components analysis in sports biomechanics: examples from on-water rowing. *Sports biomechanics*, *18*(3), 317-341.

Watts, P. B., Joubert, L., Lish, A. K., Mast, J. D., & Wilkins, B. (2003). Anthropometry of young competitive sport rock climbers. *British Journal of Sports Medicine*, *37*(5), 420-424.

Wheaton, B. (2004). Introduction: mapping the lifestyle sport-scape. In B. Wheaton (Ed.), *Understanding lifestyle sports: Consumption, identity and difference.* (pp.1-28). London, UK: Routledge.

Whipp, B. J., & Wasserman, K. (1969). Efficiency of muscular work. *Journal of Applied Physiology*, *26*(5), 644-648.

Whiting, K., & Varette, K. (2004). *The ultimate guide to whitewater kayaking.* Ontario: Heliconia Press.

Winning, D. (2002). A short history of paddlesport in Britain. In F. Ferrero (Ed.), *British Canoe Union: canoe and kayak handbook.* 3rd ed (pp.8-18). Gwynedd, UK: Pesda Press.

World Rowing (2018, September 16). World rowing – elite. Retrieved from http://www.worldrowing.com/elite/.

Zamparo, P., Pendergast, D. R., Termin, B., & Minetti, A. E. (2002). How fins affect the economy and efficiency of human swimming. *Journal of Experimental Biology*, 205(17), 2665-2676.

Zsidegh, M. (1981). A survey of the physiological and biomechanical investigations made into kayaking, canoeing and rowing. *Hungarian Review of Sports Medicine, 22*, 97-116.

Appendices

Appendix A: Participant Information Sheet – Phase 1 Anthropometrics

Title of Project: Optimum sitting height for paddle stroke efficiency in female white water kayakers

Title of this Phase: Anthropometrics of the white water kayaking population.

Level of Study: MPhil/PhD
Investigator: Shelley Broomfield
Contact details: sbroomfield@bournemouth.ac.uk / sbroomf1@stu.chi.ac.uk / 01202961523

The Wider Project background
The project as a whole is designed to establish the optimum sitting height for female white water kayakers in order for them to achieve the best paddle stroke efficiency possible. The reasoning behind this aim is that current white water boats are designed around a male specification and then shrunk to fit smaller (often female) paddlers. This means that the boats are not specifically designed in order to allow for different anthropometric, or body, measurements of females when compared to males. This means that they are less likely to achieve an efficient forwards paddle stroke when compared to their male counterparts. It is believed that by raising sitting height in female boats, a more efficient stroke can be realised, however it is unknown how much the sitting height should be raised in order to achieve the "most" efficient paddle stroke, and this is what the project aims to find out. The project is split into 3 phases:

1. Anthropometrics of white water kayakers
2. Identifying the most efficient seat height
3. Testing the formula for calculating optimum sitting height.

This Phase of the Project: Phase 1

The purpose of this study is to establish a "normative profile" of anthropometrics for the entire population of recreational white water kayakers, both male and female. This means that the researcher wants to know what the size and shape of the white water kayaking population is. This is useful to aid kayak manufacturers to design correctly sized equipment and also for academics to see how this population compares to the general population and other kayaking populations, such as slalom and white water racers.

In the context of the wider project, this phase will enable the researcher to identify the differences between male and female measurements. This will allow identification of the range of seat heights that the seat raises should fall within, ultimately being used to inform phase 2 of the project.

Why you have been asked to participate in Phase 1?

This research project involves taking body measurements of both male and female individuals who would refer to themselves as a "white water kayaker". It is acceptable that you participate in other kayaking activities outside of white water, but if you were asked to describe the type of kayaking you do predominantly, this would be white water. If you fit the above description then I would like to take your measurements in order to produce a more accurate profile of white water kayakers in the UK.

If you agree, what will happen?

By consenting to participate in the current investigation you will be asked some background information such as age, gender and length of time kayaking and then you will be measured. The measurements taken will include your height, weight and sitting height. You will then have body landmarks located and marked using eye-liner pencil in order for more specific measurements to be taken. These will include:

- 8 Skinfold measures: triceps, subscapular, supraspinale, calf, abdominal, thigh, biceps and iliac crest.
- 9 lengths measured: Arm span, arm length, forearm length, hand length, thigh length, leg length, lower leg length, tibia length and foot length.
- 6 breadth measures: Shoulder breadth, Anterior-Posterior (front to back) chest depth, transverse (across) chest breadth, pelvis breadth, humerus breadth and femur breadth.
- 12 girth measures taken: head girth, relaxed arm girth, flexed arm girth, forearm girth, wrist girth, chest girth, waist girth, hip girth, upper thigh girth, mid-thigh girth, calf girth and ankle girth.

These measurements will be taken on the right hand side of the body and will be measured twice, if needed a third measurement may be taken. Either an average or the median will be then be taken. The measurements will be taken at a time and location convenient and comfortable for you. This is most likely to be your kayak club clubhouse. You will be required to wear shorts and t-shirt (or a vest top will be better for females) for most of the measurements. Males will be required to remove their tops for some of the measurements and females wearing a vest top will be asked to move the top intermittently to allow certain sites to become available to measure. Dignity will be maintained at all times. The researcher is a qualified ISAK Anthropometrist. You will be able to see your raw results once collected.

Your rights

You are entitled to withdraw at any point during the investigation. Anonymity will be strictly maintained in the write up of any data. Post measurement, you will be provided with a copy of your own raw data.

The investigation

It is aimed that the findings from this study will be disseminated through my PhD thesis, research journals, kayaking related publications and academic conferences and that this improved knowledge could be used to educate other people such as manufacturers of white water kayaking equipment to encourage them to use the data available to design appropriately fitting equipment, as well as coaches and National Governing Bodies to enhance their understanding of the white water kayaking population and enable them to advise participants and manufacturers appropriately regarding equipment use and fit. It is evident from existing research that a number of kayaking populations have been investigated for their anthropometric make up, but these tend to be either elite populations of competitive athletes or children in order to talent ID them for elite competition. Therefore it is clear that the non-competitive population of white water kayakers deserve their own attention in order to achieve better understanding and use of appropriate and up to date data used to design equipment.

What will happen to the data collected?

The measurements taken from the data collection sessions will be securely stored for a minimum of three years. The data will be presented, where possible, as a population group and therefore individual data will not be visible. If individual data is presented, this will be done using a participant number and no names will be used to ensure anonymity. Primarily the data will be presented within the PhD thesis, which will be read and marked by examiners. The information from the thesis will further inform research publications, conference presentations and kayaking related publications, however again the protection and anonymity of participants will be paramount within this process.

What happens next?

After reading this information sheet and agreeing to participate within the project, we will arrange a mutually agreed time and location for measurement to take place. Before measurement is commenced, you will be asked to complete an informed consent form.

Further information

If you have any further questions regarding the project or the research process, feel free to contact me through the contact details at the beginning of the sheet.

Thank you for your time and consideration

Shelley
Shelley Broomfield
Certified ISAK Anthropometrist
Associate Lecturer in Biomechanics and Performance Analysis
Bournemouth University **I** Fern Barrow **I** Poole **I** Dorset **I** BH12 5BB
01202 961523
Or
Postgraduate Researcher
University of Chichester
Sbroomf1@stu.chi.ac.uk

Appendix B: Consent Form Study One

The University of Chichester

CONSENT FORM

Tel: +44 (0)1243 816000
Fax: +44 (0)1243 816080

Bishop Otter Campus,
College Lane,
Chichester,
West Sussex
PO19 6PE UK

www.chiuni.ac.uk

I, ... (PRINT NAME)

hereby give my consent to participate in the following ~~test~~/activity *[please delete as appropriate]*.

[insert details]

The activity will involve having anthropometric data taken from the body, consisting of measurements of a range of body limbs and variety of heights being taken. This will include skinfold measurements; girth, width and length of limb measurements; height, sitting height and weight measurements. By signing the below I am agreeing I have read and understood the participant information sheet and give full consent to the measurements taking place.

By signing this form I confirm that:

- the purpose of the test/activity has been explained to me;
- I am satisfied that I understand the procedures involved;
- the possible benefits and risks of the test/activity have been explained to me;
- any questions which I have asked about the test/activity have been answered to my satisfaction;
- I understand that, during the course of the test/activity, I have the right to ask further questions about it;
- the information which I have supplied to The University of Chichester prior to taking part in the test/activity is true and accurate to the best of my knowledge and belief and I understand that I must notify promptly of any changes to the information;
- I understand that my personal information will not be released to any third parties without my permission;
- I understand that my participation in the test/activity is voluntary and I am therefore at liberty to withdraw my involvement at any stage;
- I understand that, if there is any concern about the appropriateness of my continuing in the test/activity, I may be asked to withdraw my involvement at any stage;
- I understand that once the test/activity has been completed, the information gained as a result of it will be used for the following purposes only:

[insert details]

Thesis in pursuit of PhD, journal article and conference presentations.

NAME OF THE SUBJECT ....

SIGNATURE OF THE SUBJECT ....

DATE ....

NUMBER OF YEARS PADDLING……………………………………

If you would like your **raw data** sent to you or **to be involved with the study at a later date** (delete as appropriate) please include your email address:

....

Appendix C: Participant Information Sheet – Phase 2 Sitting height efficiency

Participant Information Sheet – Phase 2 Sitting height efficiency calculation

Title of Project: Optimum sitting height for paddle stroke efficiency in female white water kayakers

Title of this Phase: Establishing the most efficient sitting height for female White Water Kayakers

Level of Study: MPhil/PhD

Investigator: Shelley Ellis
Contact details: sellis@bournemouth.ac.uk / sbroomf1@stu.chi.ac.uk / 01202961523

The Wider Project background
The project as a whole is designed to establish the optimum sitting height for female white water kayakers in order for them to achieve the best paddle stroke efficiency possible. The reasoning behind this aim is that current white water boats are designed around a male specification and then shrunk to fit smaller (often female) paddlers. This means that the boats are not specifically designed in order to allow for different anthropometric, or body, measurements of females when compared to males. This means that they are less likely to achieve an efficient forwards paddle stroke when compared to their male counterparts. It is believed that by raising sitting height in female boats, a more efficient stroke can be realised, however it is unknown how much the sitting height should be raised in order to achieve the "most" efficient paddle stroke, and this is what the project aims to find out. The project is split into 3 phases:

4. Anthropometrics of white water kayakers
5. Identifying the most efficient seat height
6. Testing the formula for calculating optimum sitting height.

This Phase of the Project: Phase 2

The purpose of this study is to establish the most efficient sitting height for female white water kayakers based on their anthropometrics or body sizes. This is the main phase of the overall project and will enable participants to find out which seat height was most mechanically efficient for them. This means the sitting height that gives you the most mechanically efficient paddle stroke, for example, the stroke that enables you to move the boat through the water more easily for the same amount of effort that you put in to paddling it. It will also enable further calculations to be carried out to establish a calculation that the rest of the population may be able to use in order to work out their own sitting height.

Why you have been asked to participate in Phase 2?

This research project requires female participants of 18 years or older who have been involved in white water kayaking for at least 2 years and have experience of paddling a number of rivers. They should be confident with paddling forwards. If you fit the above description then I would like to record your paddling in a controlled environment in order to work out which sitting height is most efficient for you.

If you agree, what will happen?

On day 1 of testing the following will take place:

By consenting to participate in the current investigation you will be asked some background information such as age, gender and length of time kayaking and then you will have some body measurements taken. These measurements taken will include your height, weight, arm span and sitting height. You will then have body landmarks located and marked using eye-liner pencil in order for more specific measurements to be taken. These will include:

- 8 Skinfold measures: triceps, subscapular, supraspinale, calf, abdominal, thigh, biceps and iliac crest.
- 6 lengths measured: upper arm, forearm, leg (to illiospinale), leg (to trochanterion), upper leg, lower leg.

- 6 breadth measures: Shoulder breadth, Anterior-Posterior (front to back) chest depth, transverse (across) chest breadth, pelvis breadth, humerus breadth and femur breadth.

- 8 girth measures taken: relaxed arm girth, flexed arm girth, chest girth, waist girth, hip girth, upper thigh girth, mid-thigh girth, calf girth.

These measurements will be taken on the right hand side of the body and will be measured twice, if needed a third measurement may be taken. Either an average or the median will be then be taken. You will be required to wear shorts and t-shirt (or a vest top will be better for females) for these measurements. Females wearing a vest top will be asked to move the top intermittently to allow certain sites to become available to measure. Dignity will be maintained at all times. The researcher is a qualified ISAK Anthropometrist. You will be able to see your raw results once collected.

Once the body measures have been taken, you will be asked to select your boat from the two sizes available. Then one of the paddles used for the study will be used to match your own paddle as closely as possible in terms of length, feather and blade size. You will then need to change into a swimming costume and have body markers attached to locations on your body. These will be on your head, arms, chest and back They will mostly be stuck to your skin with tape appropriate for skin use.

You will then be given time to adjust the boat fit for comfort and then you will be given some time to paddle the boat until you are fully familiar with the boat. You will do a few static trials of you sitting in your boat and then you will then be asked to paddle the boat across the length of a swimming pool at a comfortable speed 5 times for each seat raise. You will self-select the maximum seat raise you are able to fit in the boat comfortably with. The seat raises will be introduced in a random order and you will be able to adjust the boat for comfort in between height changes if needed.

On day 2:

You will be timed over a short slalom course in the pool. This will be done 3 times at each seat raise which will again be introduced to you in a random order. If there was not time to take the body measurements, these will also take place here.

Your rights

You are entitled to withdraw at any point during the investigation. Anonymity will be strictly maintained in the write up of any data. Post measurement, you will be provided with a copy of your own raw data if requested.

The investigation

It is aimed that the findings from this study will be disseminated through my PhD thesis, research journals, kayaking related publications, media, and social media, kayaking related conferences, and academic conferences and that this improved knowledge could be used to educate other people such as manufacturers of white water kayaking equipment to encourage them to use the data available to design appropriately fitting equipment, as well as coaches and National Governing Bodies to enhance their understanding of the white water kayaking population and enable them to advise participants and manufacturers appropriately regarding equipment use and fit. It is evident from existing research that a number of kayaking populations have been investigated for their athropometric make up, but these tend to be either elite populations of competitive athletes or children in order to talent ID them for elite competition. Therefore it is clear that the non-competitive population of white water kayakers deserve their own attention in order to achieve better understanding and use of appropriate and up to date data used to design equipment.

What will happen to the data collected?

The measurements taken from the data collection sessions will be securely stored for a minimum of three years post PhD completion. The data will be presented, where possible, as a population group and therefore individual data will not be visible. If individual data is presented, this will be done using a participant number and no names will be used to ensure anonymity. Primarily the data will be presented within the PhD thesis, which will be read and marked by examiners. The information from the thesis will further inform research journals, kayaking related publications, media, and social media, kayaking related conferences, and academic conferences, however again the protection and anonymity of participants will be paramount within this process.

What happens next?

After reading this information sheet and agreeing to participate within the project, we will arrange a mutually agreed time for measurement to take place. Before measurement is commenced, you will be asked to complete an informed consent form.

Further information

If you have any further questions regarding the project or the research process, feel free to contact me through the contact details at the beginning or end of the sheet.

Thank you for your time and consideration

Shelley
Shelley Ellis
Certified ISAK Anthropometrist
Lecturer in Biomechanics and Performance Analysis
Bournemouth University I Fern Barrow I Poole I Dorset I BH12 5BB
01202 961523

Or
Postgraduate Researcher
University of Chichester
Sbroomf1@stu.chi.ac.uk

Appendix D: Consent Form Study Two

University of Chichester

The University of Chichester

CONSENT FORM

Tel: +44 (0)1243 816000
Fax: +44 (0)1243 816080

Bishop Otter Campus,
College Lane,
Chichester,
West Sussex
PO19 6PE UK

www.chiuni.ac.uk

I, ………………………………………………………………………… (PRINT NAME)

hereby give my consent to participate in the following ~~test~~/activity *[please delete as appropriate]*.

The activity will involve having anthropometric data taken from the body, consisting of measurements of a range of body limbs and variety of heights being taken. This will include skinfold measurements; girth, width and length of limb measurements; height, sitting height and weight measurements. You will then be required to have markers attached to the skin and perform a number of trials kayaking the length of a swimming pool. Followed by on day 2 a slalom course will be navigated twice for each sitting height. By signing the below I am agreeing I have read and understood the participant information sheet and give full consent to the measurements taking place.

By signing this form I confirm that:

- the purpose of the test/activity has been explained to me;
- I am satisfied that I understand the procedures involved;
- the possible benefits and risks of the test/activity have been explained to me;
- any questions which I have asked about the test/activity have been answered to my satisfaction;
- I understand that, during the course of the test/activity, I have the right to ask further questions about it;
- the information which I have supplied to The University of Chichester prior to taking part in the test/activity is true and accurate to the best of my knowledge and belief and I understand that I must notify promptly of any changes to the information;
- I understand that my personal information will not be released to any third parties without my permission;
- I understand that my participation in the test/activity is voluntary and I am therefore at liberty to withdraw my involvement at any stage;
- I understand that, if there is any concern about the appropriateness of my continuing in the test/activity, I may be asked to withdraw my involvement at any stage;
- I understand that once the test/activity has been completed, the information gained as a result of it will be used for the following purposes only:

[Insert details]

Thesis in pursuit of PhD, journal articles, interest pieces and conference presentations.

NAME OF THE SUBJECT ……………………………………

SIGNATURE OF THE SUBJECT ……………………………

DATE ………………………………………………………………

NUMBER OF YEARS PADDLING……………………………

If you would like your **raw data** sent to you or **to be involved with the study at a later date** (delete as appropriate) please include your email address:

……………………………………………………………………

Appendix E: Raw data for participants

Table E.1: Participant 1 raw mean and SD data for boat movements

Mean and standard deviation raw data from each seat raise	Rolling R (degrees)	Rolling R SD (degrees)	Rolling L (degrees)	Rolling L SD (degrees)	Heave (mm)	Heave SD (mm)	Yaw (degrees)	Yaw SD (degrees)	Pitch (degrees)	Pitch SD (degrees)
0cm	2.50	0.78	-4.27	0.78	15.20	4.83	12.92	2.43	1.80	0.32
1cm	4.21	0.60	-2.78	1.28	17.74	5.03	11.58	1.84	1.56	0.36
2cm	2.87	1.12	-5.00	0.79	20.12	4.90	13.56	1.95	1.72	0.40
3cm	5.25	1.06	-3.09	0.91	18.91	4.74	12.68	2.84	1.83	0.45
4cm	3.07	1.03	-4.90	0.95	26.28	4.12	12.81	2.28	1.67	0.31
5cm	5.14	1.01	-4.67	1.11	16.11	2.91	12.77	1.79	1.62	0.34
6cm	4.00	1.75	-5.38	0.96	18.65	5.94	13.53	2.75	2.00	0.25
7cm	3.54	1.94	-3.88	1.24	17.61	5.16	12.33	2.27	1.88	0.38

Table E.2: Participant 1 raw mean and SD data for technique measures

mean and standard deviation raw data from each seat raise	Average velocity change (mm/s)	SD velocity change (mm/s)	Slalom (s)	slalom SD (s)	Average force R stroke (N)	Average force R SD (N)	Average force L stroke (N)	Average force L SD (N)	R arm reach (mm)	R arm reach SD (mm)	L arm reach (mm)	L arm reach SD (mm)	Stroke length R-L (mm)	Stroke length R-L SD (mm)	Stroke length L-R (mm)	Stroke length L-R SD (mm)
0cm	26.77	0.06	49.13	0.85	83.47	5.13	53.18	7.80	1200.90	11.51	1189.89	7.61	1635.77	106.48	1704.68	140.24
1cm	24.05	0.05	51.62	1.46	78.68	11.22	64.84	14.37	1193.04	12.42	1189.98	15.18	1727.40	188.43	1478.49	233.18
2cm	25.20	0.06	52.64	0.78	98.57	8.44	72.78	6.82	1223.76	12.27	1215.59	11.76	1810.97	74.04	1692.45	77.51
3cm	25.98	0.06	48.96	0.51	95.37	4.50	48.66	8.76	1216.09	14.40	1213.76	12.32	1876.45	265.47	1647.43	229.20
4cm	25.59	0.05	53.17	1.93	97.47	4.52	76.46	4.73	1210.52	13.78	1201.48	6.55	1748.90	93.94	1604.12	119.05
5cm	24.28	0.05	52.35	1.30	85.55	15.38	76.84	9.26	1199.09	12.90	1202.71	12.25	1712.39	92.74	1709.82	107.15
6cm	25.05	0.05	53.37	1.11	93.78	8.07	75.72	3.81	1200.46	14.44	1202.59	17.84	1738.32	196.48	1673.93	195.62
7cm	27.25	0.04	51.39	1.06	86.16	9.50	58.11	3.30	1158.74	15.70	1177.51	13.66	1682.32	129.71	1694.85	152.91

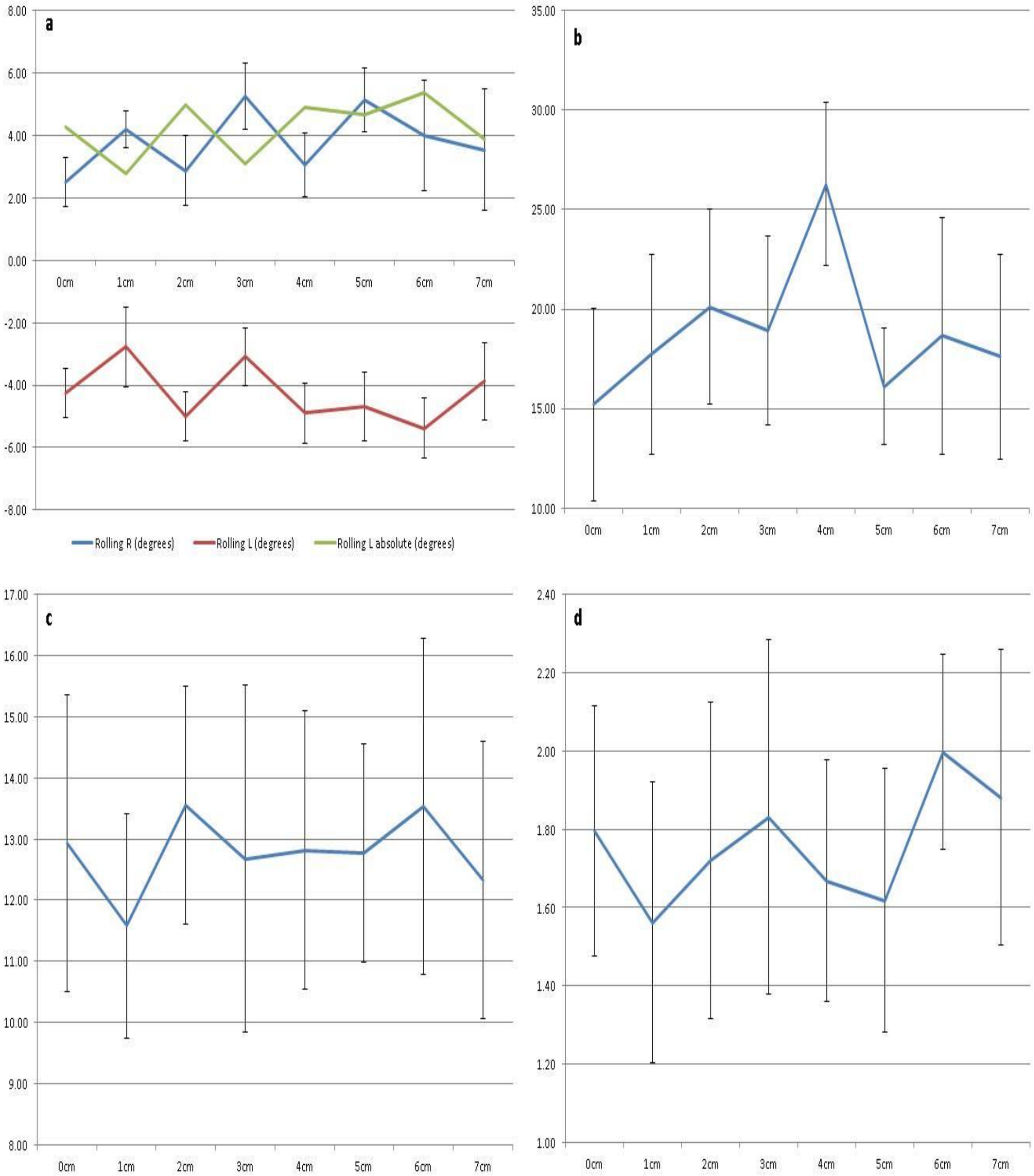


Figure E.1: Graphs to show boat movements for Participant 1. a) Rolling, b) Heave, c) Yaw, d) Pitch

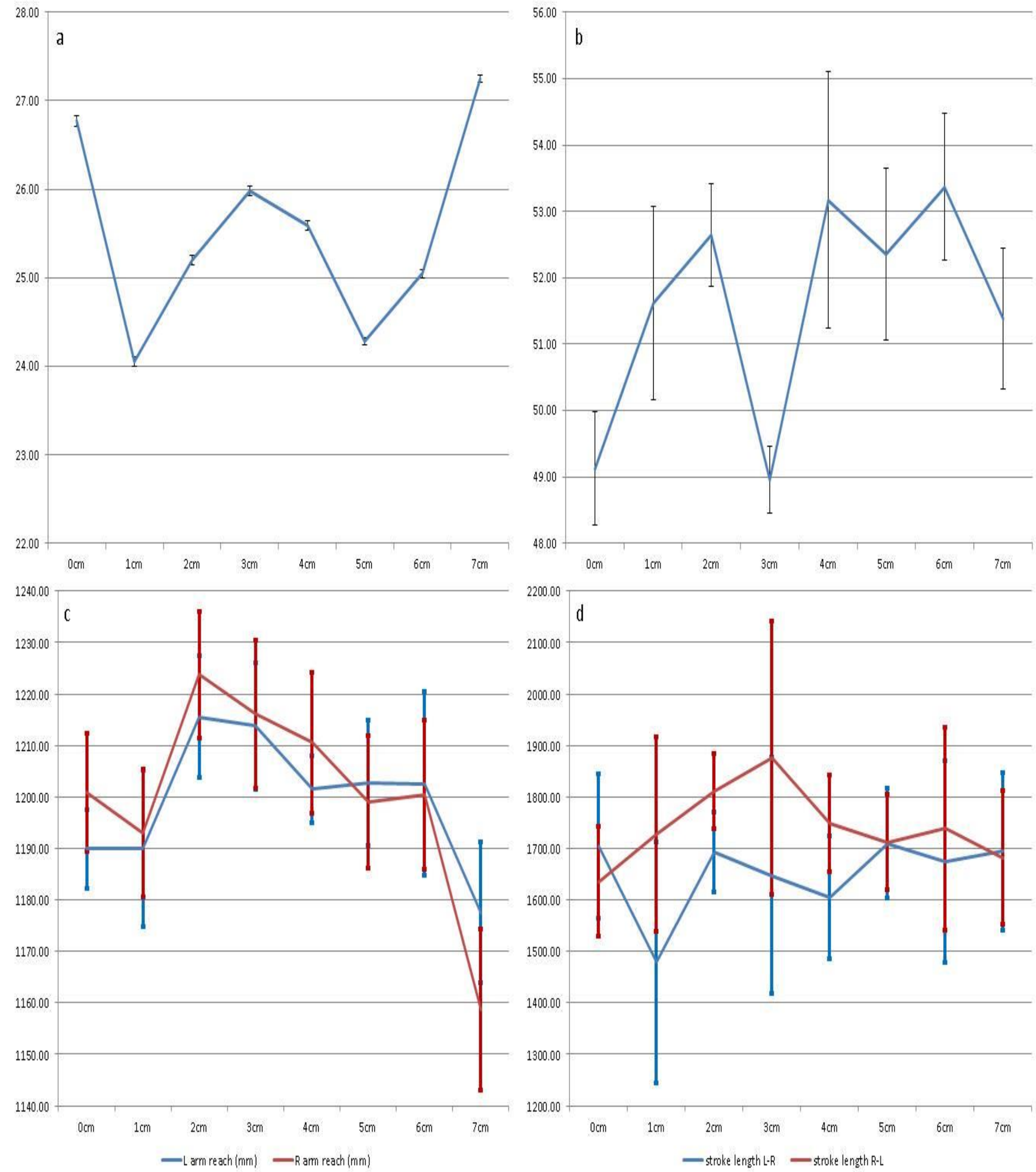


Figure E.2: Graphs to show technique measures for Participant 1. a) Average velocity change, b) Slalom times, c) Arm reach, d) Stroke length

Table E.3: Participant 2 raw mean and SD data for boat movements

mean and standard deviation raw data from each seat raise	Rolling R (degrees)	Rolling R SD (degrees)	Rolling L (degrees)	Rolling L SD (degrees)	Heave (mm)	Heave (mm)	Yaw (degrees)	Yaw SD (degrees)	Pitch (degrees)	Pitch SD (degrees)
0cm	6.56	2.46	-5.91	2.68	18.71	5.18	10.12	2.28	1.25	0.40
1cm	4.21	1.51	-4.93	1.21	21.23	7.09	8.80	2.48	1.22	0.29
2cm	7.91	2.83	-6.53	2.01	19.87	6.45	10.29	1.81	1.29	0.28
3cm	6.01	2.06	-6.25	1.49	21.33	5.77	9.72	3.39	1.16	0.34
4cm	5.07	2.13	-5.36	1.15	21.33	8.81	10.84	3.55	1.48	0.41
5cm	4.33	1.04	-6.56	1.29	16.96	5.95	10.05	2.51	1.24	0.35
6cm	4.75	2.30	-5.73	1.93	19.18	6.39	8.40	1.65	1.13	0.43
7cm										

Table E.4: Participant 2 raw mean and SD data for technique measures

mean and standard deviation raw data from each seat raise	Average velocity change (mm/s)	SD velocity change (mm/s)	Slalom (s)	slalom SD (s)	Average force R stroke (N)	Average force R SD (N)	Average force L stroke (N)	Average force L SD (N)	R arm reach (mm)	R arm reach SD (mm)	L arm reach (mm)	L arm reach SD (mm)	Stroke length R-L (mm)	Stroke length R-L SD (mm)	Stroke length L-R (mm)	Stroke length L-R SD (mm)
0cm	15.85	0.06	48.67	0.18	77.68	7.92	70.48	6.65	1198.18	14.89	1199.77	15.48	1336.77	132.26	1517.07	145.83
1cm	15.71	0.05	49.59	1.47	68.11	8.27	65.38	10.06	1200.37	20.74	1201.61	24.72	1438.87	118.44	1486.16	105.25
2cm	18.85	0.07	47.62	1.80	64.93	3.55	68.72	7.14	1204.56	17.68	1209.72	15.55	1343.07	177.13	1488.82	209.17
3cm	15.67	0.06	48.53	0.35	83.37	1.86	62.66	3.79	1187.39	19.21	1182.61	11.00	1275.29	154.41	1491.34	167.60
4cm	20.72	0.07	50.79	1.04	75.15	7.53	66.94	8.85	1188.82	17.52	1182.60	11.44	1474.43	167.08	1466.96	211.78
5cm	14.93	0.05	50.33	0.85	67.54	17.97	63.07	13.67	1186.79	13.15	1185.81	9.07	1270.80	137.23	1469.30	162.85
6cm	15.17	0.05	50.06	0.45	71.07	7.17	69.16	8.08	1180.08	11.52	1178.23	19.74	1369.12	196.61	1405.62	131.19
7cm																

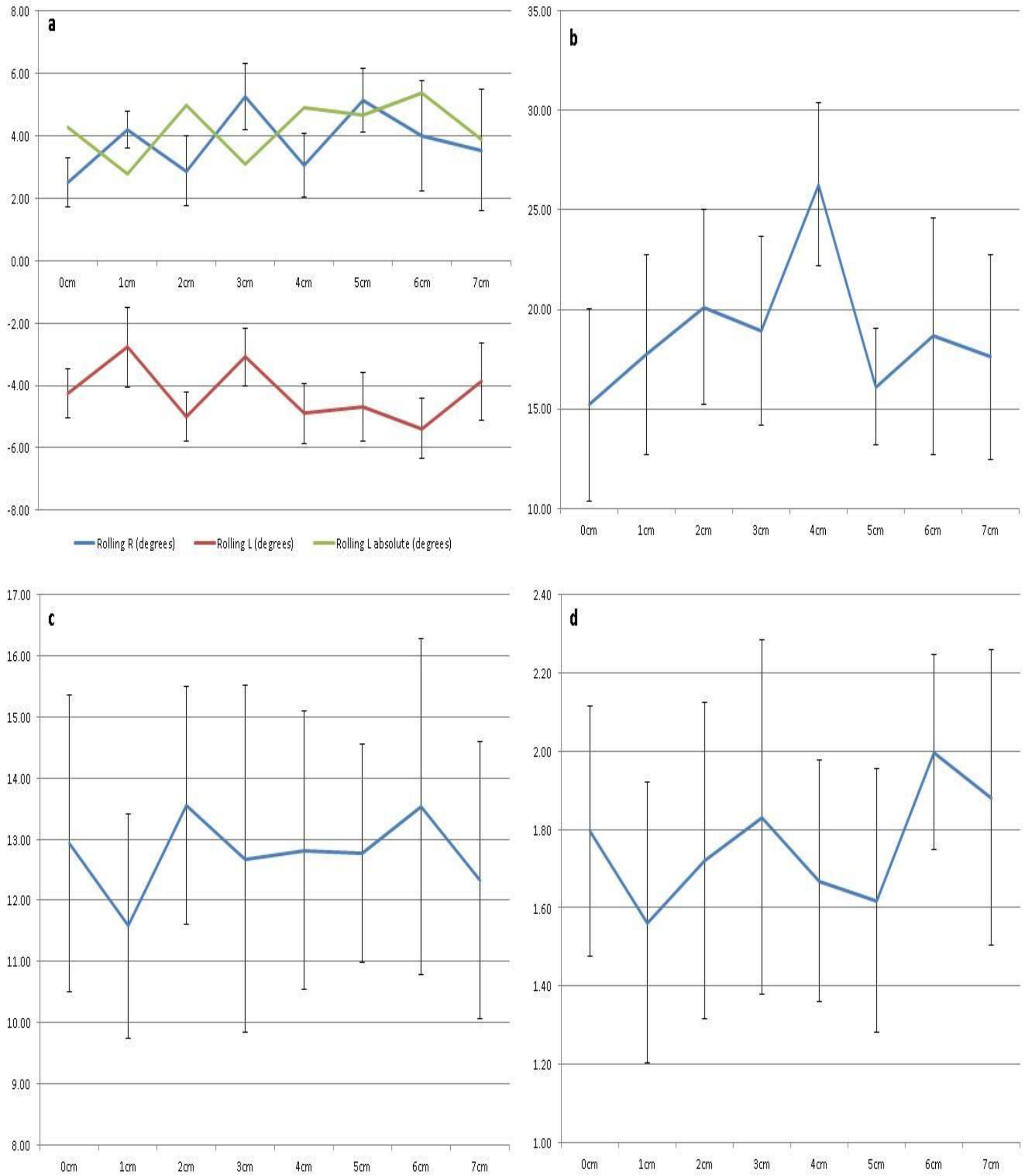


Figure E.3: Graphs to show boat movements for Participant 2. a) Rolling, b) Heave, c) Yaw, d) Pitch

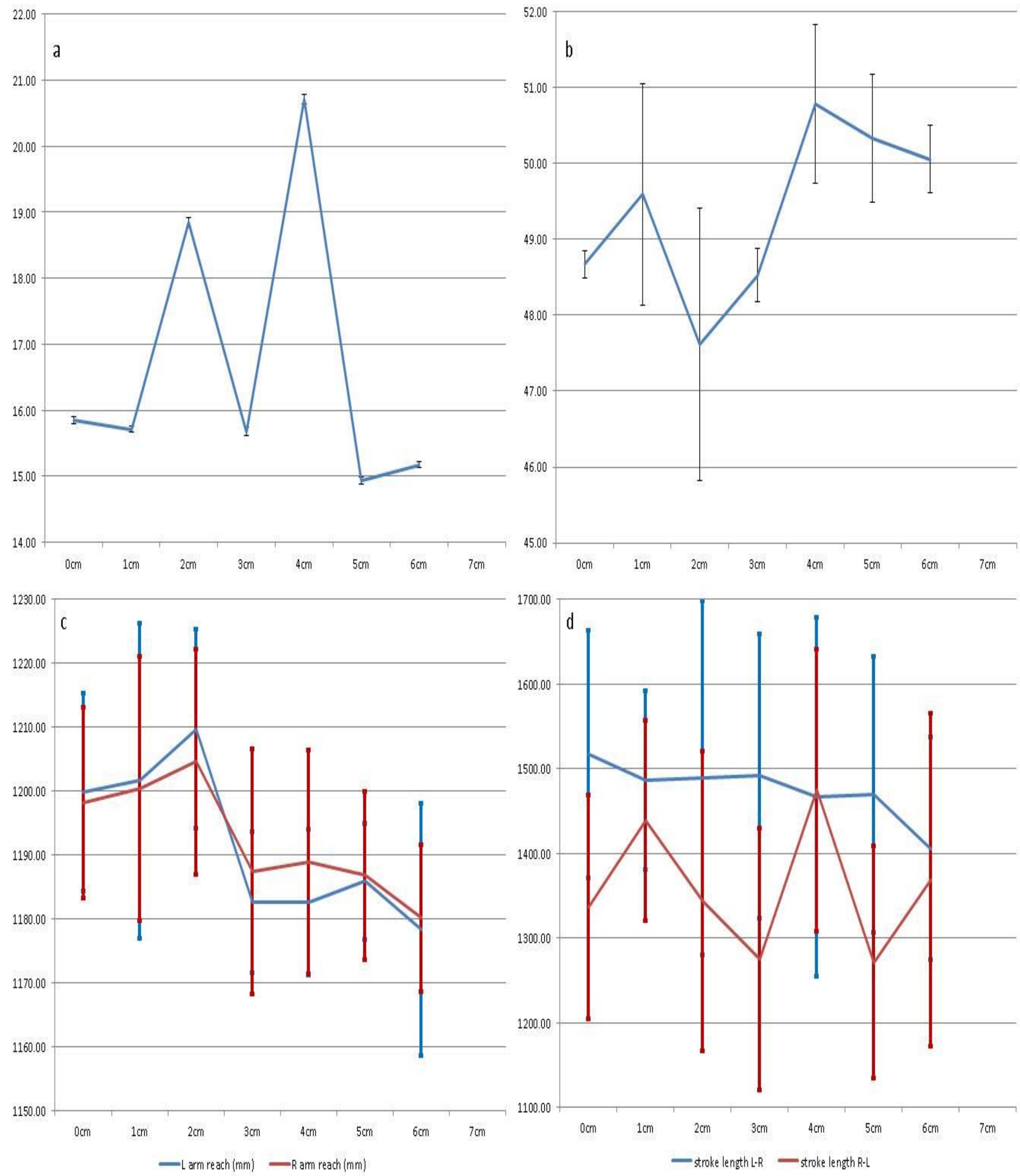


Figure E.4: Graphs to show technique measures for Participant 2. a) Average velocity change, b) Slalom times, c) Arm reach, d) Stroke length

Table E.5: Participant 3 raw mean and SD data for boat movements

mean and standard deviation raw data from each seat raise

	Rolling R (degrees)	Rolling R SD (degrees)	Rolling L (degrees)	Rolling L SD (degrees)	Heave (mm)	Heave (mm)	Yaw (degrees)	Yaw SD (degrees)	Pitch (degrees)	Pitch SD (degrees)
0cm	5.4922543	1.426257	-10.70489	1.413818	24.49004	4.302327	10.98582	2.16524174	2.12197	0.39626742
1cm	12.304917	3.255802	-7.342074	2.556	25.5935	8.59283	11.54512	1.92090613	2.133569	0.44582035
2cm	8.5487367	0.894084	-10.24223	2.674821	24.73784	7.402232	10.95041	1.66355091	1.777706	0.42656608
3cm	10.400007	1.704528	-7.538689	2.053807	21.92791	7.80049	10.33794	2.46768442	1.902954	0.37514927
4cm	11.700971	0.951432	-7.550446	1.886951	17.9906	8.558775	11.14694	2.75743402	2.092365	0.70224598
5cm	8.6682463	3.808218	-5.304788	2.81577	23.81857	7.917225	9.947764	2.5172027	2.216293	0.41000171
6cm	[redacted]									
7cm	[redacted]									

Table E.6: Participant 3 raw mean and SD data for technique measures

mean and standard deviation raw data from each seat raise

	Average velocity change (mm/s)	SD velocity change (mm/s)	Slalom (s)	slalom SD (s)	Average force R stroke (N)	Average force R SD (N)	Average force L stroke (N)	Average force L SD (N)	R arm reach (mm)	R arm reach SD (mm)	L arm reach (mm)	L arm reach SD (mm)	Stroke length R-L (mm)	Stroke length R-L SD (mm)	Stroke length L-R (mm)	Stroke length L-R SD (mm)
0cm	29.93	0.07	57.17	0.47	103.08	8.49	83.75	5.61	1262.38	15.52	1271.93	19.72	1616.70	140.60	1752.28	207.94
1cm	32.49	0.06	62.41	1.01	104.40	6.41	86.11	9.85	1285.85	15.45	1268.13	19.28	1653.97	101.97	1663.46	203.20
2cm	24.57	0.07	59.16	0.99	92.06	11.33	91.81	5.34	1271.17	12.96	1273.62	13.14	1471.07	197.64	1601.80	133.20
3cm	28.90	0.06	58.70	1.29	92.40	5.87	86.31	6.74	1268.34	14.28	1263.78	20.35	1423.88	349.54	1852.46	259.03
4cm	29.32	0.06	65.14	5.81	102.88	7.59	98.49	11.59	1283.13	20.89	1251.73	20.85	1455.86	376.69	1568.22	183.09
5cm	33.68	0.07	58.82	2.85	102.59	14.33	93.08	2.05	1304.34	17.31	1279.25	15.58	1514.39	273.91	1807.97	282.87
6cm	[redacted]															
7cm	[redacted]															

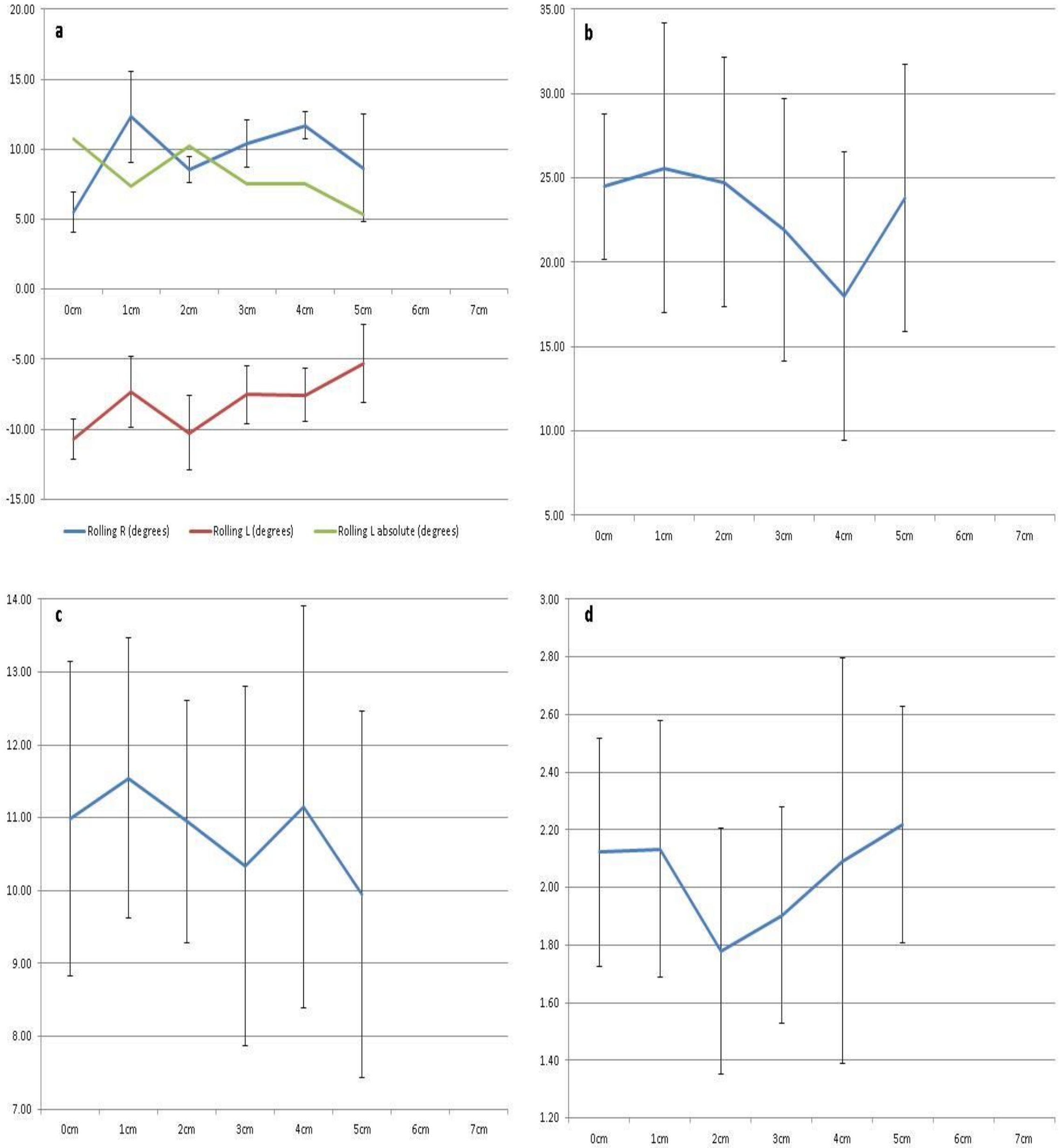


Figure E.5: Graphs to show boat movements for Participant 3. a) Rolling, b) Heave, c) Yaw, d) Pitch

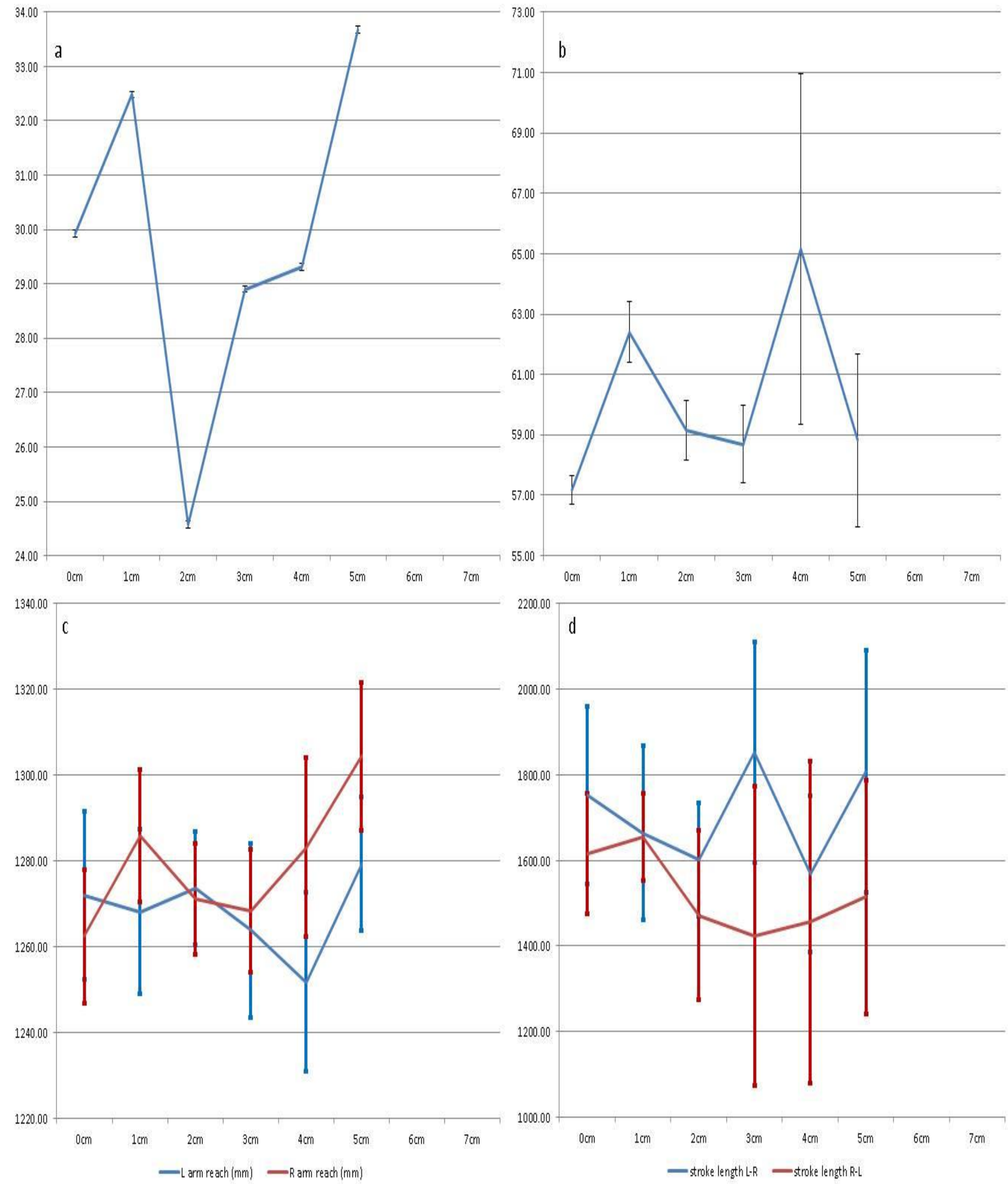


Figure E.6: Graphs to show technique measures for Participant 3. a) Average velocity change, b) Slalom times, c) Arm reach, d) Stroke length

Table E.7: Participant 4 raw mean and SD data for boat movements

		Rolling R (degrees)	Rolling R SD (degrees)	Rolling L (degrees)	Rolling L SD (degrees)	Heave (mm)	Heave (mm)	Yaw (degrees)	Yaw SD (degrees)	Pitch (degrees)	Pitch SD (degrees)
mean and standard deviation raw data from each seat raise	0cm	6.56	2.10	-9.43	1.22	13.42	4.67	11.92	1.90	3.84	0.93
	1cm	6.94	2.31	-7.84	1.49	16.83	7.27	13.16	2.22	4.49	0.74
	2cm	5.17	1.85	-9.54	3.26	15.97	7.54	11.80	2.92	5.99	1.15
	3cm	5.44	2.66	-10.61	1.84	19.04	9.35	13.96	2.47	5.51	0.93
	4cm	5.60	3.33	-11.35	2.76	14.89	7.72	11.19	2.92	5.13	0.88
	5cm	5.96	1.62	-8.21	2.45	20.60	6.00	12.90	1.87	4.73	1.07
	6cm	[redacted]									
	7cm										

Table E.8: Participant 4 raw mean and SD data for technique measures

		Average velocity change (mm/s)	SD velocity change (mm/s)	Slalom (s)	slalom SD (s)	Average force R stroke (N)	Average force R SD (N)	Average force L stroke (N)	Average force L SD (N)	R arm reach (mm)	R arm reach SD (mm)	L arm reach (mm)	L arm reach SD (mm)	Stroke length R-L (mm)	Stroke length R-L SD (mm)	Stroke length L-R (mm)	Stroke length L-R SD (mm)
mean and standard deviation raw data from each seat raise	0cm	37.42	0.13	58.41	0.75	119.95	14.45	121.40	20.85	1168.16	32.93	1164.93	35.07	1461.17	158.72	1368.88	219.31
	1cm	40.98	0.09	59.07	4.87	142.84	19.68	114.73	15.55	1180.84	36.54	1190.82	30.05	1503.35	151.76	1444.94	154.90
	2cm	44.31	0.13	54.32	0.56	171.37	19.97	130.82	11.78	1204.86	37.87	1178.02	47.24	1416.16	118.50	1484.86	120.09
	3cm	25.01	0.78	60.05	0.37	144.46	23.81	112.25	19.80	1168.19	35.60	1191.83	52.77	1649.59	392.80	1366.26	352.03
	4cm	41.27	0.10	56.54	1.40	167.79	21.67	128.36	6.00	1163.17	48.19	1163.21	54.28	1464.14	139.67	1438.55	199.87
	5cm	43.35	0.07	59.20	1.18	143.63	26.95	119.22	5.01	1150.86	30.46	1169.27	42.06	1676.36	116.84	1534.50	113.76
	6cm	[redacted]															
	7cm																

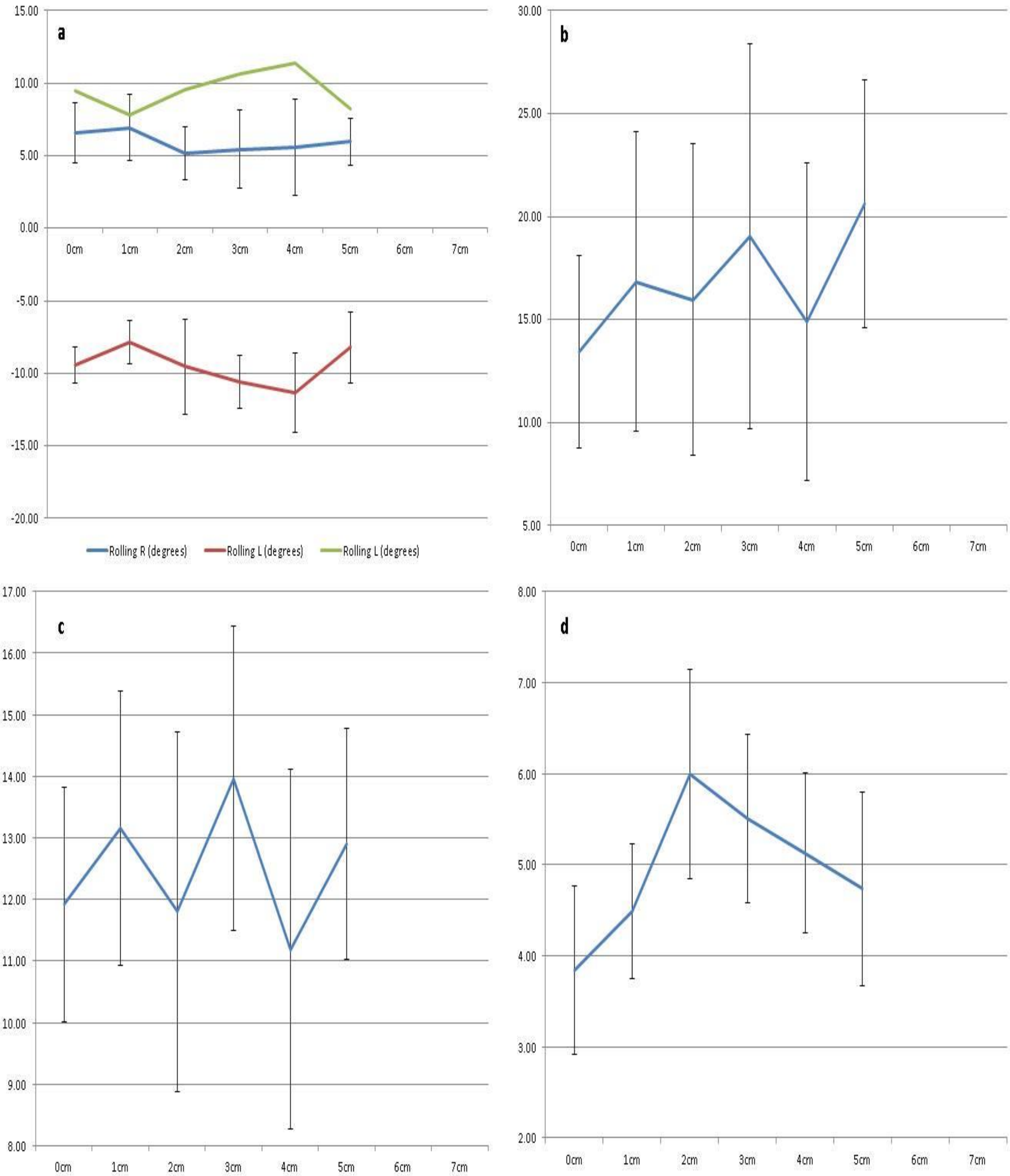


Figure E.7: Graphs to show boat movements for Participant 4. a) Rolling, b) Heave, c) Yaw, d) Pitch

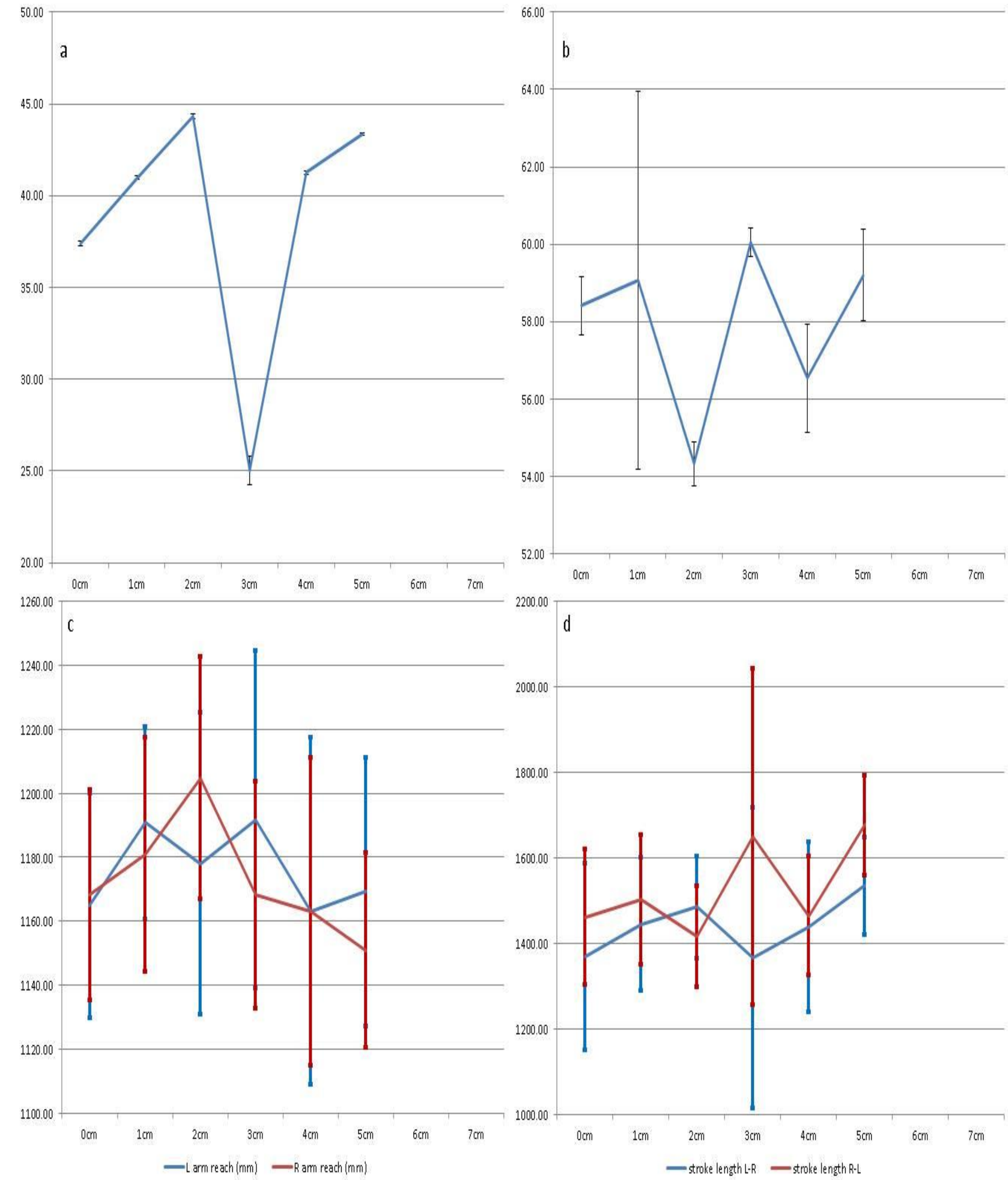


Figure E.8: Graphs to show technique measures for Participant 4. a) Average velocity change, b) Slalom times, c) Arm reach, d) Stroke length

Table E.9: Participant 5 raw mean and SD data for boat movements

mean and standard deviation raw data from each seat raise	Rolling R (degrees)	Rolling R SD (degrees)	Rolling L (degrees)	Rolling L SD (degrees)	Heave (mm)	Heave (mm)	Yaw (degrees)	Yaw SD (degrees)	Pitch (degrees)	Pitch SD (degrees)
0cm	2.93	1.86	-3.63	1.72	26.70	5.17	11.81	2.20	1.48	0.31
1cm	2.27	1.38	-2.12	0.67	27.33	6.91	11.31	2.80	1.49	0.36
2cm	2.47	1.38	-2.41	1.59	26.20	5.97	10.77	2.20	1.50	0.29
3cm	3.79	1.01	-2.55	1.73	24.32	8.37	10.50	2.53	1.55	0.31
4cm	5.25	2.43	-1.57	0.48	25.92	5.75	11.32	2.41	1.53	0.33
5cm	3.33	1.88	-2.66	1.89	24.29	5.24	10.81	2.93	1.69	0.34
6cm	[redacted]									
7cm										

Table E.10: Participant 5 raw mean and SD data for technique measures

mean and standard deviation raw data from each seat raise	Average velocity change (mm/s)	SD velocity change (mm/s)	Slalom (s)	slalom SD (s)	Average force R stroke (N)	Average force R SD (N)	Average force L stroke (N)	Average force L SD (N)	R arm reach (mm)	R arm reach SD (mm)	L arm reach (mm)	L arm reach SD (mm)	Stroke length R-L (mm)	Stroke length R-L SD (mm)	Stroke length L-R (mm)	Stroke length L-R SD (mm)
0cm	23.15	0.05	58.01	0.58	91.92	14.75	74.92	10.56	1240.70	15.42	1216.83	15.69	1371.71	108.40	1529.75	156.31
1cm	21.06	0.07	58.41	0.58	92.08	5.25	64.62	3.34	1229.86	21.18	1229.01	19.39	1341.32	152.89	1571.12	140.34
2cm	23.25	0.05	58.75	1.00	96.19	11.94	74.42	6.14	1224.92	27.83	1229.19	18.26	1360.92	123.14	1558.63	196.83
3cm	22.91	0.05	58.84	1.10	90.65	11.00	89.51	14.72	1249.03	12.54	1218.77	26.92	1305.41	162.49	1663.01	1305.41
4cm	23.23	0.03	58.20	0.78	88.30	8.16	66.78	9.35	1230.17	28.88	1209.80	21.88	1364.11	116.37	1587.60	142.44
5cm	22.18	0.05	60.27	0.84	79.88	5.05	86.61	8.99	1224.58	22.25	1204.26	20.21	1365.47	104.33	1557.12	104.67
6cm	[redacted]															
7cm																

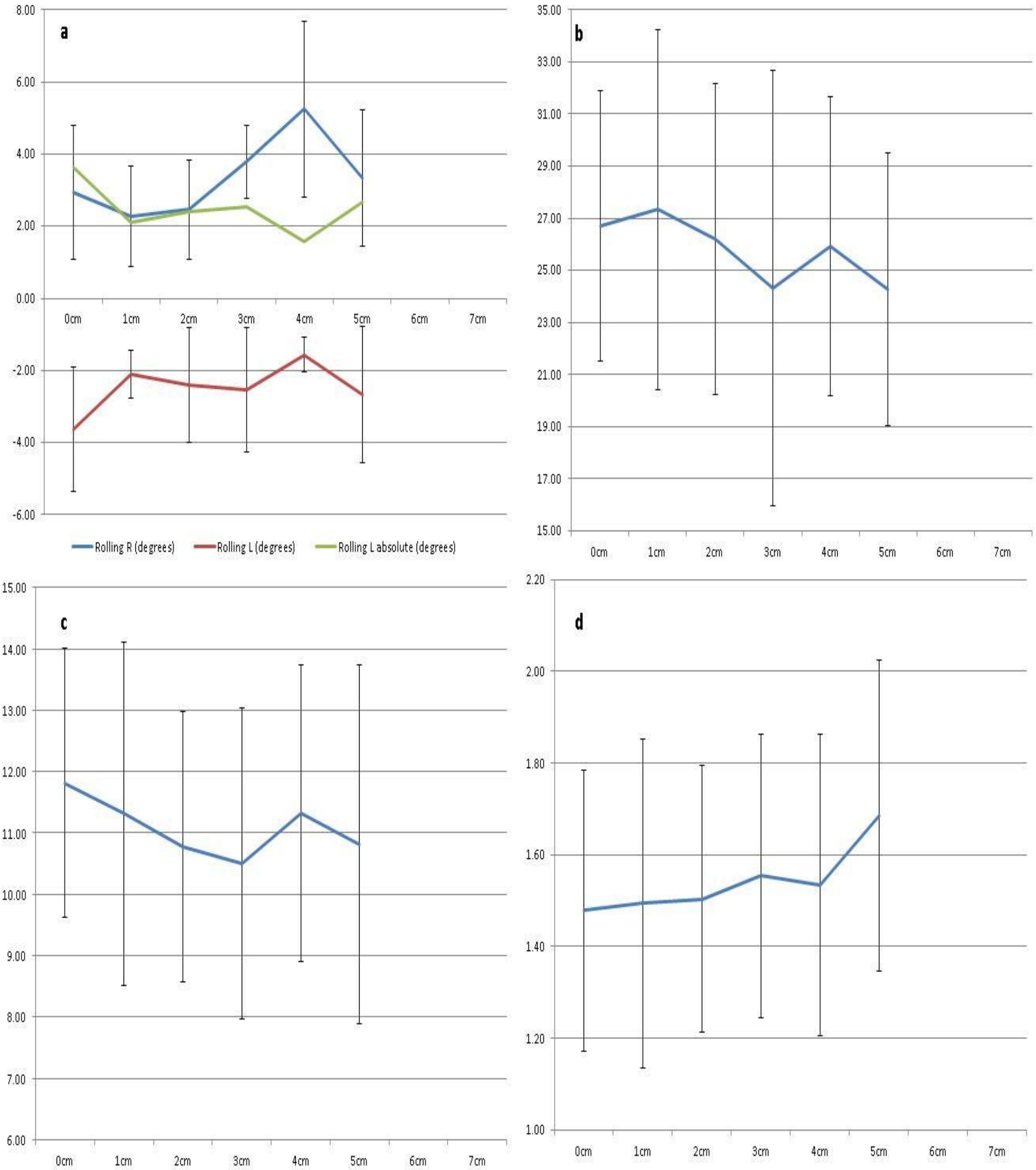


Figure E.9: Graphs to show boat movements for Participant 5. a) Rolling, b) Heave, c) Yaw, d) Pitch

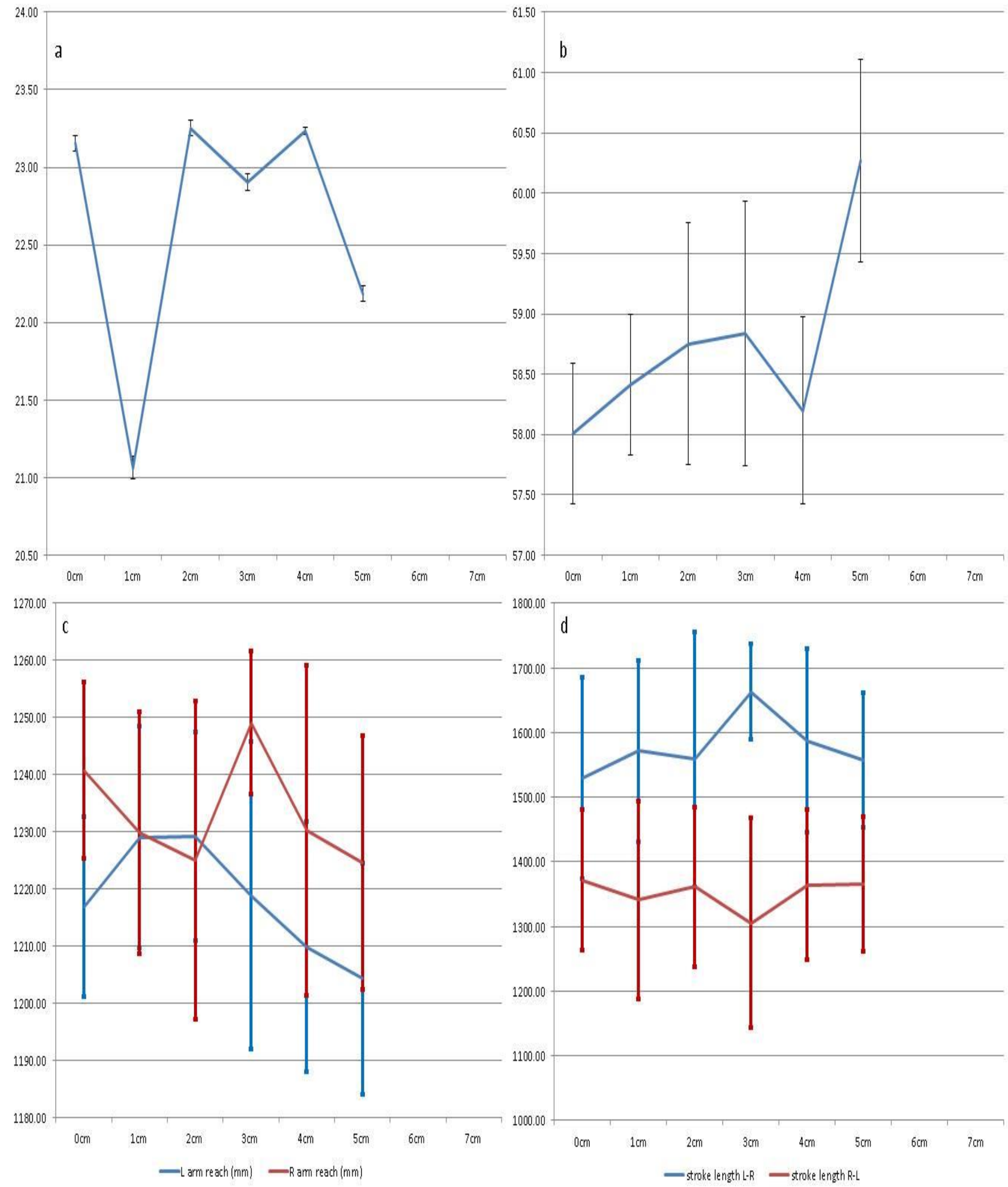


Figure E.10: Graphs to show technique measures for Participant 5. a) Average velocity change, b) Slalom times, c) Arm reach, d) Stroke length

Table E.11: Participant 6 raw mean and SD data for boat movements

mean and standard deviation raw data from each seat raise		Rolling R (degrees)	Rolling R SD (degrees)	Rolling L (degrees)	Rolling L SD (degrees)	Heave (mm)	Heave (mm)	Yaw (degrees)	Yaw SD (degrees)	Pitch (degrees)	Pitch SD (degrees)
	0cm	9.32	1.90	-7.81	1.27	16.97	5.80	15.06	3.52	1.61	0.52
	1cm	7.01	1.33	-8.78	1.96	17.29	6.53	15.14	3.38	1.63	0.50
	2cm	5.72	1.34	-11.25	1.32	18.27	6.01	14.78	2.51	1.95	0.65
	3cm	6.70	2.07	-10.34	2.44	19.04	7.82	15.66	3.29	1.99	0.55
	4cm	7.08	1.86	-10.06	1.37	14.85	4.29	14.23	2.52	1.66	0.62
	5cm	7.32	1.62	-9.63	1.45	17.10	4.35	15.58	3.53	1.89	0.60
	6cm	8.52	1.97	-9.15	1.79	17.76	6.04	13.40	2.83	1.82	0.68
	7cm	5.58	2.13	-10.16	2.49	15.27	4.55	13.13	2.71	1.64	0.59

Table E.12: Participant 6 raw mean and SD data for technique measures

mean and standard deviation raw data from each seat raise		Average velocity change (mm/s)	SD velocity change (mm/s)	Slalom (s)	slalom SD (s)	Average force R stroke (N)	Average force R SD (N)	Average force L stroke (N)	Average force L SD (N)	R arm reach (mm)	R arm reach SD (mm)	L arm reach (mm)	L arm reach SD (mm)	Stroke length R-L (mm)	Stroke length R-L SD (mm)	Stroke length L-R (mm)	Stroke length L-R SD (mm)
	0cm	24.60	0.08	61.93	0.28	95.33	5.81	121.49	5.81	1223.26	28.33	1263.01	28.63	1613.05	139.88	1589.04	137.41
	1cm	22.50	0.09	59.54	1.62	107.85	8.79	125.26	7.43	1211.21	21.51	1253.44	20.14	1567.10	126.55	1561.89	132.99
	2cm	25.17	0.09	61.86	1.22	108.30	8.66	112.84	12.19	1198.95	17.44	1261.47	24.96	1505.81	83.34	1498.87	86.92
	3cm	27.91	0.09	62.01	1.53	103.66	2.65	125.36	4.45	1225.54	26.59	1267.21	35.37	1584.06	199.16	1560.01	139.53
	4cm	23.99	0.07	60.49	0.81	93.70	8.55	106.39	9.66	1217.92	24.72	1258.37	25.21	1537.61	96.24	1543.35	117.43
	5cm	25.46	0.08	61.66	1.87	105.37	7.57	128.00	8.72	1235.27	19.23	1264.35	32.13	1564.38	119.72	1494.45	97.82
	6cm	23.60	0.09	63.28	0.84	100.44	8.04	108.15	8.59	1221.18	29.84	1253.77	23.22	1525.65	126.86	1519.61	180.79
	7cm	21.74	0.11	63.26	0.58	97.51	10.47	117.58	6.87	1222.06	23.15	1265.16	25.94	1562.13	157.49	1506.11	115.81

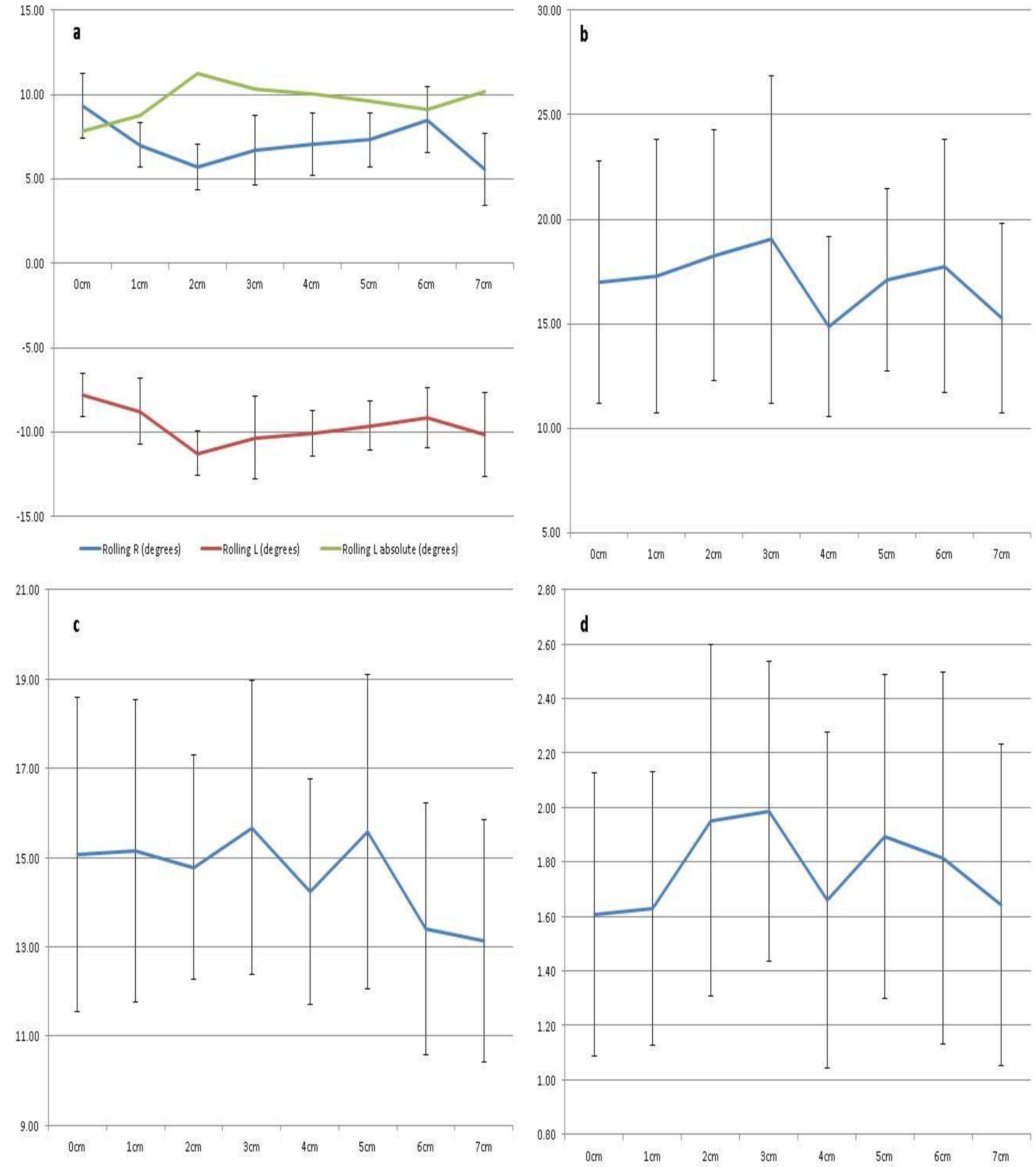


Figure E.11: Graphs to show boat movements for Participant 6. a) Rolling, b) Heave, c) Yaw, d) Pitch

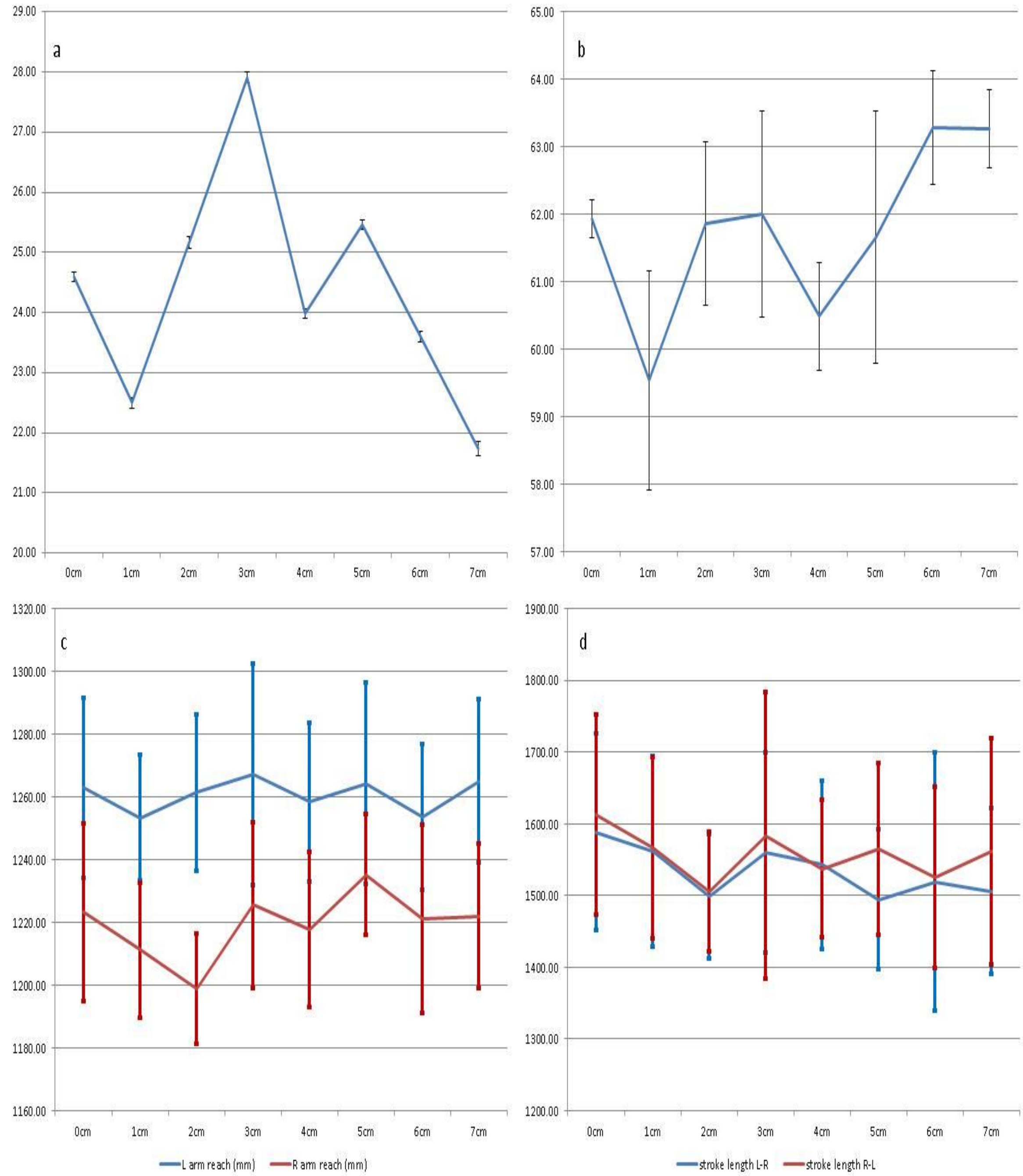


Figure E.12: Graphs to show technique measures for Participant 6. a) Average velocity change, b) Slalom times, c) Arm reach, d) Stroke length

Table E.13: Participant 7 raw mean and SD data for boat movements

mean and standard deviation raw data from each seat raise	Rolling R (degrees)	Rolling R SD (degrees)	Rolling L (degrees)	Rolling L SD (degrees)	Heave (mm)	Heave (mm)	Yaw (degrees)	Yaw SD (degrees)	Pitch (degrees)	Pitch SD (degrees)
0cm	4.70	1.80	-2.68	0.93	37.27	9.63	9.58	2.24	2.23	0.48
1cm	4.36	1.80	-2.32	2.40	35.97	7.20	10.43	2.20	2.52	0.47
2cm	1.84	2.97	-3.34	1.06	37.76	5.87	7.98	3.07	2.48	0.50
3cm	5.43	4.13	-3.76	3.57	27.59	7.04	8.58	2.59	2.48	0.64
4cm	4.17	2.79	-2.01	1.87	34.19	6.82	11.76	1.36	2.29	0.41
5cm	1.88	2.99	-3.09	3.27	33.53	10.14	8.66	1.51	2.49	0.55
6cm	[redacted]									
7cm										

Table E.14: Participant 7 raw mean and SD data for technique measures

mean and standard deviation raw data from each seat raise	Average velocity change (mm/s)	SD velocity change (mm/s)	Slalom (s)	slalom SD (s)	Average force R stroke (N)	Average force R SD (N)	Average force L stroke (N)	Average force L SD (N)	R arm reach (mm)	R arm reach SD (mm)	L arm reach (mm)	L arm reach SD (mm)	Stroke length R-L (mm)	Stroke length R-L SD (mm)	Stroke length L-R (mm)	Stroke length L-R SD (mm)
0cm	24.72	0.08	62.86	0.50	171.03	19.84	179.81	10.80	1332.51	16.53	1320.81	27.70	1788.52	199.62	1674.80	78.53
1cm	31.25	0.11	63.83	1.43	153.26	14.21	198.72	11.39	1361.24	14.16	1351.77	36.70	1792.84	103.85	1724.51	153.63
2cm	31.80	0.10	63.55	2.35	164.43	24.46	173.45	13.93	1321.65	38.17	1303.86	23.19	1858.26	161.18	1666.79	129.53
3cm	31.26	0.15	64.73	0.63	179.95	10.34	195.44	6.02	1354.39	13.54	1339.81	44.98	1682.81	188.94	1554.81	188.31
4cm	28.89	0.05	66.13	1.23	152.35	10.93	168.33	9.89	1331.16	34.08	1297.29	22.84	1910.78	236.76	1536.32	344.13
5cm	29.76	0.07	66.84	1.43	172.78	16.60	172.58	8.11	1351.59	21.54	1331.35	34.13	1704.18	228.61	1707.28	147.83
6cm	[redacted]															
7cm																

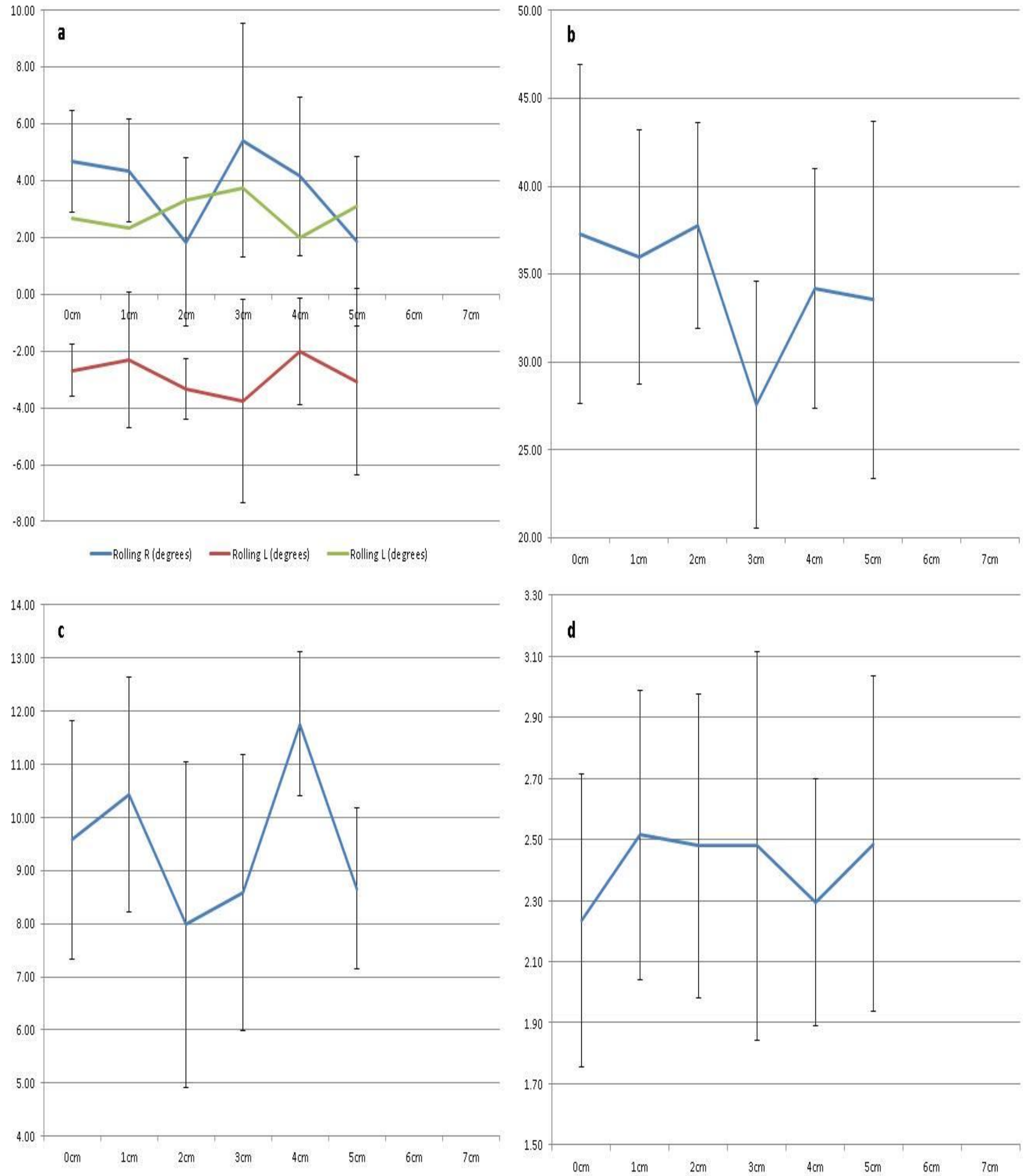


Figure E.13: Graphs to show boat movements for Participant 7. a) Rolling, b) Heave, c) Yaw, d) Pitch

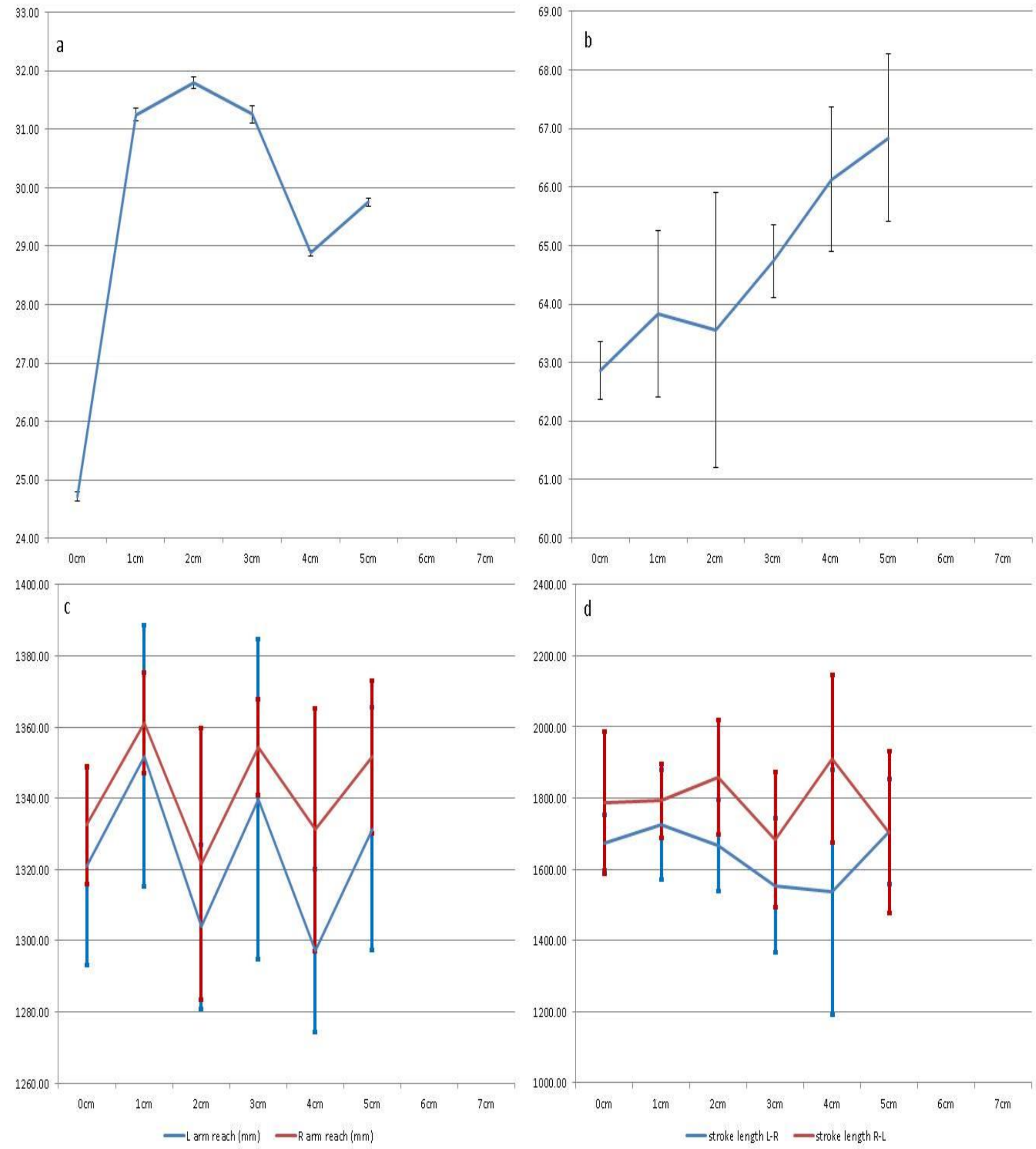


Figure E.14: Graphs to show technique measures for Participant 7. a) Average velocity change, b) Slalom times, c) Arm reach, d) Stroke length

Appendix F: Calculating efficiency raw data for all methods all participants

Table F.1: Participant 1 results used to rank the first, first and second and ranking scores for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	1	4	1	6	5	7	2	2	2	4	7	8	2
1	6	1	4	1	1	1	4	1	4	7	6	5	8
2	2	7	7	8	4	4	6	8	5	1	1	2	4
3	8	2	6	3	6	6	1	6	1	2	2	1	6
4	3	6	8	5	3	5	7	7	7	3	5	3	7
5	7	5	2	4	2	2	5	3	8	6	3	6	1
6	5	8	5	7	8	3	8	5	6	5	4	4	5
7	4	3	3	2	7	8	3	4	3	8	8	7	3

Table F.2: Participant 1 results used to calculate percentage difference for each seat raise from most efficient result.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	0	42.40	0	10.99	13.92	10.70	0.34	5.90	8.87	1.89	2.14	13.71	0.30
1	51.09	0	15.47	0	0	0	5.29	0	28.51	2.54	2.13	8.27	14.51
2	14.00	57.18	27.88	15.73	9.61	4.65	7.25	22.44	39.72	0	0	3.55	1.02
3	71.11	10.57	21.80	9.05	15.90	7.71	0	19.17	0	0.63	0.15	0	3.72
4	20.52	55.30	53.46	10.13	6.62	6.19	8.24	21.33	44.44	1.09	1.17	7.04	6.38
5	69.25	50.93	5.85	9.78	3.57	0.96	6.70	8.36	44.92	2.04	1.07	9.14	0
6	46.33	63.90	20.43	15.58	24.50	4.05	8.62	17.51	43.52	1.92	1.08	7.64	2.12
7	34.55	33.17	14.71	6.29	18.59	12.46	4.85	9.07	17.70	5.46	3.18	10.91	0.88

Table F.3: Participant 1 results used to calculate percentiles for each seat raise from most efficient to inefficient result.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	0	57.31	0	68.09	53.57	85.08	3.82	24.05	16.03	35.16	67.49	100	2.22
1	62.18	0	22.97	0	0	0	60.33	0	57.41	47.25	67.26	61.93	100
2	13.64	85.28	44.39	100	36.13	35.83	83.53	100	85.57	0	0	27.20	7.51
3	100	11.88	33.54	55.52	61.87	60.37	0	83.91	0	11.80	4.80	0	26.97
4	20.72	81.39	100	62.50	24.51	48.07	95.43	94.50	98.65	20.35	37.07	52.99	45.69
5	96.01	72.76	8.26	60.21	13.00	7.28	76.92	34.53	100	37.94	33.82	68.17	0
6	54.64	100	31.19	98.95	100	31.15	100	75.94	96.02	35.83	34.14	57.39	15.51
7	37.85	42.35	21.76	38.01	73.40	100	55.12	37.59	33.52	100	100	80.66	6.47

Table F.4: Participant 1 results used to calculate coefficient of variation for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	31.22	18.36	31.79	18.79	17.76	0.24	1.74	6.14	14.67	0.96	0.64	6.51	8.23
1	14.23	45.96	28.33	15.86	23.03	0.22	2.82	14.26	22.17	1.04	1.28	10.91	15.77
2	39.15	15.88	24.34	14.38	23.55	0.23	1.48	8.56	9.37	1.00	0.97	4.09	4.58
3	20.25	29.65	25.04	22.37	24.74	0.22	1.03	4.72	18.00	1.18	1.01	14.15	13.91
4	33.63	19.40	15.66	17.79	18.42	0.20	3.63	4.63	6.19	1.14	0.55	5.37	7.42
5	19.59	23.66	18.05	14.05	20.84	0.19	2.48	17.98	12.06	1.08	1.02	5.42	6.27
6	43.80	17.89	31.82	20.33	12.42	0.20	2.07	8.61	5.03	1.20	1.48	11.30	11.69
7	54.77	32.07	29.29	18.44	20.05	0.14	2.07	11.02	5.68	1.36	1.16	7.71	9.02

Table F.5: Participant 1 results used to calculate standard error of the mean for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	0.23	0.30	1.39	0.65	0.08	0.02	0.35	2.29	3.49	2.97	2.20	30.74	44.35
1	0.20	0.52	1.26	0.58	0.08	0.01	0.59	5.61	7.19	3.11	4.21	52.26	70.31
2	0.37	0.46	1.41	0.56	0.10	0.02	0.32	4.22	3.41	3.54	3.72	24.68	25.84
3	0.38	0.37	1.12	0.86	0.10	0.01	0.21	2.01	3.92	3.72	3.56	80.04	69.11
4	0.36	0.39	1.03	0.69	0.08	0.02	0.79	2.26	2.37	4.15	2.07	29.71	45.00
5	0.34	0.45	0.78	0.54	0.09	0.01	0.53	7.69	4.63	3.72	4.33	32.79	37.88
6	0.55	0.36	1.65	0.87	0.07	0.02	0.45	4.04	1.91	4.35	5.95	65.49	73.94
7	0.58	0.39	1.18	0.63	0.08	0.01	0.43	4.25	1.47	3.93	3.65	34.67	46.10

Table F.6: Participant 2 results used to rank the first, first and second and ranking scores for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	6	4	2	5	5	5	3	6	7	3	3	5	1
1	1	1	5	2	3	4	4	3	3	2	2	2	4
2	7	6	4	6	6	6	1	1	5	1	1	4	3
3	5	5	6	3	2	3	2	7	1	5	5	6	2
4	4	2	7	7	7	7	7	5	4	4	6	1	6
5	2	7	1	4	4	1	6	2	2	6	4	7	5
6	3	3	3	1	1	2	5	4	6	7	7	3	7
7													

Table F.7: Participant 2 results used to calculate percentage difference for each seat raise from most efficient result.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	43.63	18.03	9.77	18.59	9.93	6.01	2.19	17.88	11.74	0.53	0.83	9.79	0
1	0	0	22.36	4.74	7.48	5.10	4.07	4.78	4.24	0.35	0.67	2.44	2.06
2	61.08	27.88	15.79	20.26	12.46	23.19	0	0	9.23	0	0	9.32	1.88
3	35.31	23.59	22.78	14.64	2.47	4.85	1.89	24.86	0	1.44	2.27	14.48	1.71
4	18.49	8.35	22.80	25.39	26.31	32.48	6.45	14.60	6.60	1.32	2.27	0	3.36
5	2.89	28.41	0	17.95	8.57	0	5.54	3.95	0.65	1.49	2.00	14.84	3.20
6	12.11	15.00	12.29	0	0	1.63	5.00	9.03	9.86	2.05	2.64	7.41	7.63
7													

Table F.8: Participant 2 results used to calculate percentiles for each seat raise from most efficient to inefficient result.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	63.46	59.83	39.89	70.49	34.51	15.97	33.30	69.17	100	26.07	31.59	67.61	0
1	0	0	97.79	16.71	25.66	13.50	62.29	17.24	34.75	17.12	25.77	17.47	27.73
2	100	97.84	66.62	77.50	43.87	67.64	0	0	77.58	0	0	64.51	25.34
3	48.77	80.76	99.88	54.33	8.25	12.82	28.68	100	0	70.12	86.10	97.80	23.09
4	23.17	26.30	100	100	100	100	100	55.46	54.70	64.31	86.15	0	44.96
5	3.34	100	0	67.80	29.55	0	85.50	14.18	5.21	72.60	75.93	100	42.86
6	14.66	48.97	50.85	0	0	4.23	76.89	33.30	83.14	100	100	51.72	100
7	[redacted]												

Table F.9: Participant 2 results used to calculate coefficient of variation for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	37.55	45.40	27.69	22.51	31.63	0.36	0.37	10.19	9.44	1.24	1.29	9.89	9.61
1	35.81	24.44	33.37	28.18	24.06	0.30	2.95	12.14	15.38	1.73	2.06	8.23	7.08
2	35.82	30.83	32.45	17.59	21.61	0.37	3.78	5.47	10.39	1.47	1.29	13.19	14.05
3	34.26	23.79	27.08	34.84	29.40	0.40	0.72	2.24	6.05	1.62	0.93	12.11	11.24
4	42.03	21.45	41.30	32.78	27.43	0.34	2.05	10.02	13.22	1.47	0.97	11.33	14.44
5	23.95	19.61	35.05	24.93	28.27	0.36	1.68	26.61	21.67	1.11	0.76	10.80	11.08
6	48.31	33.73	33.30	19.59	37.78	0.31	0.89	10.08	11.69	0.98	1.68	14.36	9.33
7	[redacted]												

Table F.10: Participant 2 results used to calculate standard error of the mean for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	0.82	1.01	1.02	0.54	0.08	0.01	0.10	4.71	3.54	3.33	3.65	34.15	34.37
1	0.45	0.40	1.45	0.69	0.06	0.01	0.85	4.50	3.70	5.03	6.18	32.85	27.17
2	0.79	0.56	1.32	0.45	0.05	0.02	1.04	3.19	1.78	4.06	3.67	45.73	52.29
3	0.69	0.53	1.15	0.94	0.07	0.02	0.20	1.90	0.93	4.80	2.75	42.83	43.27
4	0.61	0.43	1.80	1.07	0.08	0.01	0.60	3.96	3.37	3.92	2.78	40.52	56.60
5	0.27	0.36	1.12	0.61	0.07	0.01	0.49	6.11	8.04	3.02	2.08	34.31	39.50
6	0.64	0.58	1.39	0.41	0.09	0.01	0.26	3.61	3.21	2.64	4.79	52.55	31.82
7	[redacted]												

Table F.11: Participant 3 results used to rank the first, first and second and ranking scores for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	1	6	4	4	4	4	1	5	1	6	3	2	3
1	6	2	6	6	5	5	5	6	2	2	4	1	4
2	2	5	5	3	1	1	4	1	4	4	2	4	5
3	4	3	2	2	2	2	2	2	3	5	5	6	1
4	5	4	1	5	3	3	6	4	6	3	6	5	6
5	3	1	3	1	6	6	3	3	5	1	1	3	2
6	[redacted]												
7													

Table F.12: Participant 3 results used to calculate percentage difference for each seat raise from most efficient result.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	0	67.46	30.60	9.92	17.66	19.67	0	11.29	0	3.27	0.57	2.28	5.56
1	76.56	32.22	34.89	14.86	18.20	27.76	8.75	12.56	2.78	1.43	0.87	0	10.75
2	43.54	63.52	31.58	9.60	0	0	3.42	0	9.18	2.58	0.44	11.71	14.51
3	61.76	34.79	19.73	3.85	6.81	16.22	2.63	0.37	3.01	2.80	1.22	14.95	0.00
4	72.22	34.94	0	11.37	16.26	17.64	13.03	11.10	16.18	1.64	2.17	12.74	16.62
5	44.86	0	27.88	0	21.96	31.30	2.83	10.82	10.56	0	0	8.81	2.43
6	[redacted]												
7													

Table F.13: Participant 3 results used to calculate percentiles for each seat raise from most efficient to inefficient result.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	0	100	85.49	64.99	78.49	58.80	0	89.30	0	100	26.59	16.20	35.24
1	100	37.73	100	100	81.14	86.89	65.66	100	16.02	44.08	40.40	0	66.49
2	44.86	91.43	88.75	62.77	0	0	24.93	0	54.68	79.06	20.47	79.49	88.19
3	72.04	41.37	51.79	24.43	28.56	47.56	19.09	2.73	17.38	85.81	56.23	100	0
4	91.13	41.59	0	75.07	71.74	52.15	100	87.68	100	50.54	100	86.10	100
5	46.62	0	76.65	0	100	100	20.62	85.37	63.34	0	0	60.67	15.65
6	[redacted]												
7													

Table F.14: Participant 3 results used to calculate coefficient of variation for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	25.97	13.21	17.57	19.71	18.67	0.25	0.82	8.23	6.70	1.23	1.55	8.70	11.87
1	26.46	34.81	33.57	16.64	20.90	0.18	1.62	6.14	11.44	1.20	1.52	6.17	12.22
2	10.46	26.12	29.92	15.19	24.00	0.27	1.68	12.31	5.82	1.02	1.03	13.44	8.32
3	16.39	27.24	35.57	23.87	19.71	0.19	2.20	6.36	7.81	1.13	1.61	24.55	13.98
4	8.13	24.99	47.57	24.74	33.56	0.22	8.92	7.37	11.77	1.63	1.67	25.87	11.67
5	43.93	53.08	33.24	25.30	18.50	0.20	4.84	13.96	2.20	1.33	1.22	18.09	15.65
6	[redacted]												
7													

Table F.15: Participant 3 results used to calculate standard error of the mean for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	0.54	0.53	1.24	0.72	0.11	0.02	0.21	4.24	2.81	4.68	6.57	46.87	78.59
1	1.15	1.28	3.04	0.68	0.13	0.02	0.41	3.21	4.93	5.15	7.87	45.60	82.96
2	0.32	1.09	1.85	0.55	0.11	0.02	0.41	5.66	2.67	3.74	4.38	69.88	44.40
3	0.54	0.84	2.01	0.74	0.09	0.01	0.53	2.94	3.37	4.12	7.20	123.58	91.58
4	0.36	0.84	2.85	1.04	0.23	0.02	2.60	3.79	5.80	7.38	8.51	188.35	81.88
5	1.20	1.15	1.98	0.84	0.10	0.02	1.16	7.16	1.02	4.80	5.19	91.30	94.29
6	[redacted]												
7													

Table F.16: Participant 4 results used to rank the first, first and second and ranking scores for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	5	3	1	3	1	2	3	1	4	4	5	5	5
1	6	1	4	5	2	3	4	2	2	2	2	3	3
2	1	4	3	2	6	6	1	6	6	1	3	6	2
3	2	5	5	6	5	1	6	4	1	3	1	2	6
4	3	6	2	1	4	4	2	5	5	5	6	4	4
5	4	2	6	4	3	5	5	3	3	6	4	1	1
6	[redacted]												
7													

Table F.17: Participant 4 results used to calculate percentage difference for each seat raise from most efficient result.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	23.71	18.46	0	6.36	0	39.75	7.26	0	7.83	3.09	2.28	13.72	11.41
1	29.15	0	22.51	16.18	15.61	48.41	8.36	17.42	2.18	2.01	0.08	10.88	6.01
2	0	19.58	17.33	5.34	43.84	55.69	0	35.30	15.27	0	1.17	16.83	3.29
3	5.12	30.13	34.60	22.06	35.72	0	10.01	18.54	0	3.09	0	1.61	11.60
4	7.91	36.60	10.38	0	28.78	49.06	4.00	33.25	13.39	3.52	2.43	13.51	6.45
5	14.08	4.65	42.21	14.24	20.91	53.66	8.59	17.97	6.02	4.58	1.91	0	0
6	[redacted]												
7													

Table F.18: Participant 4 results used to calculate percentiles for each seat raise from most efficient to inefficient result.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	78.83	45.40	0	26.48	0	64.27	71.42	0	49.30	67.97	93.98	82.70	98.44
1	100	0	47.40	71.03	30.17	82.75	82.80	44.52	13.34	44.48	3.53	66.49	53.23
2	0	48.45	35.46	22.12	100	100	0	100	100	0	48.27	100	29.50
3	15.39	79.17	78.19	100	77.46	0	100	47.67	0	67.91	0	10.29	100
4	24.12	100	20.46	0	59.89	84.23	38.77	93.03	86.79	77.20	100	81.56	57.03
5	44.37	10.63	100	61.84	41.59	95.02	85.19	46.05	37.54	100	78.83	0	0
6	[redacted]												
7													

Table F.19: Participant 4 results used to calculate coefficient of variation for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	32.05	12.96	34.76	15.97	24.18	0.34	1.28	12.04	17.18	2.82	3.01	10.86	16.02
1	33.28	18.96	43.19	16.89	16.56	0.23	8.25	13.78	13.55	3.09	2.52	10.09	10.72
2	35.76	34.19	47.22	24.72	19.17	0.28	1.03	11.66	9.00	3.14	4.01	8.37	8.09
3	48.88	17.38	49.12	17.70	16.87	3.10	0.61	16.48	17.64	3.05	4.43	23.81	25.77
4	59.39	24.32	51.85	26.09	17.18	0.25	2.47	12.91	4.68	4.14	4.67	9.54	13.89
5	27.12	29.83	29.13	14.50	22.53	0.16	1.99	18.77	4.20	2.65	3.60	6.97	7.41
6	[redacted]												
7													

Table F.20: Participant 4 results used to calculate standard error of the mean for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	0.58	0.35	1.13	0.49	0.17	0.04	0.30	6.46	9.33	7.36	8.05	38.49	53.19
1	0.70	0.50	1.45	0.57	0.13	0.03	1.99	8.80	6.95	8.17	6.89	35.77	38.73
2	0.56	1.15	2.18	0.69	0.20	0.03	0.23	8.93	5.27	8.47	11.46	28.74	31.01
3	0.61	0.56	1.87	0.66	0.18	0.17	0.15	10.65	8.86	7.77	12.80	98.20	85.38
4	1.11	1.04	1.73	0.75	0.16	0.02	0.57	10.83	2.68	10.78	12.45	32.92	49.97
5	0.42	0.74	1.28	0.48	0.20	0.02	0.53	12.05	2.24	7.39	10.52	30.17	31.55
6	[redacted]												
7													

Table F.21: Participant 5 results used to rank the first, first and second and ranking scores for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	3	6	5	6	1	4	1	4	4	2	4	1	6
1	1	2	6	4	2	1	3	5	1	4	2	5	3
2	2	3	4	2	3	5	4	6	3	5	1	4	4
3	5	4	2	1	5	3	5	3	6	1	3	6	1
4	6	1	3	5	4	4	2	2	2	3	5	3	2
5	4	5	1	3	6	2	6	1	5	6	6	2	5
6	[redacted]												
7													

Table F.22: Participant 5 results used to calculate percentage difference for each seat raise from most efficient result.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	25.38	79.55	9.48	11.72	0	9.46	0	14.02	14.76	0.67	1.01	0	8.35
1	0	29.90	11.81	7.42	1.02	0	0.68	14.19	0	1.55	0.01	2.24	5.68
2	8.18	42.64	7.60	2.51	1.70	9.89	1.26	18.53	14.09	1.95	0	0.79	6.48
3	50.16	47.68	0.13	0	4.98	8.38	1.42	12.63	32.29	0	0.85	4.95	0
4	79.07	0	6.51	7.48	3.69	9.80	0.32	10.01	3.29	1.52	1.59	0.56	4.64
5	37.60	51.95	0	2.89	13.09	5.19	3.82	0	29.08	1.98	2.05	0.46	6.58
6	[redacted]												
7													

Table F.23: Participant 5 results used to calculate percentiles for each seat raise from most efficient to inefficient result.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	22.23	100	79.29	100	0	95.48	0	73.86	41.37	34.09	49.58	0	100
1	0	26.62	100	61.89	7.33	0	17.64	74.79	0	78.42	0.73	45.85	68.96
2	6.52	41.03	62.94	20.42	12.22	100	32.69	100	39.37	98.60	0	16.28	78.32
3	51.21	47.40	1.01	0	36.42	84.11	36.68	66.01	100	0	41.80	100	0
4	100	0	53.58	62.42	26.86	99.08	8.34	51.63	8.67	77.16	77.77	11.47	56.59
5	35.41	53.13	0	23.60	100	51.21	100	0	88.36	100	100	9.41	79.46
6	[redacted]												
7													

Table F.24: Participant 5 results used to calculate coefficient of variation for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	63.45	47.26	19.35	18.59	20.72	0.21	1.01	16.05	14.09	1.24	1.29	7.90	10.22
1	60.83	31.43	25.27	24.77	23.95	0.34	0.99	5.70	5.16	1.72	1.58	11.40	8.93
2	55.90	65.93	22.79	20.42	19.30	0.21	1.71	12.42	8.25	2.27	1.49	9.05	12.63
3	26.66	67.87	34.43	24.10	19.86	0.24	1.86	12.13	16.45	1.00	2.21	12.45	4.41
4	46.33	30.52	22.20	21.28	21.36	0.11	1.33	9.25	14.00	2.35	1.81	8.53	8.97
5	56.63	70.96	21.57	27.12	20.16	0.23	1.39	6.33	10.38	1.82	1.68	7.64	6.72
6	[redacted]												
7													

Table F.25: Participant 5 results used to calculate standard error of the mean for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	0.54	0.54	0.89	0.53	0.06	0.01	0.24	6.60	5.28	3.45	3.60	25.55	39.08
1	0.49	0.24	1.18	0.64	0.07	0.02	0.24	2.35	1.49	4.74	4.34	37.08	33.08
2	0.37	0.53	1.13	0.50	0.06	0.01	0.41	5.34	2.74	6.07	4.08	29.03	46.39
3	0.38	0.86	1.64	0.68	0.07	0.02	0.45	5.50	7.36	2.96	6.73	40.62	19.60
4	0.77	0.20	1.07	0.58	0.06	0.01	0.32	3.65	4.18	6.30	4.89	28.22	32.68
5	0.49	0.67	0.91	0.73	0.07	0.01	0.34	2.26	4.02	5.11	4.52	24.59	26.17
6	[redacted]												
7													

Table F.26: Participant 6 results used to rank the first, first and second and ranking scores for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	8	1	3	5	1	5	5	2	5	3	4	1	1
1	4	2	5	6	2	2	1	7	6	7	8	3	2
2	1	8	7	4	7	6	4	8	3	8	5	8	7
3	3	7	8	8	8	8	6	5	7	2	1	2	3
4	5	5	1	3	4	4	2	1	1	6	6	6	4
5	6	4	4	7	6	7	3	6	8	1	3	4	8
6	7	3	6	2	5	3	8	4	2	5	7	7	5
7	2	6	2	1	3	1	7	3	4	4	2	5	6

Table F.27: Participant 6 results used to calculate percentage difference for each seat raise from most efficient result.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	50.15	0	13.33	13.68	0	12.33	3.94	1.72	13.25	0.98	0.33	0	0
1	22.68	11.61	15.19	14.23	1.35	3.42	0	14.03	16.29	1.97	1.09	2.89	1.72
2	2.45	36.08	20.66	11.77	19.40	14.59	3.83	14.45	5.89	2.98	0.45	6.88	5.84
3	18.12	27.78	24.72	17.58	21.08	24.83	4.06	10.09	16.37	0.79	0	1.81	1.84
4	23.70	25.10	0	7.99	3.26	9.81	1.58	0	0	1.41	0.70	4.79	2.92
5	26.86	20.85	14.05	17.02	16.36	15.75	3.49	11.72	18.44	0	0.23	3.06	6.14
6	41.64	15.73	17.82	2.01	12.24	8.19	6.10	6.94	1.64	1.15	1.07	5.57	4.47
7	0	26.08	2.77	0	2.13	0	6.06	3.98	10.00	1.08	0.16	3.21	5.36

Table F.28: Participant 6 results used to calculate percentiles for each seat raise from most efficient to inefficient result.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	100	0	50.63	76.17	0	46.36	63.85	11.16	69.87	33.06	30.49	0	0
1	38.22	28.01	58.30	79.45	5.78	12.27	0	96.86	87.32	66.23	100	42.85	28.71
2	3.70	100	81.71	64.87	91.19	55.53	62.07	100	29.86	100	41.66	100	95.33
3	29.77	73.29	100	100	100	100	65.98	68.21	87.78	26.78	0	27.03	30.70
4	40.18	65.21	0	43.15	14.05	36.38	25.29	0	0	47.77	64.16	70.35	48.31
5	46.36	52.88	53.58	96.51	75.60	60.33	56.54	79.92	100	0	20.78	45.39	100
6	78.56	38.77	69.37	10.54	55.31	30.14	100	46.15	8.13	38.80	97.56	81.50	73.40
7	0	68.11	9.97	0	9.14	0	99.47	26.04	51.80	36.38	14.91	47.48	87.68

Table F.29: Participant 6 results used to calculate coefficient of variation for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	20.43	16.24	34.17	23.37	32.43	0.33	0.45	6.09	4.78	2.32	2.27	8.67	8.65
1	18.93	22.30	37.78	22.31	30.89	0.40	2.73	8.15	5.93	1.78	1.61	8.08	8.51
2	23.42	11.71	32.91	16.99	33.10	0.37	1.97	8.00	10.80	1.45	1.98	5.53	5.80
3	30.96	23.60	41.07	21.00	27.69	0.31	2.46	2.56	3.55	2.17	2.79	12.57	8.94
4	26.24	13.64	28.89	17.73	37.22	0.30	1.33	9.12	9.08	2.03	2.00	6.26	7.61
5	22.11	15.08	25.42	22.64	31.47	0.32	3.03	7.19	6.81	1.56	2.54	7.65	6.55
6	23.16	19.56	34.04	21.08	37.56	0.37	1.33	8.00	7.94	2.44	1.85	8.32	11.90
7	38.18	24.50	29.81	20.62	35.92	0.53	0.92	10.74	5.84	1.89	2.05	10.08	7.69

Table F.30: Participant6 results used to calculate standard error of the mean for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	0.49	0.34	1.27	0.91	0.11	0.03	0.16	2.60	2.60	6.87	6.75	36.12	35.48
1	0.35	0.52	1.46	0.90	0.10	0.02	0.94	3.93	3.32	5.07	5.20	32.68	36.88
2	0.35	0.31	1.23	0.65	0.12	0.02	0.70	3.87	5.45	4.11	5.88	20.83	22.44
3	0.60	0.63	2.02	0.85	0.11	0.02	0.88	1.19	1.99	6.65	7.91	49.79	36.03
4	0.52	0.35	0.86	0.63	0.12	0.02	0.47	3.82	4.32	5.83	5.78	24.85	28.48
5	0.49	0.40	1.25	0.91	0.13	0.03	1.08	3.39	3.90	4.97	7.57	30.91	27.13
6	0.57	0.48	1.39	0.78	0.14	0.02	0.49	3.60	4.29	7.24	5.33	31.72	46.68
7	0.67	0.69	1.04	0.75	0.12	0.03	0.33	4.68	3.43	5.62	6.29	42.09	29.90

Table F.31: Participant 7 results used to rank the first, first and second and ranking scores for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	5	3	5	4	1	1	1	4	4	4	4	4	3
1	4	2	4	5	6	4	3	2	6	1	1	3	1
2	1	5	6	1	3	6	2	3	3	6	5	2	4
3	6	6	1	2	4	5	4	6	5	2	2	6	5
4	3	1	3	6	2	2	5	1	1	5	6	1	6
5	2	4	2	3	5	3	6	5	2	3	3	5	2
6	[redacted]												
7													

Table F.32: Participant 7 results used to calculate percentage difference for each seat raise from most efficient result.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	87.61	28.82	29.87	18.15	0	0	0	11.55	6.60	2.13	2.32	6.61	2.92
1	81.43	14.38	26.39	26.52	11.87	23.32	1.53	0.59	16.56	0	0	6.37	0
2	0	49.76	31.13	0	10.42	25.02	1.09	7.62	3.00	2.95	3.61	2.79	3.40
3	98.91	60.85	0	7.24	10.42	23.34	2.93	16.61	14.91	0.50	0.89	12.69	10.35
4	77.71	0	21.38	38.22	2.69	15.53	5.06	0	0	2.23	4.11	0	11.54
5	2.38	42.49	19.45	8.14	10.69	18.47	6.14	12.57	2.49	0.71	1.52	11.43	1.00
6	[redacted]												
7													

Table F.33: Participant 7 results used to calculate percentiles for each seat raise from most efficient to inefficient result.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	79.68	38.50	95.26	42.25	0	0	0	67.68	37.79	72.56	56.83	53.63	26.42
1	70.20	17.71	82.46	64.72	100	92.28	24.37	3.27	100	0	0	51.74	0
2	0	75.73	100	0	87.06	100	17.34	43.75	16.84	100	87.94	23.04	30.67
3	100	100	0	15.89	87.06	92.40	46.98	100	89.23	17.30	21.96	100	90.17
4	64.95	0	64.92	100	21.61	58.86	82.08	0	0	75.97	100	0	100
5	1.23	61.69	58.45	17.95	89.51	71.17	100	74.05	13.98	24.36	37.49	90.63	9.15
6	[redacted]												
7													

Table F.34: Participant 7 results used to calculate coefficient of variation for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	38.23	34.52	25.83	23.35	21.44	0.32	0.79	11.60	6.01	1.24	2.10	11.16	4.69
1	41.36	103.66	20.02	21.14	18.85	0.34	2.23	9.27	5.73	1.04	2.71	5.79	8.91
2	161.76	31.85	15.55	38.39	20.03	0.32	3.69	14.88	8.03	2.89	1.78	8.67	7.77
3	76.10	94.84	25.52	30.22	25.62	0.48	0.97	5.74	3.08	1.00	3.36	11.23	12.11
4	66.97	93.35	19.93	11.53	17.66	0.16	1.86	7.18	5.87	2.56	1.76	12.39	22.40
5	159.21	106.00	30.23	17.39	22.10	0.23	2.13	9.61	4.70	1.59	2.56	13.41	8.66
6	[redacted]												
7													

Table F.35: Participant7 results used to calculate standard error of the mean for each seat raise.

seat raise	Rolling R (degrees)	Rolling L (degrees)	Heave (mm)	Yaw (degrees)	Pitch (degrees)	Average velocity change (mm/s)	Slalom (s)	Average force R stroke (N)	Average force L stroke (N)	R arm reach (mm)	L arm reach (mm)	stroke length R-L (mm)	stroke length L-R (mm)
0	0.73	0.41	2.41	1.00	0.14	0.03	0.29	8.87	4.83	5.51	9.23	70.57	35.12
1	0.64	1.39	1.80	0.83	0.13	0.04	0.82	6.36	5.10	4.48	12.23	36.72	62.72
2	1.33	0.38	1.96	1.37	0.14	0.04	1.36	12.23	6.23	13.49	7.33	72.08	45.80
3	1.56	1.46	1.82	0.98	0.18	0.05	0.36	4.62	2.69	4.51	14.99	71.41	76.88
4	1.40	0.84	1.76	0.61	0.11	0.02	0.71	4.89	4.42	10.78	7.22	96.66	114.71
5	1.22	1.09	2.46	0.61	0.14	0.03	0.82	7.42	4.68	6.81	10.29	86.41	49.28
6	[redacted]												
7													