# Cardiff School of Sport

**DISSERTATION ASSESSMENT PROFORMA:**

Empirical

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## Dissertation title: Positional and postural effects on systolic and diastolic parameters at rest: A Pilot Study.

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| **Title and Abstract (5%)** | Title to include: A concise indication of the research question/problem.  
Abstract to include: A concise summary of the empirical study undertaken. |
| **Introduction and literature review (25%)** | To include: outline of context (theoretical/conceptual/applied) for the question; analysis of findings of previous related research including gaps in the literature and relevant contributions; logical flow to, and clear presentation of the research problem/question; an indication of any research expectations, (i.e., hypotheses if applicable). |
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POSITIONAL AND POSTURAL EFFECTS ON SYSTOLIC AND DIASTOLIC PARAMETERS AT REST: A PILOT STUDY

DISSERTATION SUBMITTED UNDER THE DISCIPLINE OF PHYSIOLOGY & HEALTH

TIMOTHY BRECHT

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Date: 19.03.2015

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Abstract

Aim: The initial aim of this study was to investigate exercise effects on diastolic mechanical function to determine to what extent the diastolic phase of the cardiac cycle contributed to efficient exercise performance. However, due to a lack of clear exercise data; the study aims developed and restructured. Therefore, the new study aim was to run a pilot study to investigate the positional and postural effects on systolic and diastolic parameters at rest, with the intention of running a full research study into positional and postural effects on systolic and diastolic parameters during exercise.

Methods: Five males (height: 1.80m ± 0.08m; weight: 80.2 ±7.2kg; age: 24 ± 5 years) volunteered to participate in, and completed the study. Physical fitness (measured via VO$_2$ max and double-leg-press strength tests), and cardiac data (measured via echocardiography) was collected and recorded from all five participants.

Results: During both systole and diastole, the peak twisting/untwisting velocity was higher in the seated position than the supine position. The time-to-peak twisting/untwisting velocity was also quicker in the seated position. Systolic twist peak was higher in the seated position than the supine position. Stroke volume and flow propagation velocity were both marginally higher in the seated position than the supine position.

Conclusion: These findings suggest that positional and postural factors affect the mechanical performance of the left ventricle at rest.
1.1 – A Brief History of Cardiac Research

It was Aristotle (384-322 B.C.) who first observed the function of the cardiovascular system in animals and human corpses (Shoja, Tubbs, Loukas & Ardalan, 2008). Once Aristotle had identified the importance of the heart, cardiac function became both a popular research focus, and a cause for controversy. Galen (130-200 A.D.) described the critical importance of the heart in his aptly titled work “On the Usefulness of the Parts of the Body” in which he wrote “the fibers of the heart far surpass all others” claiming that “no other instrument performs such continuous, hard work as the heart”. Galen’s views differed from Aristotle’s, however, as Galen believed the heart was surpassed in importance only by the liver to the general functions of the body (May, 1968). The differing views of Aristotle and Galen were the cause of much controversy, and it was not until some years later that Leonardo da Vinci, (1452-1518) was the first to identify the four ventricles within the heart and to define the heart as a muscle as opposed to “special tissue” as previously suggested by Galen (Keele, 1951). Da Vinci’s discoveries, articulated beautifully and clearly through his drawings, set the foundations for the research that would eventually reveal the link between the heart and the circulatory system of arteries and veins. The physician William Harvey (1578-1657), was the first accurately to describe the circulatory system, and the contribution of the heart to blood distribution (Shackleford, 2003). Harvey’s work was accepted by Rene Descartes (1596-1650), a philosopher from France, who, by studying and critiquing Harvey’s work, suggested the widely accepted modern view that the heart was essentially a pump (Hall, 1972).
The relative contributions of these men have set the foundations for years of research within the field of Cardiology. While Aristotle, da Vinci and Harvey used human and animal bodies - both living and dead - to inform their research, research in modern Sport and Exercise Cardiology must be non-invasive, ethical and applicable to mass populations. The vast majority of cardiac research within Sport and Exercise today is performed via Echocardiography, or ultrasound. Swedish researchers Edler and Hertz were the first to use ultrasound to investigate cardiac function in 1954 (Edler & Hertz, 2004). Today, Echocardiography can be used, either directly or indirectly, to examine, quantify and research a wide variety of cardiac functions, such as; Ejection Fraction (EF), Stroke Volume (SV), Twist and Untwist, Intra-Ventricular Pressure Gradients (IVPG) and Flow Propagation Velocity (FPV), all of which are of critical importance to the research field of Sport and Exercise. (Feigenbaum, Mastouri, & Sawada, 2012).

1.2 – Left-Ventricular Mechanics: Twist and Untwist
Since the discovery of the left-ventricle’s contribution to all aspects of cardiac function, left-ventricular mechanics have been at the forefront of Exercise Cardiology, as well as Medicinal Cardiology research. The contraction and relaxation (systole and diastole) phases of left-ventricular mechanics are often referred to as left-ventricular twist and untwist, due to the rotational movement of the ventricle during these phases. Leonardo da Vinci had already identified the “twisting” of the left-ventricle in the 16th Century whilst observing the activity of the heart in animals (Evans, 1936), and Richard Lower, a physician from the University of Oxford described left-ventricular twist as mirroring “the wringing of a linen cloth to squeeze out the water” (Lower, 1669). Geleijnse & van Dalen (2008) explain that the three dimensional helical structure of the left-ventricle results in a cyclic twisting (systole) and untwisting (diastole) of the left-ventricle apex relative to its base. Nakatani (2011) explains that this cyclic twist causes the generation of potential
energy, responsible for the ejection of blood, and the cyclic untwist causes the release of this energy, responsible for the refilling of the ventricle.

Rowland (2009) found that Stroke Volume (SV) – the volume of blood ejected from the left ventricle in one contraction – plateaued during incremental exercise; Stöhr, Gonzalez-Alonso & Shave (2011) report that this plateau is generally observed at between 40% and 50% of maximal exercise intensity. Poliner et al., (1980) explain that stroke volume is determined by subtracting end-systolic volume (ESV) from end-diastolic volume (EDV), values which are determined by the level of rotation and torsion (twist) at the left ventricle (Buckberg, Hoffman, Mahajan, Saleh & Coghlan, 2008). Despite this clear link, it has yet to be proved that the level of twist in the left ventricle plateaus at the same exercise intensity as stroke volume; therefore we cannot accept that twist is the sole predictor of exercise performance. Additionally, not all studies mirror the results of a stroke volume plateau, as found in Stöhr et al., (2011), with one study reporting a continued increase of stroke volume to maximal exercise intensity in endurance athletes (Gledhill, Cox & Jamnik, 1994). This dispute within the literature of a finite level of stroke volume plateau – and indirectly: left-ventricular twist - appears to depend upon trained status; as Gledhill et al., (1994) tested endurance athletes, while Stöhr et al., (2011) tested healthy males.

If we accept that left-ventricular twist determines stroke volume, and we also accept that the plateau observed in stroke volume within healthy humans, (when compared to the lack of a plateau in endurance athletes) appears to be a direct determinant of exercise performance, then we must accept that the degree of left-ventricular twist is a significant determinant of exercise performance. This hypothesis would suggest that, much like stroke volume, the later the stage at which left-ventricular twist plateaus, the better the performance in incremental exercise.
1.3 – The Systolic Contribution

The systolic phase of the cardiac cycle is responsible for the ejection of blood from the left ventricle, in order to supply the body with the blood and oxygen it requires to function (Sengupta, Tajik, Chandrasekaran & Khandheria, 2008). The previously mentioned twisting motion that occurs during systole is actually responsible for a healthy ejection fraction; Nakatani (2011) explains that if the myocardial fibres were to contract alone as opposed to twisting, ejection fraction would not exceed 20%. van Dalen, Soliman, Vletter, ten Cate & Geleijnse (2008) found that the optimisation of left ventricular twist helped to maintain systolic function in individuals as they aged. This finding shows that left ventricular twist is essential in the determination of an individual’s systolic capability. This finding is reinforced in a study by Stöhr et al., (2011) where the relationship between stroke volume and left ventricular twist has a correlation $r^2$ value of 0.94. The same study found that the relationship between left ventricular twist and untwisting velocity had an $r^2$ value of 0.99; the practical deduction of this is that systolic and diastolic function are strongly interdependent. This finding may have seemed relatively obvious; however, without having been explicitly proven, it would be difficult to justify a study focussing on diastole.

The contribution of systolic function to exercise is widely known and accepted within the literature; whilst it is important to understand the systolic phase of the cardiac cycle, the following research is interested primarily in diastolic function. To examine fully diastolic function, however, it is important to collect systolic variables, such as left-ventricular twist and stroke volume, as without these variables, it is not possible to prove that superior diastolic function is preferable with regard to exercise performance (Foster & Lease, 2006).
1.4 – The Diastolic Contribution

The diastolic phase of the cardiac cycle is responsible for the filling of the left ventricle (Geleijnse & van Dalen, 2008). It was Galen who first suggested that the left ventricle acted as an active suction pump, opposing Harvey’s theory that left-ventricular filling was a passive process (Luciani, 1905). Despite the early hypothesis of Galen (130-200 AD), it was not until 1908 that Osler wrote “there is very convincing proof of an active diastole” stating that there was “no longer any doubt about mechanically active diastole” (Hoover, 1908). The initial theory, now proven fact, that diastole is an active process that is pivotal to the function of the heart is clearly an interesting study topic within Sport and Exercise, as more modern hypotheses about the diastolic function within exercise performance begin to appear. For example, in a study by Gledhill et al., (1994), subjects were divided into trained and untrained groups. Members of the trained group were found to have a significantly shorter filling time when compared with their untrained counterparts. This implies that trained individuals have a superior diastolic function, requiring less time to fill the left-ventricle to perform the same relative intensity of work as untrained individuals. A study by Stöhr et al., (2011), previously mentioned, shows a very strong correlation ($r^2 = 0.97$) between untwisting velocity and stroke volume; the practical deduction of this is that diastolic function variables are clearly relevant even when discussing systolic parameters. van Dalen et al., (2009) investigated the effect of heart shape on left ventricular twist; however, despite collecting and investigating a number of diastolic variables, such as untwist, they chose to report solely systolic results (peak systolic twist; peak systolic rotation). This is arguably a limitation of the study, even though the focus of the study was systolic function. Whether a limitation or not, it highlights a consistent systolic focus within the literature, and a consistent lack of focus on diastolic function; despite significant justification to do so.
Over one-third of heart failure patients have normal function in systole; while diastolic function is impaired (Vasan, Benjamin & Levy, 1995). The deduction we can make from this is that diastolic function is not only crucial in exercise performance, as shown by the Gledhill et al., (1994) study, but that it is also of critical importance to the overall health in human populations. Paulus et al., (2007) emphasised the necessity for clear evidence when diagnosing diastolic dysfunction, and Yotti et al., (2011) identify Doppler echocardiography as the method of choice for said evidence in clinical situations. Interestingly, Doppler echocardiography is often used in Sport and Exercise environments in order to collect and analyse cardiac variables; so while data collection within Sport and Exercise focussed studies is critical to the formation of a successful research study, it can also potentially highlight potential health abnormalities in subjects, the importance of which would far surpass any study aims. The justification for a study investigating diastolic function, therefore, is strong, due to the relative gap in the literature focussing on this element of cardiac function, in addition to the added benefits of potentially screening individuals’ health during data collection.

1.5 – Intra-Ventricular Pressure Gradients

The laws of physics – and, specifically, pressure-gradient force - states that all liquids will move from areas of high pressure to low pressure, unless acted on by an external force (Thomas & Popovic, 2005). Blood is no exception to this, and this relatively simple rule is pivotal in explaining the mechanics of diastolic re-filling. Falsetti, Verani, Chen & Cramer, (1980) explain that these pressure differences cause blood to move from the mitral valve into the left ventricle during diastole. This process is regarded as “diastolic filling” and is pivotal in the potential available for systolic function (Gledhill et al., 1994). Yotti et al., (2005) explain that cardiac muscle contracts and twists - changing shape during systole; the result is an instantaneous pressure differential between the atria and ventricles, and
when the opposite relaxation and untwisting takes place, the pressure differential results in suction of blood into the left ventricle during diastole.

Calculations of intra-ventricular pressure gradients can be obtained using Doppler echocardiography (Yotti et al., 2004) and as such are an incredibly useful technique of measuring both systolic and diastolic function due to their non-invasive nature. Despite the seemingly complex nature of this analysis, Intra-ventricular pressure gradients were initially measured over fifty years ago (Laszt & Muller, 1951) and have since been proved to be an important technique in the analysis of the diastolic contribution to cardiac function (Thomas & Popovic, 2005). Despite the importance and usefulness of intra-ventricular pressure gradients in the evaluation of both systolic and diastolic function; we have neither the appropriate equipment nor the knowledge effectively to extract and utilise this information. Therefore, a subsequent technique is used, to ascertain indirectly information on intra-ventricular pressure gradients: Flow Propagation Velocity.

1.6 – Flow Propagation Velocity

The use of Doppler echocardiography in order to measure flow propagation velocity for the purpose of ventricular relaxation was proposed first by Brun, Tribouilloy & Duval (1992). Early use of flow propagation velocity analysis was primarily medicinally focussed, to identify patients with flow patterns associated with common heart diseases (Pearson, Labovitz, Mrosek, Williams & Kennedy, 1987). However, flow propagation velocity techniques are incredibly useful in the assessment of diastolic function from a Sport and Exercise point of view, as Doppler echocardiography is a relatively stress-free and non-invasive technique that can easily be applied to exercise environments. Flow propagation velocity is also a technique that can be used indirectly to determine intra-ventricular pressure gradients (Garcia et al., 1999).
A number of diastolic variables were investigated by Voon et al., (2006) to determine whether flow propagation velocity in isovolumic relaxation was dependent on preload. The extent to which the authors were able to examine the various components responsible for diastole shows the usefulness and practical capability of echocardiography to measure flow propagation velocity, and to use this data to assess and make reasonable assumptions regarding pressure differentials. As mentioned previously, this study, in addition to countless others (Vletter et al., 2003; Takatsuki et al., 1996; Vasan et al., 1999), investigated and reported data that would primarily concern medical populations, due to a focus on heart failure and diastolic dysfunction. This extensive supply of literature related to diastolic dysfunction highlights a gap in the supply of literature around ordinary diastolic function. Additionally, there are gaps in the literature when it comes to using flow propagation velocity data to examine and determine what constitutes superior diastolic function, from a sport and exercise perspective.

1.7 – Study and Research Aims

The focus of this study is to investigate the contribution of the diastolic phase of the cardiac cycle to overall exercise performance. The aim of the study is to determine how the left-ventricular mechanics in diastole contribute to the ability of young male adults to continue exercise.

Previous research has focussed primarily on the systolic contribution, with specific regard to the ejection of blood facilitating increased performance. While there has been some research into diastolic function, and its relative contribution to exercise performance, there are still gaps in the literature with regard to the relative contributions of the systolic and diastolic phases during various phases of incremental exercise. By performing an in-depth
analysis of various variables associated with diastole; such as untwist and flow propagation velocity, and comparing these variables with associated variables of systole, such as twist and stroke volume, it is possible to determine in what way, and to what extent each phase of cardiac contraction contributes to overall exercise performance. Similarly, by comparing resting data to several stages of incremental exercise, it is possible to examine how a shift in intensity may result in a shift in the relative contribution of the two phases.

This study has a number of hypotheses: firstly; it was hypothesised that a plateau would be observed at a sub-maximal intensity for both stroke volume and left-ventricular twist. From this initial hypothesis, a second hypothesis can be extrapolated; that left-ventricular untwist and flow propagation velocity would continue to increase, and not to plateau, in order to cater for the plateaus observed in twist and stroke volume. A third hypothesis, relating to exercise intensity, is that as intensity increases, less time will be available for each individual contraction; and that the re-filling of the left-ventricle, occurring during diastole, will become more significant than at resting levels.
2.1 – Study Population and Ethical Approval

Ethical approval for the present study was given by the ethics committee at Cardiff Metropolitan University (see Appendix A). Five healthy and active male individuals (height: 1.80m ± 0.08m; weight: 80.2 ±7.2kg age: 24 ± 5 years) volunteered to participate in, and completed, the study. Prior to providing written consent (see Appendix D), each individual was asked to read the participant information sheet (see Appendix C) in its entirety, and was given the opportunity to ask questions regarding the study. Individuals were also asked to fill in a participant health screening questionnaire (AHA/ACSM Health Questionnaire, see Appendix B) to confirm that they should be able to exercise safely. Individuals who did not satisfy the health questionnaire were not considered for participation within the study.

2.2- Experimental Procedures & Data Collection

Individuals participating in this study were required to attend two separate laboratory sessions at Cardiff Metropolitan University. The two sessions were required to be on separate days, a minimum of forty-eight hours and a maximum of four weeks apart. Session One was a screening session, the purpose of which was to assess the fitness of the individual, in addition to prescribing the exercise intensity for Session Two. Session Two involved similar exercise protocols to the screening test, but also involved echocardiography and data collection.
2.2a - Session 1

On arrival at the laboratory, individuals would be given a brief on the protocol for the session by a member of the research team. The brief included the opportunity to ask questions. A full verbal description of the session and its components was given, in addition to the explanation of the participant information sheet. Consent forms and screening questionnaires were signed; and once the individual was deemed fit for participation, anthropometric measurements could be taken.

Height was recorded using a stadiometer (Holtain, Fixed Stadiometer, Pembs, UK) and body mass was recorded using calibrated digital scales (Vogel & Halke, SECA Model 770, Hamburg, Germany). The resistance for the VO$_2$ max protocol was calculated using a predetermined set of equations (see Appendix E). From here, individuals would put on a heart rate monitor (Polar, Kempele, Finland) and adjust the supine cycle ergometer (Angio, 2003, Lode, Groningen, Netherlands) to the optimal position for their stature. Once lying flat on the cycle ergometer, the participant was fitted with a facemask that was connected to the gas analysis system (Oxycon Erich JaegerPro, Hoechberg, Germany). A resting lactate sample was collected from the earlobe. The cycle ergometer would then be tilted 40º to the left and the individual would commence a stepped VO$_2$ max test, with resistance increasing every sixty seconds until the point of volitional exhaustion. Upon completion of the VO$_2$ max test, the cycle ergometer was tilted back to the flat position, where a post-exercise lactate sample was taken from the earlobe.

From here, a compulsory rest period, consisting of a minimum of thirty minutes and a maximum of one hour, was taken. Following the rest period, the participant would perform an eight-repetition maximum, followed by a one-repetition maximum test on the seated double-leg-press machine (45º double-leg-press, 20-20 Fitness, UK). Prior to these tests,
individuals were given the opportunity to warm up, by first lifting a sub-maximal weight to allow familiarisation with the testing protocols and technique. Both the one-repetition maximum and the eight-repetition maximum tests were terminated upon failure to complete the prescribed repetitions. Upon completion of the double-leg-press tests, individuals were free to leave the laboratory.

2.2b - Session 2

On arrival at the laboratory, individuals would again be given a brief on the protocol for the second session by a member of the research team. Following this, the participant would be asked to consult his previous consent forms and screening questionnaires, and asked to notify a member of staff had any of the previous answers changed. Once participants were deemed fit to continue participation, anthropometric measurements would be taken again in the same format as in Session One.

Participants would then be asked to step into the bathroom and self-insert a rectal core temperature probe (MLT1407, AD Instruments, UK). This was to allow for the continuous monitoring of core body temperature and this data was not used for analysis or investigation. The individual would lie flat on the cycle ergometer, at which point the facemask was applied to the individual, as in Session One, in order to analyse expired respiratory gases. A pulse oximeter (Nonin, 8500) was applied to the earlobe for continuous monitoring of arterial oxygen saturation. A blood pressure cuff (FinometerPRO, FMS, Arnhem, Netherlands) was applied to the middle finger of the right hand in order continuously to monitor systolic and diastolic blood pressure. An ECG (E9, GE Vingmed Ultrasound, Horten, Norway) was applied to the participant. The cycle ergometer was then tiled 40° to the left, and resting images would be collected using the ultrasound machine (E9, GE Vingmed Ultrasound, Horten, Norway). The individual would then commence the
test protocol, which consisted of ten one minute stages cycling at sixty revolutions per minute, starting at 10% of the maximum power output achieved in Session One, and increasing by ten percent each minute until the stage consisting of 100% maximum power output achieved in Session One was complete.

Throughout the test protocol, during the last thirty seconds of each minute, ultrasound data collection would take place. On commencement of the cycling test protocol, and following a minimum of half an hour and a maximum of one hour rest, individuals would be seated on the leg-press machine, and wearing exactly the same equipment as in the cycling test protocol, would perform eight repetitions of double leg press at ten percent increments, from 10%-100% of the eight repetition maximum achieved in Session One. Each set was separated by a ninety second rest period, and data collection took place in the final four repetitions of each set. The final four repetitions consisted of a three-second isometric hold of the weight, with the legs at a 90° angle. Upon finishing the tenth set of double leg press, all data collection equipment was removed from the participant, who was free to leave the laboratory.

2.3 - Data Analysis

In order to analyse captured echocardiographic data images, the software EchoPac (Version 112.0.1) was used. To establish twisting and untwisting data, images are marked at both end-diastole and end-systole, and the relative twist and torsion in the left ventricle can be calculated (Figure 1.) In order to establish flow propagation velocities, images providing pressure differentials related to the distance from the ultrasound probe are used (Figure 2.) to establish pressure gradients and velocity data. In order to establish stroke volume data, a triplane analysis is performed on echocardiograph images (Figure 3.) at
end-diastole and end-systole, providing end-diastolic volume, end-systolic volume, ejection fraction, and stroke volume data.

Figure 1. Examples of echocardiograph images used for establishing twist/untwist data.

Figure 2. An example of the echocardiograph image type used to establish flow propagation velocity data.
Figure 3. An example of the echocardiograph image type (triplane) used to establish stroke volume, ejection fraction, end-diastolic volume and end-systolic volume data.

Calculations of mean and standard deviations, in addition to the creation and presentation of all tabular and graphical data, were completed using Microsoft Excel 2010 (Microsoft, USA). Statistical analyses were not performed in the current study, as the sample size was too small.
Chapter Three: Results

3.1 Baseline Results

Five male individuals participated in and completed the study. Baseline characteristics for the five subjects are presented in the table below. Data is displayed as the mean ± standard deviation (Table 1).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>SD</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>24 ± 5</td>
<td></td>
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<tr>
<td>Height (cm)</td>
<td>180.3 ± 8.3</td>
<td></td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>80.2 ± 7.2</td>
<td></td>
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<tr>
<td>VO2 Max (ml/kg/min)</td>
<td>39.2 ± 4.9</td>
<td></td>
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<tr>
<td>1RM Leg Press (kg)</td>
<td>290 ± 121</td>
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</tr>
<tr>
<td>8RM Leg Press (kg)</td>
<td>192 ± 84</td>
<td></td>
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<tr>
<td>Resting Flow Propagation Velocity (cm/s)</td>
<td>74 ± 16</td>
<td></td>
</tr>
<tr>
<td>Resting Stroke Volume (ml)</td>
<td>68 ± 8</td>
<td></td>
</tr>
<tr>
<td>Resting Peak Twist Velocity (º/sec)</td>
<td>110 ± 33</td>
<td></td>
</tr>
<tr>
<td>Resting Time-to-Peak Twist Velocity (ms)</td>
<td>208 ± 58</td>
<td></td>
</tr>
<tr>
<td>Resting Peak Untwist Velocity (º/sec)</td>
<td>-128 ± 47</td>
<td></td>
</tr>
<tr>
<td>Resting Time-to-Peak Untwist Velocity (ms)</td>
<td>481 ± 211</td>
<td></td>
</tr>
<tr>
<td>Resting Peak Systolic Twist (º)</td>
<td>15 ± 4</td>
<td></td>
</tr>
<tr>
<td>Resting Heart Rate (bpm)</td>
<td>62 ± 12</td>
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</tr>
</tbody>
</table>

Mean heart rate in the supine position was 60 ± 6 bpm, and in the seated position was 63 ± 17 bpm (Figure 4.). The standard deviation in the seated position is much greater than in the supine position, showing a wider variety of heart rates in individuals when seated.
Mean systolic twist in the supine position was $14 \pm 5^\circ$, and in the seated position was $16 \pm 3^\circ$ (Figure 5.). The marginally higher result in the seated position indicates that individuals elicited a greater degree of twist in this position. Additionally, the lower standard deviation in the seated position results indicates less variation in this position.
Mean stroke volume in the supine position was 68 ± 10 ml, and in the seated position was 69 ± 7 ml (Figure 6.). The similar mean values indicate that there was a low variation between stroke volume values between the two positions.

![Stroke Volume Data](image)

Figure 6. Stroke volume data in the supine and seated positions. Data is presented as mean ± SD for all five participants in both positions.

Mean flow propagation velocity in the supine position was 71 ± 9 cm/s, and in the seated position was 77 ± 21 cm/s (Figure 7.). The standard deviation in the seated position is far greater than in the supine position, indicating that individuals had a wider range of flow propagation velocity values when seated.
Figure 7. Flow propagation velocity data in the supine and seated positions. Data is presented as mean ± SD for all five individuals in both positions.

3.2 Systolic Twist and Stroke Volume

Four out the five individuals tested elicited a greater degree of systolic twist when in the seated position (Figure 8.). There was one exception to this; the one individual who showed a greater degree of twist while supine. Four out of the five individuals tested elicited greater stroke volumes when seated (Figure 9.). Again, there was only case where stroke volume was higher in the supine position. The peak systolic twist velocities (Figure 10.) showed the same trend, with four out of five individuals eliciting a higher peak twist velocity in the seated position, with the sole exception of the one individual eliciting greater twist velocity when supine. Similarly, with regard to the time-to-peak twist velocity results (Figure 11.), four out of five individuals achieved a quicker time to peak twist velocity in the seated position. There is again, a sole exception, with one individual achieving a quicker time-to-peak twist velocity while supine.
Figure 8. Systolic twist data in the supine and seated positions for all five participants. Individuals’ data points are linked by a dotted line.

Figure 9. Stroke volume data in the supine and seated positions for all five participants. Individuals’ data points are linked by a dotted line.
Figure 10. Peak twist velocity data in the supine and seated positions for all five participants. Individuals’ data points are linked by a dotted line.

Figure 11. Time-to-peak twist velocity data in the supine and seated positions for all five participants. Individuals’ data points are linked by a dotted line.

3.3 Diastolic Untwist and Flow Propagation Velocity

Three out of five participants flow propagation velocity results (Figure 12.) were higher in the supine position. One individual elicited the same flow propagation velocity in both the supine and seated positions; one individual elicited a much greater flow propagation
velocity in the seated position. Peak diastolic untwist velocity data (Figure 13.) showed four out of five individuals eliciting greater velocities when seated. The sole exception in this case showed greater untwisting velocity in the supine position. The time-to-peak untwist velocity data (Figure 14.) showed more variation. Two individuals showed greater time-to-peak untwist velocity in the supine position, while the three remaining individuals showed greater time-to-peak untwist velocity in the seated position.

Figure 12. Flow propagation velocity data in the supine and seated positions for all five participants. Individuals’ data points are linked by a dotted line.
Figure 13. Peak untwist velocity data in the supine and seated positions for all five participants. Individuals’ data points are linked by a dotted line.

Figure 14. Time-to-peak untwist velocity data in the supine and seated positions. Individuals’ data points are linked by a dotted line.
3.4 Mean Results Summary

Mean results for all participants in systolic parameters (Figure 15.) show that individuals tended to achieve peak twist quicker in the seated position than supine. Peak twist velocity was greater in the seated position. Stroke volume was almost identical in both conditions.

Mean results for all participants in diastolic parameters (Figure 16.) show that individuals tended to achieve peak untwist quicker in the seated position. Peak untwist velocity was greater in the seated position. Flow propagation velocity was slightly higher in the seated position.

Mean systolic twist peak results (Figure 17.) for all five participants showed a greater degree of twist in the seated position. The relatively large standard deviation results for systolic twist shows a broad range of results, indicating varied responses from across the five tested participants.

![Systole Diagram](image)

Figure 15. Mean systolic parameters for all five participants. Data is presented as mean ± SD for all five individuals in both positions. Each individual parameter data point is linked by a dotted line.
Figure 16. Mean diastolic parameters for all five participants. Data is presented as mean ± SD for all five individuals in both positions. Each individual parameter data point is linked by a dotted line.

Figure 17. Mean twist peak results for all five participants. Data is presented as mean ± SD for all five individuals in both positions. The data points for the supine and seated positions are linked by a dotted line.
Chapter Four: Discussion & Conclusion

4.1 – Study Aims

The primary aim of this study was to determine how the left-ventricular mechanics in diastole contribute to the ability of young male adults to continue exercise. This study initially aimed to investigate a large number of male individuals, at rest, in addition to at ten exercise intensities (10%, 20%, 30%, and so on.), up to maximal. However, unfortunately, through no fault of the researchers or sonographer, imaging during exercise became increasingly difficult. This led to data being collected that was unusable due to the lack of clarity of the images, and a lack of consistent image numbers for each individual. As a result of this, the decision was taken to report only resting images for five individuals, who produced the full spectrum of clear and usable images. While this was not the initial aim of the study, the use of resting images alone allows for a more in-depth analysis of cardiac function per individual. This study will, henceforth, be regarded as a pilot study for future research, which will continue along the initially proposed data collection plan.

As a result of this, the current investigation must restructure its focus due to the availability of data for analysis. With a full spectrum of resting images for five individuals in both the supine position and the seated position, it is possible to investigate the differences between the collected systolic parameters and diastolic parameters between the two positions. While not the initial aim of the study, postural and positional resting data analysis is not an insignificant research area. In a study investigating oesophageal pressure, Owens et al., (2012) found that pleural and oesophageal pressures were significantly different between the seated and supine position. This difference was caused by an increased pressure found in the abdominal region, due to muscular activation, and transferred across the diaphragm. Clearly, in this example, pressure increase across the
chest area resulted in increased pressure on the oesophagus itself; however, it is still unclear whether this same variation in position will have a significant effect on cardiac parameters. With this in mind, the discussion portion of this study will focus upon the effects of position and postural variation to systolic and diastolic parameters at rest.

4.2 – Systolic Twist and Stroke Volume

This study found that four out of five individuals showed greater stroke volumes when seated compared with stroke volumes elicited in the supine position (Figure 9.). The one individual who was the sole exception to this displayed a much higher stroke volume when supine (77ml as opposed to 65ml when seated). One explanation for why stroke volume data varies with position and posture is the hydrostatic pressure gradient concept. Hinghofer-Szalkay (2011) explains that when an individual’s position or posture changes, the distribution of these pressures will change depending on the alignment of the body to the acceleration field – which in this case: is gravity. The contribution of gravity to venous return and blood distribution may explain why we see variation in stroke volume with positional changes.

In an echo of the stroke volume results, the same four individuals showed greater peak twist velocity in the seated position than the supine position (Figure 10.). Again, the same individual was the sole exception, displaying greater peak twist velocity in the supine position. Time-to-peak twist velocity results showed the same four individuals achieving their peak twist velocity quickest in the seated position (Figure 11.). As in the first two results, the same individual is the sole exception, achieving peak twist velocity quickest in the supine position. It should be noted, however, that whilst only one individual in four displayed this clear difference; the other result that clearly stands out is the individual who
shows a dramatically different time-to-peak twist velocity when supine (203ms) compared with his seated (68ms) result.

By analysing each systolic parameter individually, it is possible to analyse the literature surrounding that specific parameter, to begin to understand what may cause these results to occur. However, in order fully to understand how systolic function varies with position, we must look at the systolic phase as a whole, and examine how each parameter reacts to a change in another. When we examine the mean systolic parameter results of all five participants together (Figure 15.), we can see that stroke volume remains almost identical in both positions. However, peak twist velocity increases, and the time to achieve this peak twist velocity is also quicker when seated. When we consider the fact that in both positions, stroke volume is the same, we can conclude that the heart is ejecting the same amount of blood per contraction in both positions. This means that, in line with Hinghofer-Szalkay’s (2011) study, gravity may play a part in assisting in the distribution of blood, reducing the stress placed on the heart, and reducing the speed at which it is forced to twist to eject the blood from the left ventricle. This would explain why the seated position elicited greater peak twist velocity, and time-to-peak twist velocity results, due to the increased requirement of cardiac contribution when gravity plays less of a role compared with its relative contribution while in the supine position.

Another theory is that due to the nature of the supine position, individuals may have been unknowingly in a state of minor isometric contraction in order to hold themselves in an unnatural position on a supine cycle ergometer. Despite the seeming insignificance of such a minor state of muscular contraction, the variation observed between the seated and supine positions may well be a result of this increased stress on the muscular system (Quinn, Smith, Vroman, Kertzer & Olney, 2001).
It is worth mentioning, too, that the sole exception in all three systolic parameters displayed no abnormal characteristics or baseline results when compared with the remaining individuals tested in the study. Therefore, it must be concluded that further research is necessary to investigate whether these exceptions are anomalies, or in fact an indication of a true trend within certain populations. For this further research, it would be necessary to attain a far greater study population, in order reliably to investigate whether these trends observed in this individual are observed to the same scale in greater populations.

4.3 – Diastolic Untwist and Flow Propagation Velocity

Three out of five individuals showed higher flow propagation velocity in the supine position (Figure 12.). One individual showed no change in flow propagation velocity between the seated and supine position, and one individual showed a much greater flow propagation velocity in the seated position. These results are relatively varied across the five participants, and as a result they do not provide much insight into flow propagation velocity variation by position and posture. What is clear, however, is that flow propagation velocity data is a justifiable variable for inclusion in studies related to cardiac function. Further research could indicate why flow propagation velocity data did not display the hypothesised results or consistent results across participants, in the current study.

The results for peak diastolic untwist velocity showed four out of five individuals eliciting greater velocities in the seated position (Figure 13.). The one exception elicited the opposite, with a greater velocity in the supine position. The time-to-peak untwist velocity data was relatively varied; with three individuals showing greater time to achieve peak untwist velocity while seated, and two while supine (Figure 14.). The stand out result in this
instance is the individual who showed a far greater time-to-peak untwist velocity in the supine position (1066ms) when compared with his seated result (367ms). After an in depth analysis of this individual’s baseline characteristics and full data spectrum, which showed little clear variation from the other participants, it must be concluded that this individual’s result was an anomaly. However, having said this, further research, making use of a far greater study population, could explain how and why this result occurred, potentially highlighting an inconsistency within certain populations.

In the same way as previously mentioned for systole, individual diastolic parameter results can inform us only on very specific elements of that cardiac phase. It is not until we examine these diastolic parameters together that we can examine how each parameter may affect the others, and the entire process of diastole. When we examine the mean diastolic parameter results of all five participants together (Figure 16.), we can see that, when seated, flow propagation velocity is slightly higher, peak untwist velocity is greater, and the time to achieve this peak untwist velocity is quicker. In exactly the same way as mentioned in the systolic section of the discussion, an explanation for these results could be the increased role of gravity in the supine position, reducing the requirement for cardiac intervention and increased activity (Hinghofer-Szalkay, 2011). This would explain why the seated position elicited greater levels of untwisting velocity. Another explanation is that, due to the minor increased mean heart rate in the seated position (63bpm) when compared with the supine position (60bpm), there remained less time for both systole and diastole in each contraction. Both positions were measured during rest, and so the relative intensity was almost identical, which explains why stroke volume and flow propagation velocity results were similar between positions; the only difference was the minor contribution of gravity to blood distribution while supine, resulting in a slightly lower heart rate. The increased heart rate observed in the seated position reduces the time available
for systole and diastole, and results in a quicker twist/untwisting velocity, in addition to the
time-to-peak twist/untwist velocity.

More variation was found within diastolic function than in the systolic parameters. In
addition, any exceptions observed within the study population were not always in the same
individual, as was the case in the systolic parameters. This may indicate that, while
systolic function remains relatively stable across study populations, diastolic function is
more subject to variation and fluctuation. If this were true, it would indeed justify the initially
proposed research direction, and potentially provide some insight into the relative
contribution of diastole to cardiac performance during exercise. To prove this fully, though,
a far greater study population would be necessary in order to report data from a wider
population base. At present, the study population is not large enough to provide reliable or
valid data on such an as yet unproven hypothesis.

4.4 – Gravity, Blood Distribution and Venous Return

It is well known that gravity effects both the distribution of blood and the return of blood to
the heart for further distribution. Lilywhite (1988) showed how the circulatory system varies
in different breeds of snake, with the tree snake - which constantly scales tall vertical
climbs - having to resist strong pressure gradients and in turn displaying a very different
circulatory system to the common sea snake. Galvin, Drummond and Nirmalan (2007)
explain how gravity aids in the distribution of blood flow to the lungs due to the hydrostatic
pressure differential between regions of the pulmonary arterial system. Meissner et al.,
(2007) report the wide range of factors affecting venous return, including cardiac
interaction, efficient venous valves, muscular pumps, and pressure gradients. The
explanation provided in the study by Meissner et al., (2007) of efficient venous return
explains to us how the body is able to efficiently distribute and return blood to the body
while in extreme postural variations, such as the difference between standing up and lying down. There is a much slimmer variation of posture and position in the two positions examined in this study; seated and supine – however, if this pilot study is able to find and prove the relative effects of such a slim change in posture and position, then this pilot study will have been effective and achieved its aims in setting a precedent for a full research study into more extreme variations in posture and position.

4.5 – Study Limitations

The first clear limitation of this study is the small sample size. Five individuals is an exceptionally low number for a research project. What this means is that for any potential findings, we must take into consideration the possibility of the results having occurred by chance. Usually, statistical analyses can be performed on data to cater for this possibility; however, a sample size of five is too low to run even these statistical analyses effectively. This reduces the reliability of the present study, in addition to reducing the validity of the results attained. Initially, it was hypothesised that the sample population would have been much larger; however, due initially to difficulty in recruitment of participants, sample size was dramatically reduced, and subsequently due to a number of unforeseen circumstances, some of the tested individuals’ data became unusable. If this study were to be run as a full research project rather than a pilot study, the sample size would have to be far greater than it is in this study to allow for reliable, valid data, in addition to the inclusion of statistical analyses.

Another limitation is the lack of data available for individuals at exercise. While this data was collected during the study, subsequent analysis of the data showed it to be unusable. This happened for a number of reasons. Firstly, during exercise, in order to perform echocardiography and collect image data, the sonographer asks the participant to hold his
or her expired breath for a brief moment as the images are collected. This is to ensure that a full lung does not obstruct the view of the heart. The problems arise in exercise echocardiography when at relatively high intensities; individuals find it more difficult to hold their breath due to the strenuous nature of doing so. This means that as exercise intensity increases, the clarity of images tends to decrease. While this is unavoidable, it is a shame that in the present study, it resulted in all exercise data being unusable. A second reason for the lack of exercise data is that there was a lack of consistent images for each individual. What this means is that if for individual “A” we had a full spectrum of data at 10%, 20% and 30% exercise intensity, but for individual “B” we had only intensities 10%, 30% and 50%, it would not be possible to compare accurately and investigate the differences between individual “A” and “B” in this scenario.

4.6 – Contribution of Pilot Study and Future Research Direction

While the previous section has studied and presented the limitations of this pilot study, it is important to emphasise that no study is without benefits and application. Even if we simply take the limitations section, and apply what we have learned to the future, full research study, we will be able potentially to avoid running into the same issues and will be able therefore to run a more efficient and successful study.

This pilot study found that individuals showed similar levels of stroke volume and flow propagation velocity whilst at rest in both the seated and supine positions. While seated, individuals showed increased peak twisting and untwisting velocities, as well as a quicker time-to-peak twisting and untwisting velocities. Individuals also showed greater degrees of systolic twist in the seated position.
Future research should therefore continue to investigate the effect of position and posture on the mechanical function of the heart. While this pilot study investigated and reported data at rest, future research should investigate and report data across a full spectrum of exercise intensities in order to develop knowledge on how position and posture affect the performance output of the heart. Additionally, the initial proposed research direction of investigation into left-ventricular diastolic mechanical function would provide a solid base for a research study, as justified in Chapter One. The current research study initially planned to investigate this diastolic function in more detail, however, as previously explained, did not satisfactorily answer the many gaps in the literature that were justified in the literature review section. This means that there are still gaps in the literature, and therefore, there is still a justification and a requirement for a study investigating diastolic function.

It can therefore be concluded that this pilot study initially justified the necessity and requirement for investigation into diastolic function, and, after a re-structure of focus and study aims, also justified the requirement for further research into the effects of position and posture on cardiac function, both at rest and during exercise.

4.7 – Conclusion

In conclusion, this study shows evidence that the function of the heart muscle varies depending on position and postural factors when at rest. In both systole and diastole, the peak twist/untwist velocity was greater in the seated position when compared with the supine position. In addition, the time to achieve this peak twist/untwist velocity was quicker in the seated position. Flow propagation velocity was marginally higher while seated, while stroke volume showed almost no change. Peak systolic twist was higher in the seated
position. This pilot study therefore sets a precedent for a full research study into postural and positional effects of cardiac function during exercise.

Further research is required to answer the initial research question proposed regarding diastolic function, and its relative contribution to the performance output of the cardiac cycle during exercise. Further research is also required to confirm whether the observed positional variations in cardiac function are observed during exercise protocols.
REFERENCES


When undertaking a research or enterprise project, Cardiff Met staff and students are obliged to complete this form in order that the ethics implications of that project may be considered.

If the project requires ethics approval from an external agency such as the NHS or MoD, you will not need to seek additional ethics approval from Cardiff Met. You should however complete Part One of this form and attach a copy of your NHS application in order that your School is aware of the project.

The document *Guidelines for obtaining ethics approval* will help you complete this form. It is available from the [Cardiff Met website](#).

Once you have completed the form, sign the declaration and forward to your School Research Ethics Committee.

**PLEASE NOTE:**
Participant recruitment or data collection must not commence until ethics approval has been obtained.

**PART ONE**

<table>
<thead>
<tr>
<th>Name of applicant:</th>
<th>Timothy Brecht</th>
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<tr>
<td>Supervisor (if student project):</td>
<td>Dr Eric Stöhr</td>
</tr>
<tr>
<td>School:</td>
<td>Cardiff School of Sport</td>
</tr>
<tr>
<td>Student number (if applicable):</td>
<td>St20018719</td>
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<tr>
<td>Programme enrolled on (if applicable):</td>
<td>Sport and Exercise Science</td>
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<tr>
<td>Project Title:</td>
<td>Do the heart and arteries respond differently during cycling compared with resistance exercise?</td>
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<td>Expected Start Date:</td>
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<tr>
<td>Approximate Duration:</td>
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<td>Funding Body (if applicable):</td>
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| Other researcher(s) working on the project: | Dr Eric Stöhr (CSS, principal investigator)  
Miss Jane Black (CSS)  
Dr Joseph Esformes (CSS)  
Dr Jon Oliver (CSS)  
Mr Owain Smallwood (CSS)  
Mr Thomas Jake Samuel (CSS) |
| Will the study involve NHS patients or staff? | No |
| Will the study involve taking samples of human origin from participants? | Yes |

In no more than 150 words, give a non technical summary of the project

The heart plays an essential role in delivering the increased blood flow required during exercise. Previous studies have shown that left ventricular strain and twist (‘LV mechanics’) and arterial function contribute significantly to this aim (7, 8, 13). However, it is not known whether the change
in LV mechanics and arterial function during incremental exercise is associated with other fundamental physiological variables or whether this occurs independently of established parameters. Furthermore, whether the cardiac and vascular responses depend on the mode of exercise (‘endurance’ vs. ‘resistance’ exercise) is also not known. Therefore, the aim of this project is twofold: 1) to compare LV mechanics and arterial function during incremental cycling vs. double leg press exercise and 2) to determine whether the change in LV mechanics and arterial function during cycling and double leg press exercise is associated with the change in other physiological variables as outlined below.

<table>
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<th>Does your project fall entirely within one of the following categories:</th>
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<td>Paper based, involving only documents in the public domain</td>
<td>No</td>
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<tr>
<td>Laboratory based, not involving human participants or human tissue samples</td>
<td>No</td>
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<tr>
<td>Practice based not involving human participants (e.g., curatorial, practice audit)</td>
<td>No</td>
</tr>
<tr>
<td>Compulsory projects in professional practice (e.g., Initial Teacher Education)</td>
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If you have answered YES to any of these questions, no further information regarding your project is required. If you have answered NO to all of these questions, you must complete Part 2 of this form.

**DECLARATION:**
I confirm that this project conforms with the Cardiff Met Research Governance Framework

<table>
<thead>
<tr>
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<th>Date: 15/07/2014</th>
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<tbody>
<tr>
<td>Timothy Brocht</td>
<td>Mr.</td>
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**FOR STUDENT PROJECTS ONLY**

Name of supervisor: Dr. Eric Stöhr

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Signature of supervisor: Eric Stöhr

**Research Ethics Committee use only**

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<th>Dr. Brendan Cropley</th>
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<th>25/08/2014</th>
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<tr>
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Details of any conditions upon which approval is dependant:

All track changes should be removed from participant documents before use.
APPENDIX B
PARTICIPATION SCREENING QUESTIONNAIRE

AHA/ACSM HEALTH/FITNESS FACILITY PREPARTICIPATION SCREENING QUESTIONNAIRE

Assess your health needs by marking all true statements.

History
You have had:
___ A heart attack
___ Heart surgery
___ Cardiac catheterization
___ Coronary angioplasty (PTCA)
___ Pacemaker/implantable cardiac defibrillator/rhythm disturbance
___ Heart valve disease
___ Heart failure
___ Heart transplantation
___ Congenital heart disease

If you marked any of the statements in this section, consult your physician or other appropriate healthcare provider before engaging in exercise. You may need to use a facility with a medically qualified staff.

Other health issues
___ You have diabetes
___ You have or asthma other lung disease
___ You have burning or cramping in your lower legs when walking short distances
___ You have musculoskeletal problems that limit your physical activity
___ You have concerns about the safety of exercise
___ You take prescription medication(s)
___ You are pregnant

Symptoms
___ You experience chest discomfort with exertion
___ You experience unreasonableness breathlessness
___ You experience dizziness, fainting, blackouts
___ You take heart medications

Cardiovascular risk factors
___ You are a man older than 45 years
___ You are a woman older than 55 years, you have had a hysterectomy, or you are postmenopausal
___ You smoke, or quite within the previous 6 mo
___ Your BP is greater than 140/90
___ You don’t know your BP
___ You take BP medication
___ Your blood cholesterol level is >200 mg/DL
___ You don’t know your cholesterol level
___ You have a close blood relative who had a heart attack before age 55 (father or brother) or age 65 (mother or sister)
___ You are physically inactive (i.e., you get less than 30 min. of physical activity on at least 3 days per week)
___ You are more than 20 pounds overweight

If you marked two or more of the statements in this section, you should consult your physician or other appropriate healthcare provider before engaging in exercise. You might benefit by using a facility with a professionally qualified exercise staff to guide your exercise program.

___ None of the above is true

You should be able to exercise safely without consulting your physician or other healthcare provider in a self-guided program or almost any facility that meets your exercise program needs.


www.acsm-msae.org/jpt-concertemplate-journalsmsae/media/9898e.htm
RESEARCH PROJECT

Do the heart and arteries respond differently during cycling compared with resistance exercise?

Name of principal investigator: Dr. Eric Stöhr
Name of co-investigators: Miss Jane Black, Mr Tim Brecht, Mr Owain Smallwod, Mr Jake Samuels, Dr Joseph Esformes, Dr Jon Oliver

This document provides information on:

1) The background and aim of the research project
2) The role of the researchers
3) Your role as a participant
4) Benefits of taking part
5) How data will be collected
6) Risks
7) How the results will be used
8) Your rights

IMPORTANT: The purpose of this document is to assist you in making an informed decision about whether you wish to volunteer for this research project. Your right as a voluntary participant is that you are free to enter or withdraw from the study at any time. This simply means that you are in full control of the part you play in informing the research and what anonymous information is used in its final reporting.

1) Background and aims of the research
   - The heart and arteries play an important role in making sure that the body gets all the blood and oxygen it needs during exercise.
• At the moment, some heart function called “twist” increases when exercise intensity increases continuously during cycling, but it is not known if this increase is related to other important parameters like the change in oxygen used or lactate produced.

• Also, it is not known if your heart and arteries respond in the same way during cycling and resistance exercise.

• The aim of this study is to measure the function of your heart and arteries during incremental cycling and resistance exercise and compare the responses with established parameters of fitness such as your oxygen consumption and lactate production.

2) The role of the researchers:

The researchers will be responsible for conducting and overseeing all stages of the research project. In addition to carrying out the scientific part of the project, we are there to provide you with personal guidance and assistance in relation to any questions or issues you may have. During your first visit, we will explain all the project details so that you feel comfortable with knowing exactly what will be required. We will also assist you with the completion of the health questionnaire and answer any questions you may have in relation to the project. While our research interest is to collect novel and valuable information on your heart and arteries during exercise, your health and safety is of primary importance to us and has precedence over our research interests. In relation to this, you will not only be able to ask questions and inform us about issues while in the laboratory but you will also be able to contact Dr Eric Stöhr at any time outside laboratory contact time. We encourage you to talk to us at any time should you feel uncomfortable or have questions related to the project.

3) Your role as a participant:

We are very grateful should you choose to take part in this research project and we will treat you with respect at all times and try our best to explain everything to you so that you have an enjoyable experience. While we need to ensure the scientific quality of our work, we also aim to create a friendly and fun environment in the laboratory during your visits.
Your role is to **visit the laboratory on two occasions**, during which will evaluate your health through completion of a brief questionnaire (5 minutes), assess your current exercise fitness and maximal strength and examine the function of your heart and arteries during progressively increasing cycling and resistance exercise. The first visit will last approximately 1 hour, the second visit 2.5 hours (including a 1 hour break).

4) **Direct and indirect benefits of taking part:**

Your participation is potentially of direct and indirect benefit to you:

**Direct:** By participating you will learn how your heart and arteries (=your cardiovascular system) respond to different types of exercise. You will also get to know about your general fitness as assessed in the fitness test and you will experience how state-of-the-art research is conducted in an exercise laboratory. We will be happy to share your personal results from this study with you.

**Indirect:** Your participation will contribute to our general knowledge on the human heart. Your participation will inform researchers and clinicians and may help to develop further research into the influence of endurance and resistance exercise on cardiovascular function.

5) **How data will be collected:**

You will need to attend the laboratory on two occasions. The purpose of each visit and what you will be required to do is outlined below.

**Visit 1 (estimated duration ~1 hour)**

During your first visit, you can ask questions about the research and, when all your questions are answered, you will:

- Fill out a consent form and a health questionnaire (see both attached). According to the guidelines of the American College of Sports Medicine (ACSM), you will be considered healthy and free to enroll in this study if you do not have more than two cardiovascular risk factors. Should the completion of the questionnaire reveal that you do have more than two risk factors, you will, unfortunately, not be able to partake in this research project.
• Have your leg dimensions assessed using a tape measure and calipers to measure your skin thickness.

• Perform a standard maximal exercise test according to ACSM guidelines. The purpose of this test is to assess your fitness. To do so, you will be asked to sit on a supine bicycle and wear a face mask through which you will breathe normal room air. We will collect your expired air in a computer attached to the face mask at rest and during exercise. Exercise intensity will start at a very easy level and become progressively harder until you are unable to continue further. At this point, we will lower the exercise intensity but ask you to keep cycling for another few minutes. This cool down is for your own safety to avoid dizziness following your exercise effort. Following 30-60 minutes of rest (depending on how quickly your heart rate returns back to resting heart rate), you will perform double leg press exercise, consisting of 8 repetitions followed by a brief recovery period (~30 seconds). The weights your legs will push against will be increased until you are unable to physically perform a ninth double leg extension. Following this, visit one will be completed.

Visit 2 (estimated duration ~1h45 minutes)

During visit two, upon arrival we will:

• Ask you to go to the bathroom and self-insert a rectal temperature probe (see in list of equipment at the end). We will then measure your weight and you will lie down on a supine bicycle. You will be required to remove the clothing on your upper body for the purpose of the heart scans and you will wear sports shorts.

• We will attach various pieces of equipment to your body, none of which are invasive. Please see the end of this information sheet for a list of all the equipment and their purpose. These pieces of equipment will record data continuously from the moment they are attached until the experiment is completed.

• Once all the equipment is attached, we will measure the function of your heart and arteries at rest using ultrasound. We will take pictures of your heart from two locations on your chest: the upper left side of your chest and from the middle left side.
1) You will then **perform cycling exercise**, with the exercise intensity starting at 10% of your maximum achieved in visit 1 and increasing every minute by 10%.

2) You will rest for 30-60 minutes, depending on your heart rate.

3) You will then sit down on the double leg press machine and perform 8 repetitions at 10% of your maximum achieved in visit 1. After 8 repetitions you will rest for one and a half minutes and then perform another 8 repetitions at 20% of your 8RM. This will be repeated until you have completed 100% of 8RM, thereby also concluding the whole study.

6) **Risks**

For healthy individuals, there are two small risks associated with this project.

1) You may feel light-headed or dizzy following the maximal exercise effort during visit one.

To minimize this risk, we will ask you to continue to cycle at low exercise intensities (~50 Watts) after your maximal effort, for at least 3 minutes, thereby minimizing the risk of dizziness or light-headedness.

2) There is a very small risk of infection associated with lactate sampling from your earlobe. To minimise this risk, researchers who will be taking blood samples or handle blood samples for processing will wear gloves at all times and appropriately disinfect areas with alcohol swabs. We will ensure that these standard operating procedures will be adhered to at all times.

3) In addition, please note that should you feel unwell at any time point during this experiment, we strongly encourage you to notify a member of the research team immediately. We will then interrupt the procedure and fully abort if you continue to feel unwell or if we are worried about your health and safety.

7) **How the data / research will be used:**

Your data will be analysed and your results will be anonymously used in conference presentations and research publications according to the principles of scientific conduct.
You will not be identifiable in any way during conference presentations or in peer-review publication.

**Protection to your privacy**
Your identity will not be disclosed in any written transcripts, notes or associated documentation that informs the research and its findings. Furthermore, any personal information about you will remain confidential according to the guidelines of the Data Protection Act (1998).

**8) Your rights**

**IMPORTANT:** Your right as a voluntary participant is that you are free to enter or withdraw from the study at any time. This simply means that you are in full control of the part you play in informing the research and what anonymous information is used in its final reporting.

**Contact details**

If you require further information or have any outstanding queries, feel free to contact the principal investigator or a co-investigator.

**Dr Eric Stöhr**
Cardiff School of Sport, Cardiff Metropolitan University, CF23 6XD, United Kingdom
Email: estohr@cardiffmet.ac.uk
Telephone: 02920 416531 or 07598 933008

**Miss Jane Black**
Cardiff School of Sport, Cardiff Metropolitan University, CF23 6XD, United Kingdom
Email: jblack@cardiffmet.ac.uk
Telephone: 02920 416593
List of equipment used in this project

**Note:** All equipment that will be used in the experiment is listed below. The principal investigator or co-investigators have used these scientific instruments in previous experiments.

<table>
<thead>
<tr>
<th>Name</th>
<th>Technology; purpose</th>
<th>How the equipment will be used</th>
<th>Picture of equipment under below number</th>
</tr>
</thead>
<tbody>
<tr>
<td>E9, GE Medical, UK</td>
<td>Ultrasound, measures heart function</td>
<td>A transducer with gel will be placed on the chest on two locations.</td>
<td>1</td>
</tr>
<tr>
<td>Vividq, GE Medical, UK</td>
<td>Ultrasound, measures the function of your arteries</td>
<td>A transducer with gel will be placed on your neck and upper arm.</td>
<td>2</td>
</tr>
<tr>
<td>FinometerPRO, FMS, Netherlands</td>
<td>Photoplethysmography; Continuous blood pressure measurement</td>
<td>A small finger cuff will be placed around the middle finger of the right hand and calibrated once with a standard upper arm blood pressure cuff. The finger cuff will then pulsate for the duration of data collection.</td>
<td>3</td>
</tr>
<tr>
<td>Sphygmocor and Collin CBM-7000, Japan</td>
<td>Applanation tonometry; assessment of the radial pulse</td>
<td>A wristband will be placed on the left wrist and adjusted so that a small tonometer will be placed above the radial artery, which will continuously detect the pulse waveform of the radial artery.</td>
<td>4</td>
</tr>
<tr>
<td>Oxiplex</td>
<td>Near-infra-red-spectroscopy; skeletal muscle oxygenation</td>
<td>A large block with emitting light will be attached to the vastus lateralis muscle of the right leg using elastic bandages.</td>
<td>5</td>
</tr>
<tr>
<td>Trigno</td>
<td>Electromyography; neural skeletal muscle activation</td>
<td>Wireless electromyographic electrodes will be taped to the quadriceps and hamstring muscles of both legs.</td>
<td>6</td>
</tr>
<tr>
<td>BCI</td>
<td>Oxygen sensor; Continuous assessment of whole-body oxygen saturation</td>
<td>A finger clip will be attached to the index finger of the right hand.</td>
<td>7</td>
</tr>
<tr>
<td>OxyconPro, Jaeger, Germany</td>
<td>Respiratory gas assessment; Continuous recording of oxygen consumption and other associated respiratory / metabolic data</td>
<td>A mask will be placed over the participants' mouth and nose and secured to the head with velcro straps.</td>
<td>8</td>
</tr>
<tr>
<td>MLT1407, ADInstruments, UK</td>
<td>Temperature sensor; continuous internal body temperature monitoring</td>
<td>A soft, flexible rectal thermometer will be self-inserted by the participants and secured to the participants' hip using body tape.</td>
<td>9</td>
</tr>
</tbody>
</table>
CONSENT FORM

Title of Project:
Do the heart and arteries respond differently during cycling compared with resistance exercise?

Principal Investigators:
Dr Eric Stöhr estohr@cardiffmet.ac.uk
Miss Jane Black iblack@cardiffmet.ac.uk
Participant Identification Number: iCDT_

1. I confirm that I have read and understand the information sheet related to this study. I have had the opportunity to consider this information, ask questions and have had my questions answered satisfactorily.  
   YES ☐  NO ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reasons, without my medical care or legal rights being affected.  
   YES ☐  NO ☐

3. I understand that data collected in this project will not be used for commercial purposes.  
   YES ☐  NO ☐

4. I agree that if I become unable to continue giving my consent during the project, I will  
   YES ☐  NO ☐
be withdrawn from the project and data or tissue already collected under consent will be anonymised and used for research purposes.

5. While this is a research study, we may observe abnormalities in the function of your heart or arteries. Do you wish to be informed about these should we think something warranted further medical consultations?

6. I agree that the principal and co-investigators of this study may use my data anonymously in other research projects with the purpose of answering new research questions.

7. I agree to take part in the above study.

Name of participant: Date: Signature:
................................. ...... .................................
Name of person taking consent: Date: Signature:
................................. ...... .................................

Cardiff Metropolitan University
Prifysgol Fetropolitan Caerdydd
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APPENDIX E
CALCULATION OF LOAD FOR VO2 MAX. TESTING

Optimal increment of work rate calculations

EQUATION 1 – Prediction of VO₂ max.
- Male (50.02-(0.394*age))*BW
- Female (42.83-(0.371*age))*BW

EQUATION 2 – Calculate VO₂ max. for unloaded cycling
- (5.8*BW) + 151

EQUATION 3 – Expected increase in VO₂ for a maximal test
- (EQUATION 1) – (EQUATION 2)
- (Predicted VO₂ – Unloaded VO₂)

EQUATION 4 – The expected rate of work increment
- (EQUATION 3)/103 = Watts/min.

EQUATION 5 – For Supine Cycle Ergometry
- (EQUATION 4)*0.8