Investigating the Ergogenic Potential of Ischemic Preconditioning 
and Resisted Running on Sprint Performance

by

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INVESTIGATING THE ERGOGENIC POTENTIAL OF ISCHEMIC PRECONDITIONING AND RESISTED RUNNING ON SPRINT PERFORMANCE

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University of Guelph, 2017

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Two pre-competition protocols were constructed based on physiological principles related to muscle contractile properties and ischemia-induced metabolic and neural changes. Sprint times over 0-20 m were used to assess the effectiveness of these protocols, which were designed to potentially provide an acute performance-enhancing effect. Highly-trained sprinters were recruited for both studies (Study 1, n = 20; Study 2, n = 18), as this cohort of athletes exhibits minimal inter-sprint variation, allowing changes in performance to be more confidently attributed to the intervention under examination. Neither the resisted sprinting (3, 20 m sprints running against a load equal to ~ 40% body mass) or ischemic pre-conditioning protocol (3 x 5 min occlusion) acutely affected sprint performance. These findings indicate that the intensity of the resisted sprint protocol and manner in which the ischemic pre-conditioning protocol was performed provided an insufficient pre-competition stimulus to elicit improvements in sprint performance.
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February, 2014. I suited up and ensured the knot in my tie was set just right. Three times. I was overly excited, and on my way to the Canadian Memorial Chiropractic College where I envisioned myself rocking an interview and then beginning to learn the trade of healing, over the next four years. The interview was short, 15-20 minutes at most, and I left feeling the assessors had laughed at just the right number of my jokes, perfect. A few weeks later I received a letter in the mail from CMCC. “Dear Mr. Thompson” it read, “We regret to inform you…” and I’m sure you can guess the rest. Shoot. My envisioned future then became questionable. No longer would I prefix my name with Dr. (Dr. of Chiropractic Medicine), but life continued. The following year (my 5th year at U of T) I enrolled in six courses, meant to both boost my GPA and expose me to a different learning style. One of these courses, taught by a former U of G post-doc, examined the ergogenic potential of nutritional supplements and foods in an intimate 12-person setting. This class was perfect, especially since I had decided the previous summer that I was going to heavily invest my focus into track and field. Now I would be able to learn about nutritional protocols which could potentially improve my overall athletic ability. Over the course of the semester, my reputation shifted from being the funny guy, to being someone who could and wanted to contribute to each discussion. I soon found myself immersed in material on carbohydrate manipulation in endurance athletes, the association between vitamin D status and exercise recovery time, protein timing for muscle hypertrophy, and of course, classic caffeine, as its’ ability to immediately enhance a variety of athletic traits seemed too good to be true. Of course, I self-experimented with BCAA’s, caffeine, vitamin C/D/E, probiotics, fish oil, and macronutrient timing to enhance my athletic performance over the course of that year. I had found a new calling - reading a lot, and then testing things that interested me, or I guess as it is more formally
called, *research*. I immediately began looking into what I would need to apply to graduate school. To make a repetitive story less repetitive, I didn’t get into U of T grad school. It was mid-summer when I found out, and I was beginning to wonder what I would do next if I wasn’t able to continue pursuing academics. However, as things often do, they worked out. I received a text from a great friend (Stephen Holmes – 2014 CIS 1000m champ, “Emcee Steveo”) of mine asking if I would be interested in doing research at the University of Guelph, and that he had been asked to check in on me by the U of G track coaches. A few phone calls, emails, and messages later, all I knew was there was a new “mystery man” beginning work at U of G September 2015, and that I was now going to meet a very famous, Dr. Lawrence Spriet to discuss my options. After being on campus for several hours I was mentally drained. A simple, light conversation with Dr. Spriet had somehow turned into a thorough discussion on CHO manipulation research coming out of Australia. Dr. Spriet at one point, casually let me know all the research I had been describing throughout our chat had mostly been led by a couple good friends of his who he was meeting for dinner later that week… no wonder he seemed to know every, single, thing I was talking about… (I would later learn; this feeling would be present whenever having the luxury of discussing any research topic with this exceptionally moustached gentleman). I then spent a couple hours with the head sprint coach discussing training philosophies and how his approach meshed with current academic and “real-life” coaching data. All-in-all, the trip left me even more hungry for the opportunity to learn more about how researchers around the world were attempting to improve exercise performance. Eventually, I had the privilege of coming face-to-face with the “mystery man” from PEI. We spoke a bit about my personal and sport performance related research interests and as I was leaving, Dr. Burr quickly asked if I had heard of the company - 1080 Motion, and if I knew of their sprint product.
I had not heard of it, but let me tell you how quickly I learned everything about it once I realized it was a machine designed to help sprinters train under controlled overspeed conditions… VERY QUICKLY (again, as with Dr. Spriet, I learned, Dr. Burr has a habit of giving away tiny tidbits of information that make your mind race with potential new questions). I was beginning to realize there is something special about with these Drs., I hypothesized (It was hypothesized) as a result of years of creative and logical thinking, that these individuals held super powers that allowed them to think differently than the regular humans. I cannot and will not ever be able to describe in words how excited I was to finally be going to school for something I loved learning about – making people faster.

“Do what you love, and you’ll never work another day in your life”
Chapter 1: Introduction
Introduction

Professional athletes make up a fraction of the population that participates in sport, and despite the general belief, that participating in sport as a professional career is constantly full of excitement, the constant pressure placed on these individuals to succeed is incredibly high. With the increasing pressure to repeatedly perform at a near super-human level, athletes at the highest level of sport often seek out any training, nutritional, recovery or physiological benefit possible. At this level of sport, the average talent is incredibly high, making any small change in performance extremely valuable. Professional athletes who are not integrated with a specific team, such as is commonly the case in athletics, often depend on their coaches and therapists for the most current information relevant to their sport performance. In some cases, these suggestions are based on inferred, rather than empirical evidence, which often leads to frustration when performances do not improve. This is where the contribution of an applied sports scientist can have the greatest contribution to athlete success.

According to the recently published book, “How to support a champion: The art of applying science to the elite athlete”, by Dr. Steve Ingham, the role of an applied exercise scientist is to provide the coach with ongoing feedback regarding the effectiveness of their training, and when appropriate, make suggestions on how training or nutritional protocols might be altered to achieve the desired outcome. These suggestions must be based on sound physiological principles to improve their chances of success. Within this thesis, physiological principles related to muscle contractile properties and ischemia-induced metabolic and neural changes will be used as grounds to suggest two pre-competition protocols.
While the goal of the coach is to facilitate breakthroughs in performance, the applied scientist is often tasked with determining the mechanisms responsible for the desired performance outcome, and provide a scientific rationale for adopting new training or nutritional practices. Under this premise, track and field athletes prove to be an extremely reliable cohort of land-based athletes for exercise scientists when exploring interventions meant to increase speed and power, or endurance based qualities. Since the outcomes and training of track and field athletes are essentially standardized performance tests, with less error stemming from opponent and athlete decision-making, experimental findings made using this cohort can often be adapted by team-sport athletes. For the benefits of increased reliability, familiarity with testing, reduced error, and ease of application to alternative sports, track and field athletes were recruited for the studies presented within this thesis.

The overall aim of this thesis is to contribute to the growing body of applied sports science literature, by extending physiological principles of muscle contractile properties and ischemia-induced metabolic and neural changes to pre-competition protocols, with the goal of enhancing maximal acceleration ability in highly-trained sprinters. The application of these two potential approaches are designed such that they are legal (by law and within WADA guidelines), safe, externally performed within a warm-up setting (do not require the ingestion of a substance), use limited space and limited equipment. The conclusions made within this thesis should be of interest to those aiming to enhance acceleration performance in both short-distance track and field athletes as well as team-sport athletes.
Chapter 2: Literature Review
**Resisted Sprinting**

In team sports and athletics events, the ability of an athlete to accelerate is crucial. With the obvious goal in athletics, to finish the race ahead of others, individuals who possess the ability to accelerate quickly are often well-suited for short-track events such as the 60 m and 100 m sprints. In contrast to these one-off, maximal sprints, team-sport athletes perform repeated accelerations throughout a match, interspaced with periods of standing or walking. Despite the different metabolic and neural demands between one-off maximal sprints in athletics, and the repeated acceleration demands of team sports, both groups benefit from the ability to accelerate more quickly. Improving acceleration ability has, therefore, been a huge research focus in the field of sports science and exercise performance. Techniques such as, but not limited to, weightlifting, plyometrics, and performing ballistic exercises, are common approaches to improving sprint acceleration ability. Although many approaches for improving acceleration ability exist, resisted sprint training (RST) has received the most attention.

Resisted sprinting, also referred to as weighted-sled towing, is an acceleration-specific overloading exercise which has been shown to alter running mechanics. This type of training allows athletes to spend more time in acceleration-specific positions through the use of weighted sleds, which has shown to alter body, thigh and shank angles, as well as stride length, and horizontal power production ability. The RST research has predominantly examined the ability of this method to alter acceleration ability (0 - 5 m to 0 - 40 m) through training over the course of 4 - 10 weeks. Resistive loads have typically been employed in two ways; either as a percentage of athlete body mass, or as a load which reduces sprint velocity. In studies using a percentage of body mass to determine the resistive load, 5% loads are considered light whereas, until recently, 43% would be considered heavy. Recently, the case for using resistive
loads of ~ 80 % body mass has been made, as this load was necessary to produce maximal horizontal power \(^{21}\), a known major determinant in acceleration and maximal velocity sprint performance \(^{22,23}\). At this point, only one study has examined the ability of these heavy resistive loads to improve 0 – 20 m sprint ability \(^{24}\). Using a load equal to 80 % body mass, soccer players performed two RST sessions each week, for eight weeks. This resulted in small (Effect Size = 0.2 - 0.6 x Standard Deviation) changes in 20m sprint performance, which were attributed to the moderate (ES = 0.6 - 1.2 x SD) increase in maximal horizontal force production ability. Even with the current lack of consensus regarding the optimal loading to improve acceleration performance, RST is considered a safe and effective way of improving acceleration ability within the literature \(^{17}\).

The use of RST as an acceleration tool has predominantly focused on its ability to improve acceleration over weeks of training, in a similar fashion to a resistance training program. Using RST in this way has repeatedly shown to be effective to varying degrees, however, several studies have examined the use of resisted sprints to acutely enhance performance \(^{9,11,25,26}\). The investigation of resisted sprints as a means of acutely enhancing sprint performance is derived from numerous studies that show an enhancement in acceleration performance following heavy back squats, power cleans, and other plyometric exercises \(^{27-36}\). Ordinarily, exercises used to elicit a performance effect are called conditioning exercises, as they condition the muscle to act differently during subsequent movements (greater force and rate of force production). Following the conditioning exercise, a specific outcome exercise is performed. Activities such as, but not limited to sprinting, jumping or throwing, are commonly used as the outcome exercise.

As acutely enhancing sprint performance using resisted sprints is a relatively novel idea, factors necessary to elicit improvements in previous exercise studies will be examined. A 2012
meta-analysis (not acceleration specific) including 32 independent studies, described the
necessities of a conditioning protocol to achieve the improvements in sprint speed, jumping ability, and other outcome exercises. Firstly, it has been shown that trained individuals exhibit the greatest increase in performance following a conditioning exercise.
Second, multiple sets of a conditioning exercise, using resistive exercise loads of ~ 60 – 84 % of subjects 1 – repetition maximum resulted in greater improvements compared to performing a single set. Lastly, 3 -10 minutes are necessary following the final conditioning activity to dissipate any accumulated fatigue and see an improvement in outcome exercise performance.
Although this timeframe seems broad, it appears the amount of time needed for fatigue to dissipate is dependent on training status. With these requirements in mind, characteristics of the previously conducted, acute resisted sprint studies are presented in the table below (Table 1).

<table>
<thead>
<tr>
<th>Author</th>
<th>Year Published</th>
<th>Subject training status</th>
<th>Resistive load</th>
<th># of resisted sprints</th>
<th>Rest time before performance test</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whelan et al.</td>
<td>2014</td>
<td>Physically active; completed at least 3 training sessions/wk</td>
<td>25-30% (BM)</td>
<td>3</td>
<td>1, 2, 4, 6, 8, 10 minutes</td>
<td>(-)</td>
</tr>
<tr>
<td>Winwood</td>
<td>2016</td>
<td>Rugby athletes</td>
<td>75% (BM), 150% (BM)</td>
<td>1</td>
<td>4, 8, 12 minutes</td>
<td>(+)</td>
</tr>
<tr>
<td>Seitz et al.</td>
<td>2017</td>
<td>Rugby athletes</td>
<td>75% (BM), 125% (BM)</td>
<td>1</td>
<td>15s, 4, 8, 12 minutes</td>
<td>(+)</td>
</tr>
<tr>
<td>Jarvis et al.</td>
<td>2017</td>
<td>Varsity team sport athletes</td>
<td>50% (BM)</td>
<td>1 - 3</td>
<td>4, 8, 12 minutes</td>
<td>(+)</td>
</tr>
</tbody>
</table>

Table 1. Acute RST Study Characteristics. BM, body mass

Of the four studies investigating the performance-enhancing ability of resisted sprints, the study by Whelan et al. was the only one to report no improvement in sprint performance. Based on the characteristics necessary to observe an improvement in dynamic exercise performance following a conditioning exercise, it is plausible that the lack of an effect came from inadequately trained subjects or an insufficient resistive load. On the other hand, the remaining studies all used trained athletes, heavy loads, and allowed varying levels of rest prior to their
performance test. As both the 75 % and 50 % body mass resistive sprint loads acutely enhanced performance, the minimal conditioning load is not yet apparent. It is possible that a load of 25 – 30 % BM, as used by Whelan et al. 25 may be too low to elicit an adequate conditioning effect, however, this is currently unclear, as the null effect could also have been due to the training status of their subjects.

Acute performance enhancing techniques, such as the ones previously mentioned, have mostly attributed improvements in performance to a neuromuscular phenomenon known as post-activation potentiation (PAP) 9–11,27,35,43. Although PAP is the most commonly cited mechanism to cause improvements in sprint, jump and throwing ability following an overloading exercise, the term is commonly misused in exercise performance literature. To this point, PAP does not refer to the enhancement of sprint, jump or throwing ability as it seems in exercise performance studies citing this phenomenon, but refers to the ability of muscle contractile history to influence future force production ability 44,45. Myosin light chain phosphorylation (the suspected cause of enhanced force production ability following a volitionally or electrically induced contraction 46), which results from a conditioning contractile activity such as a maximal voluntary contraction, increases the sensitivity of actin-myosin interactions to Ca$^{2+}$ 47. This myosin light chain phosphorylation that occurs following a maximal contraction suggests PAP could be a potential mechanism for the observed improvement in sprint, jump, or throwing ability following a conditioning exercise. However, a ceiling effect regarding the sensitivity of actin-myosin interactions to Ca$^{2+}$ has been observed 47. This ceiling effect is characterized by an increase in force production (following myosin phosphorylation) at low to moderate myoplasmic Ca$^{2+}$ concentrations, but not at high concentrations 47, which would be present during a maximal dynamic activity such as sprinting, suggesting this mechanism would not contribute to
subsequent exercise, in which maximal force production is desired. Despite the inability of PAP to improve maximal force production when myoplasmic Ca\(^{2+}\) concentrations are high, PAP retains the ability to improve the rate of force production via increased probability of attachment between actin and myosin\(^{45}\). This is evident through the increased rate of twitch and high-frequency tetanic contractions that develops following a potentiating conditioning stimulus\(^{48}\). Therefore, it appears the myosin phosphorylation that occurs following a conditioning stimulus would not likely increase the absolute force generated (as the phosphorylated myosin only increases cross-bridge cycling rates at low-moderate myoplasmic levels of calcium) by the muscle but would potentially improve the muscles overall rate of force development. This hypothesis could potentially explain the improvements in dynamic exercise as they are typically not limited by absolute force development, but the rate at which force can be generated.

As an alternative to the contractile-history dependent PAP phenomenon, recent focus on Titin’s contractile-history dependent contribution in muscle contractions may provide further insight into the how an overloading exercise may subsequently enhance maximal dynamic exercise performance. Titin was initially thought to play a passive role in force production, though recent evidence, as will be discussed, suggest Titin may play a greater role in eccentric force production. Firstly, the main appeal in seeking an explanation for improved dynamic exercise following a conditioning stimulus beyond that of myosin phosphorylation, is that the two-dimensional (cross-bridge theory – actin and myosin) model in which PAP operates has been suspected of being incomplete\(^{49}\). While the cross-bridge theory accurately predicts concentric and isometric muscle actions, it fails to adequately explain force generating capabilities of eccentric contractions (sarcomere force – length relationship), which are generally considered more important during dynamic exercise such as sprinting and jumping\(^{50,51}\). The
cross-bridge theory also fails to predict the contractile-history dependent phenomenon known as residual force enhancement (the ability to generate more force isometrically after performing an eccentric contraction). In light of growing evidence that the large protein Titin (molecular weight = ~4.2 MDa; Actin molecular weight = ~42 kDa; Myosin molecular weight = 520 kDa) plays a role in active lengthening contractions, an updated model of the cross-bridge theory has been proposed. With this adaptation to the cross-bridge theory, and as titin function is contractile-history dependent, it is not only plausible, but likely that titin undergoes conformational changes during near maximal exercise (conditioning exercise), as is observed with myosin, that allows future contractions, especially eccentric ones, to generate more force. Applying the conformationally based explanation of PAP into this three-dimensional (actin, myosin, and titin) active muscle filament theory, such that multiple protein filaments undergo various structural changes following a conditioning stimulus, provides a stronger rationale for how near-maximal conditioning exercises performed at relatively slow speeds would then affect dynamic activities, which are much more dependent on eccentric or “elastic” specific loading characteristics. The increased force generating capability of a previously lengthened muscle can remain present even following a period of muscle relaxation, known as passive force enhancement. It is therefore, this passive force enhancement phenomenon, which more appropriately provides a rationale for the improved sprint and jump ability following a conditioning exercise. However, minimal evidence exists to support this finding as the majority of this research is performed under isolated, single-joint scenarios.

The examination of resisted sprinting is an interesting area of research for all practitioners aiming to improve acceleration ability. This approach has commonly been explored in the literature and applied in coaching settings, although the direct mechanisms behind its
success have remained unknown. It is currently apparent that heavy resistive loads do elicit an acute performance enhancing effect but the minimal “potentiating” load required to elicit these changes is not yet known. Future exercise performance research examining the effects of RST in highly-trained athletes will help identify the specific loads necessary to induce performance enhancing effects.
Ischemic Pre-Conditioning

A novel therapeutic strategy for protecting the myocardium against ischemia was developed in 1986. Reimer et al. had previously shown that brief, repetitive periods of ischemia did not induce cell death, which, in addition to the observation that ATP depletion rates were slowed during ischemia, led to the hypothesis that non-lethal bouts of ischemia may protect the myocardium against a prolonged ischemic period. Based on this hypothesis, the first “ischemic pre-conditioning” protocol was designed. A thoracotomy was performed on forty anesthetized healthy adult dogs, which provided access to the heart. Four periods of five-minute coronary artery occlusions were then performed by snaring the coronary artery distal to its atrial appendage, prior to an extended ischemic period (40 minutes). Upon postmortem analysis, myocardium which had been pre-conditioned prior to the sustained ischemic period, had a significantly reduced infarct size (2.9 % of LV) compared with control (12.6 % of LV). This local, and incredibly invasive pre-conditioning technique, has since been deemed unnecessary, as ischemic pre-conditioning performed remotely on a limb in a less invasive manner proved equally effective for protecting the myocardium against ischemia. In 1995, Pang et al. demonstrated that skeletal muscle could similarly be pre-conditioned. Using serial muscle biopsies, it was clearly demonstrated that skeletal muscle metabolism was altered during prolonged ischemia following a pre-conditioning protocol. Pre-conditioned skeletal muscle phosphocreatine and ATP levels decreased less during prolonged ischemia, and concentrations of both recovered more quickly following reperfusion compared to the control. As ischemic pre-conditioning (IPC) proved effective at altering skeletal muscle metabolic rate, and the rate of intramuscular phosphocreatine and ATP recovery following sustained ischemia, it is
understandable how this technique would have gained interest within the field of exercise science.

The use of IPC as an ergogenic technique in sport is relatively novel, with the first IPC exercise performance study by De Groot et al. published in 2010, although its effectiveness remains controversial. For every exercise performance study that supports the use of IPC as an ergogenic technique, there are equal null findings. The opposing findings are most likely a result of our inconclusive understanding of how IPC alters neural and metabolic function, which seems to have forced IPC performance studies to randomly test the efficacy of this technique using different exercise models (for example: Wingate, repeated Wingate, repeated sprint cycling, 100 m swim sprinting, repeated 50 m swim sprinting, 30 m sprinting, 1 km rowing, leg extension, and 5 km treadmill run). Just as the mechanisms that may allow IPC to enhance performance are unclear, the optimal IPC dosage for performance (assuming it exists), also remains unknown. Therefore, the original IPC protocol (4 x 5 min of ischemia, interspaced with 5 min periods of reperfusion), that was developed to reduce myocardial infarction during periods of ischemia, remains the most commonly employed protocol in exercise performance studies. It is likely, that if a performance-enhancing IPC protocol does exist, it is not identical to that which prevents cell death. However, it may be that the dose of IPC necessary to influence metabolism is similar to the dose already used, and currently, the effects of IPC on metabolism are the most appealing to exercise performance researchers. As the use of IPC outside the clinical realm is still novel, it has only recently been evident that timing and frequency of IPC exposure relative to exercise performance are significant. IPC was shown to have an ergogenic effect 2 and 8 hours following conditioning, whereas no performance enhancing effects were observed after 1 hour. Additionally, subjects
repeatedly exposed to IPC over seven days saw drastic changes in anaerobic (increased mean power: ~4 %, peak power: ~11 %, reduced fatigue rate), and aerobic performance (increased VO$_2$ MAX: ~13 %, maximal aerobic power: ~18 %)\textsuperscript{80}. The sporadic way in which IPC is currently being investigated in the sport performance literature is inefficient, and with these recent findings it is suggested that more focus be placed on IPC protocol optimization. Alternatively, discrepant literature, which may function to discredit IPC, when it could potentially benefit sport performance, will continue to be produced when the real issue may be the protocol used.

Despite the many uncertainties surrounding the use of IPC as a performance-enhancing tool, common mechanistic observations do exist. As initially discussed, it is well-established that IPC alters metabolic function during subsequent periods of low oxygen availability\textsuperscript{56,57,59}. This is characterized by the attenuated depletion of ATP, phosphocreatine, and glycogen\textsuperscript{81,82} during prolonged periods of ischemia, suggesting a reduction in anaerobic metabolism, even though aerobic metabolism is obviously also being restricted. When IPC has preceded exercise, blood lactate levels have been reported to be lower\textsuperscript{66}, possibly suggesting that exercising energy requirements are mainly being supported by increased aerobic metabolism. However, this idea of reliance on aerobic metabolism during exercise following IPC is not always supported, as Lisbôa \textit{et al.}\textsuperscript{79} observed higher peak blood lactate levels during a maximal 50 m swim sprint. Additionally, following IPC, skeletal muscle phosphocreatine levels surpass baseline levels\textsuperscript{83}, which can act as a protective mechanism against future ischemia but can also potentially allow for improved short-duration exercise performance, which utilizes the ATP-PCr metabolic system. The overshoot of phosphocreatine observed after reperfusion is likely a result of the increased blood flow, and therefore, oxygen being delivered, as phosphocreatine recovery is
dependent on oxygen availability. At present, the way in which IPC regulates cellular metabolism during ischemia is unclear, but could potentially be explained by one of two hypotheses, individually or in combination. Firstly, IPC could induce reductions in energetically costly cellular processes, which would reduce the need for metabolism to occur, and secondly, metabolic efficiency could be improved following IPC. While both explanations are plausible, they are currently speculative. Some evidence that metabolically associated factors are altered following IPC does exist. One study by Kido et al. showed that the rate of oxygen deoxygenation in skeletal muscle following IPC was significantly increased during moderate-intensity exercise. With the support of findings by Bailey et al., that lactate accumulation was attenuated during submaximal treadmill running, this suggests that sub-maximal exercise performance after IPC may benefit from increased energy availability, made available from an increased aerobic metabolic rate.

Although IPC clearly alters metabolism, an understanding of how IPC could affect exercise performance is incomplete without including a brief overview of how IPC affects the nervous system. Pickard et al. recently demonstrated that myocardial protective factors released following IPC are secondary to vagus nerve activation. As the vagus nerve was required to be intact to observe a reduction in infarct size following prolonged ischemia, IPC-induced cardioprotection is to some degree mediated by the autonomic nervous system. Demonstrating that this is not purely a localized effect, vasodilation of a contralateral artery has been demonstrated during reperfusion following IPC (with no increased observation of cGMP, which indicates the lack of local NO presence – a potent vasodilator that would be present in the artery exposed to reperfusion), further demonstrating the ability of IPC to manipulate the interplay between parasympathetic and sympathetic, at least in regards to vascular control. The
increased contralateral vasodilation would appear to suggest that IPC increases parasympathetic, or decreases sympathetic output, however, like other investigations on the effects of IPC, there is also evidence to support the need for norepinephrine to be present in order to see a protective effect. As both branches of the autonomic nervous system seem to play a role in the effectiveness of IPC at protecting the myocardium against infarct, it is unclear exactly how IPC impacts the nervous system and whether the exact interplay between sympathetic and parasympathetic is situation dependent. Despite uncertainties regarding the effects of IPC on the nervous system, this area of research will likely be relied upon in the future for explaining how IPC influences short-duration exercise, especially when properties of metabolism are not a limiting factor.

In reviewing the available exercise performance IPC literature, a successful pre-exercise protocol is not currently obvious, as little experimentation has focused on protocol optimization. When examining whether IPC improved performance in previous research using short-duration exercise models, it seems that positive findings are inconsistent (Table 2). While Patterson et al. and Paradis-Deschênes et al. observed improvements in exercise performance following IPC, three other studies, which also used short-duration performance tests, did not. However, when examining IPC performance research utilizing highly-trained subjects, it appears

<table>
<thead>
<tr>
<th>Author</th>
<th>Year Published</th>
<th>Subject training status</th>
<th>IPC protocol</th>
<th>Outcome Measure</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gibson et al.</td>
<td>2013</td>
<td>Former competitive team sport athletes</td>
<td>3 × 5 min @ 220 mmHg</td>
<td>3 x 30 m running sprints</td>
<td>(-)</td>
</tr>
<tr>
<td>Patterson et al.</td>
<td>2014</td>
<td>Recreational team sport athletes</td>
<td>4 × 5 min @ 220 mmHg</td>
<td>12 × 6 s cycle sprints</td>
<td>(+)</td>
</tr>
<tr>
<td>Gibson et al.</td>
<td>2015</td>
<td>Former competitive team sport athletes</td>
<td>4 × 5 min @ 220 mmHg</td>
<td>5 × 6 s cycle sprints</td>
<td>(-)</td>
</tr>
<tr>
<td>Lalonde and Curnier</td>
<td>2015</td>
<td>Rugby athletes</td>
<td>4 × 5 min @ 50 mmHg above systolic BP</td>
<td>6 × 6 s cycle sprints</td>
<td>(-)</td>
</tr>
<tr>
<td>Paradis-Deschênes et al.</td>
<td>2016</td>
<td>Power/weightlifters and taekwondo athletes</td>
<td>3 × 5 min @ 200 mmHg</td>
<td>5 × 5 leg extensions</td>
<td>(+)</td>
</tr>
</tbody>
</table>
that performance improvements are common (Table 3). The consistent finding of improved exercise performance in these studies \textsuperscript{62,77,78} may suggest that only trained subjects benefit from IPC, or that the effects of IPC on performance are so small that a highly reliable population with minimal between-test variability is required to observe the change. Additionally, it is unlikely that IPC would benefit short and long duration exercise performance, as the mechanisms that would improve performance in one area would likely hinder performance in the other. Therefore, more research should examine the effects of IPC on exercise performance using highly-trained athletes to ensure small, but meaningful changes in performance are not being masked by inter-test variability.

<table>
<thead>
<tr>
<th>Author</th>
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<th>Subject training status</th>
<th>IPC protocol</th>
<th>Outcome Measure</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jean-St-Michel et al. \textsuperscript{77}</td>
<td>2011</td>
<td>Canadian national and international team members (swimming)</td>
<td>4 x 5 min @ 15 mmHg above systolic BP</td>
<td>100 and 200 m swim sprint</td>
<td>(+)</td>
</tr>
<tr>
<td>Kjeld et al. \textsuperscript{78}</td>
<td>2014</td>
<td>5 of the top 10, world-ranked free divers, 5 oarsmen ranked in the top 50 world-record list</td>
<td>4 x 5 min @ 50 mmHg above systolic BP</td>
<td>Underwater swimming distance, 1 km rowing time</td>
<td>(+)</td>
</tr>
<tr>
<td>Paradis-Deschénes et al. \textsuperscript{62}</td>
<td>2016</td>
<td>Power/weightlifters and taekwondo athletes</td>
<td>3 x 5 min @ 200 mmHg</td>
<td>5 x 5 leg extensions</td>
<td>(+)</td>
</tr>
</tbody>
</table>

The understanding of ischemic pre-conditioning is a complex area of research. A tool with many applications, but with many unclear operations, makes for a very interesting future in the field. As of now, it is apparent that IPC can be used to manipulate cellular metabolism, but only when an intact nervous system is present, which is an excellent model for displaying the interplay between the governing systems of our bodies. In regards to IPC as a performance enhancing protocol, it appears that there is merit in the continued exploration. Especially since it does not yet appear that IPC consistently improves performance in a specific exercise model.
A magnitude-based inferences (MBI) approach is a statistical method aiming to improve the ability of researchers to make clear interpretations of their findings. Unlike the $P$-value, which merely provides a binary interpretation (significant/non-significant) of an outcome, this approach is characterized by several statistics, which together, provide a more informative conclusion. The use of confidence intervals, effect sizes, and probabilities in combination can describe the magnitude and the likelihood of a true change. This statistical approach proves useful in situations that require a practical or clinically relevant interpretation of results, and has been argued to be superior to null hypothesis testing. Several reasons behind its suggested superiority over null-hypothesis testing are: results are sample-size independent, effects are described using a magnitude (trivial, small, moderate, large), results are easily interpreted, and previously designed spreadsheets for calculating results are publicly available online (www.sportsci.org).

The effect sizes used in this statistical approach have been slightly altered from Cohen’s effect sizes to be more conservative. Trivial, small, moderate, large, and extremely large effect sizes are characterized by $< 0.2$, $0.2 - 0.6$, $0.6 - 1.2$, $1.2 - 2.0$, and $2.0 - 4.0$, respectively. The smallest worthwhile change (SWC), is a commonly used term when reporting findings with this approach, and is usually synonymous with a small effect size. The SWC is typically associated with at least a small effect size (0.2), however, when supported by a strong rationale, the SWC can be changed to an alternative effect size. In addition to the reported magnitude of effect, confidence intervals of 90% about this effect are commonly used, though it is suggested that these be determined on a per-case basis depending on the repercussions of an incorrect interpretation. Probabilities, or the likelihood that the true value is within a given range of
beneficial/harmful effect sizes are calculated and allow a description of the effect size to be used. Descriptor words are based on the probability that a specific magnitude of change has occurred, and are reported as follows: <1 %, almost certainly not; 1 – 5 %, very unlikely; 5 – 25 %, unlikely or probably not; 25 – 75 %, possibly or may be; 75 – 95 %, likely or probably; 95 – 99 %, very likely; >99 %, almost certainly. In situations that have confidence intervals ranging from a small negative effect through a small beneficial effect, the results are described as unclear. This result does not mean there is no effect of the treatment on the outcome, but rather suggests the group variation is too large to observe the true effect.

The combination of effect sizes, confidence intervals and probabilities allows for results to be easily interpreted. Examples and meaning of results are provided below.

1) There was very likely a large effect from the treatment on performance. Statistical interpretation: ES = 1.2 – 2.0; Probability of true outcome being large = 95 – 99 % harmful or beneficial

2) There was a small, unclear, effect from the treatment on performance. Statistical interpretation: ES = 0.2 – 0.6; Probability of true outcome being small = 25 – 75 % harmful and 25 – 75 % beneficial

This statistical approach was used alongside a null-hypothesis testing approach for the analysis of both studies presented within this thesis. Using both statistical approaches in combination, allowed for results to be practically reported, without diverting from a classical, null-hypothesis style.
Chapter 3: Purpose and Hypotheses
Purpose

The influence of RST and IPC on maximal acceleration performance, specifically using sprint-trained athletes, is presently unclear. Despite being the best candidates to show changes in sprint performance, sprint-trained athletes have not yet been used in existing acute RST or IPC performance studies. These studies have recruited rugby\(^9,11\), anaerobically trained\(^{10}\), team sport\(^6^9\), and recreational subjects\(^{25}\). Mixed outcomes were observed in the RST studies, while the only study examining the effects of IPC on sprint performance reported null-findings. Of these five studies, only one reported individual subject between-sprint coefficient of variation\(^{11}\), which, is fundamental in providing evidence that the adopted population is able to repeatedly perform within a narrow range, allowing outcomes to be attributed to the scientific intervention rather than being masked by subject inter-sprint variability. The masking of true findings by subject pools containing large inter-sprint variability will be a limiting factor in determining the effects of an intervention, even when study design and methodologies are sound. Therefore, the purpose of this thesis was to evaluate the effects of RST and IPC on maximal acceleration performance in sprint-trained athletes, who are a highly reliable and valid cohort when examining the effects of an intervention on sprint performance.
Research Objectives and Hypotheses

Study 1: Moderate Load Resisted Sprints Do Not Improve Subsequent Sprint Performance in Varsity Level Sprinters

Objectives

Primary research objective: To investigate the effects of a 3 x 20 m, resisted sprint intervention, using a 40 % sled-equivalent load (a novel resistive device was used in place of traditional weighted sleds), on maximal 20 m acceleration performance.

Secondary objectives: 1) To characterize the population inter-sprint variation. 2) To characterize the relationship between 3 commonly used timing devices; timing gates, radar gun, 1080 Sprint.

Hypotheses

Primary hypothesis: A performance-enhancing effect will be observed following the resisted sprint intervention, as highly-trained subjects, such as those recruited in the current study, exhibit a greater ergogenic effect from conditioning stimuli.

Secondary hypothesis: 1) Inter-sprint variability in this population will be low (CV < 2%), allowing any findings to be attributed to the intervention if the effect is > 2% of CV. 2) The timing devices commonly used in the literature (timing gates and radar) will provide timing data which correlates strongly with the timing data provided by the 1080 Sprint (R > 0.85).
Study 2: Ischemic Pre-Conditioning Does Not Influence Maximal Sprint Acceleration Performance

Objectives

**Primary research objective:** To investigate the effects of a 3 x 5 min ischemic pre-conditioning protocol, ending 15 minutes prior to exercise, on maximal acceleration performance

**Secondary objectives:** 1) To characterize the perception of ischemic pre-conditioning on maximal acceleration performance. 2) To investigate whether subject perception regarding the effects of treatment on performance coincides with a decreased (improved) sprint time.

Hypotheses

**Primary hypothesis:** A performance-enhancing effect will be observed as previous work using highly-trained subjects, such as those recruited in the current study, have consistently reported improvements in exercise performance following an ischemic pre-conditioning protocol.

**Secondary hypothesis:** 1) Subjects will perceive the intervention has improved (decreased) sprint time. 2) Subjects that strongly believe the ischemic pre-conditioning protocol enhanced performance will observe an actual decrease (improvement) in sprint time.
Individual Contributions

I (Kyle Thompson) was responsible for attaining ethics approval, recruiting subjects, collecting data, analyzing data, interpreting data, and writing abstracts and manuscripts associated with the two studies within this thesis.

Alanna Whinton, Dr. Lawrence Spriet, and Dr. Jamie Burr contributed to the preparation of both manuscripts presented in this thesis through written edits and oral discussion.

Shane Ferth contributed by aiding in data collection for Study 2, and provided written feedback on the Study 1 manuscript.
Chapter 4: Manuscripts
Study 1: Moderate Load Resisted Sprints Do Not Improve Subsequent Sprint Performance in Varsity Level Sprinters


Authors: Kyle M.A. Thompson, Alanna K. Whinton, Shane Ferth, Lawrence L. Spriet, Jamie F. Burr

**ABSTRACT**

Resisted sprint training (RST) is commonly used for training in athletics and team sports to develop acceleration ability. Evidence suggests that RST may be effective as an acute intervention to improve successive sprints. While these improvements have been measured in team sport athletes, limited research has considered the short-term effects of RST training in sprint-trained athletes. Therefore, the aim of the current study was to determine if performing RST with varsity level sprinters using resistive loads of 15% body mass results in a potentiation effect, leading to improvements in subsequent maximal sprint performance over 0 - 5 m and 0 - 20 m. Competitive sprinters (n = 20), were randomly assigned to perform a pre/post maximal 20 m sprint separated by either 3 resisted (RST group) or un-resisted (URS group) sprints. The RST or URS protocol was performed on four occasions separated by at least 7 days. No significant differences were observed between the RST and URS groups comparing changes in sprint times over 0 - 5 m (URS Δ = <0.01 s ± 0.03 s, RST Δ = <0.01 s ± 0.03 s) and 0 - 20 m (URS Δ = 0.013 s ± 0.04 s, RST Δ = <0.01 s ± 0.04 s). We conclude that resisted sprints using loads of 15% body mass are ineffective at inducing a potentiating effect on subsequent sprint performance in varsity level sprinters.

Keywords: sled training, sled towing, potentiation, 1080 Sprint, horizontal power, acceleration
INTRODUCTION

The ability to accelerate is essential for athletic performance in both individual and team sports \(^9^4\). Sprint acceleration is a result of both horizontal and vertical power production, which can be increased through changes in sprint mechanics \(^9^5\) or by increasing lower limb muscle mass/strength \(^9^6,9^7\). These modifiable characteristics are, therefore, targeted by coaches aiming to improve acceleration ability. Contrast training and resisted sprint training (RST) emphasize the use of these types of specific strengthening exercises, which can ultimately improve horizontal power production, leading to enhanced acceleration.

Contrast training involves a muscular overloading exercise, which precedes an outcome exercise such as sprinting, jumping, or throwing \(^9^8\). Heavy back squats (> 90 % 1RM) and depth jump exercises are most commonly employed as overloading stimuli and are believed to elicit a post-activation potentiation response \(^4^4,9^9\). Post-activation potentiation is a physiological phenomenon believed to cause myosin regulatory light chains to become phosphorylated, leading to an increased sensitivity of actin and myosin to calcium and increased probability of attachment, which theoretically allows for greater strength and speed performance \(^4^4,9^9\). Whether it be related to the effects of post-activation potentiation, or another performance enhancing mechanism, improved sprint performances have been reported following an overloading exercise \(^3^9\). Resisted sprint-training (i.e. sprinting while pulling a weighted sled) can be considered an acceleration specific contrast training protocol because it offers the ability to overload muscles in similar positions required during an unloaded acceleration, without significantly altering sprint mechanics \(^1^7\). This specificity is vital to improving outcome exercise performance (unloaded sprinting), as performing a conditioning exercise that uses similar joint angles to the outcome exercise results in the greatest transfer effect \(^4^4,1^0^0,1^0^1\). Resisted sprint training has been reported
to cause changes in stride length, stride frequency, ground contact time, and horizontal force production, all of which can improve acceleration ability.  

Few studies have examined the potentiating effect of resisted sprints in highly-trained subjects, and of those that exist, protocol variations such as: running surface, harness attachment site, temporal pattern of data collection within athletes’ training season, measurement error, and subject characteristics could contribute to inconsistent performance within and between studies. Two recent investigations using trained rugby athletes have shown improvements in sprint performance after very heavy resisted sprints. Improved sprint performance in these studies contrasts with an earlier study by Whelan et al. who found no enhancement in sprint performance following moderate load resisted sprints (25 - 30 % body mass) in physically active, but non-specifically trained, men. Comparing these studies, differential outcomes may be attributed to both the resisted sprint load, and the subject’s training status. In the study by Whelan et al., which used lighter loads, the inter-trial and inter-individual variability of the participants may have masked performance benefits. That is, a true effect of moderate-load sprinting (if it occurred) may have been undetectable owing to the large variability about the mean changes. This is particularly likely in untrained runners who would have high variability that would overshadow relatively small, but potentially meaningful, differences. Alternatively, in the recent rugby studies the overloading exercises used to elicit a potentiating effect were performed much closer to the participants 1RM with particularly heavy loads approximating 75 % of body mass. It remains unclear if this heavy-load was thus effective because it is universally required to elicit a potentiation response, or if it is only appropriate for rugby union athletes, who train for the specific demands of a strength-dominant sport. If this is the case, it is thus possible
that lighter loads may be suitable in populations that focus more on speed of movement and accelerating their own body mass as their 1RM would be lower.

While accounting for these limitations under more tightly controlled experimental conditions, we sought to examine whether resisted sprints using a moderate load can induce a performance enhancing effect in sprint-trained subjects over 0 – 5 m and 0 – 20 m. Specifically, the study was designed such that inclusion criteria selected for highly trained sprinters as participants to limit between-sprint variation in performance, and testing was performed at a standardized period of the athletes’ competition schedule. All sprints were performed at an indoor training facility on a high quality polytan track surface, limiting extraneous or variable environmental factors; and a 1080 Sprint device was employed for resistive loading and sprint measurement. This improved replicability, specificity of load, and reduced error. The major benefit of using the 1080 Sprint over traditional sprint training sleds is in the control over the load throughout each sprint. Since it is controlled electronically using a robotic flywheel system, the resistance applied through the 1080 Sprint is highly reliable and quantifiable; as opposed to weighted sleds wherein the resistive load can change substantially depending on the coefficient of friction, which varies with the track surface, sled runner quality, and sled velocity. Finally, in addition to the study criteria that has been designed to reduce the discussed limitations, a parallel magnitude-based statistical approach was included in the study design. The use of this approach has become increasing popular in the field of sport performance research, as it is not biased by statistical power and allows for subjects within a population to be assessed individually against both their own pervious performance standard and a predetermined “meaningful” change. A strong argument for the use of this analysis when examining highly trained subjects who may expect to see relatively small changes as a result of an intervention has been made previously.
It was hypothesized that a small, but meaningful, change in sprint performance would be observed following a moderate-load resisted sprint intervention in this population. Furthermore, we hypothesized that inter-sprint variability within sprint-trained participants would be extremely low, allowing any observed changes in performance to be attributed to the resisted sprint intervention.

METHODS

Experimental Approach to the Problem

A randomized control experimental design with an un-resisted sprint control group (URS, n = 10) and intervention group (RST, n = 10) was used to determine the post-exposure effects of resisted sprint-training on subsequent 0 – 5 m and 0 – 20 m sprint performance. Inter-sprint variance of this caliber of athlete was determined prior to the intervention, to allow for any changes in performance to be more confidently attributed solely to the effect of the intervention. Testing of both the URS and RST subjects was conducted during the subjects’ indoor competitive season to ensure high-level performance during all trials. Subjects were randomly assigned to either the URS or RST group for four testing sessions. In order to evaluate the effectiveness of the resistive load used by Whelan et al.\textsuperscript{25} the resistive loading parameters in the current study were mathematically matched based on previous work, which suggests that towing speed parabolically reduces sled load\textsuperscript{21}, whereas the 1080 Sprint load is velocity independent. This relates to the fact that the resistive load is not dependent on the coefficient of friction with the ground, and is applied only in the horizontal direction. For flow-chart of Study 1 see page 79.
Subjects

Twenty track and field sprinters (male = 11, female = 9) who had previous experience with resistance training, sprint-training, and resisted sprint-training using traditional weighted sleds were recruited for the study (age = 20 ± 2 years, female body mass = 59 ± 6 kg, male body mass = 76.1 ± 7.8 kg) (Table 1). Subjects were excluded if their primary indoor track event was ≥300m. In addition to the acceleration training days during which data was collected, subjects completed 2-3 resistance training sessions, one maximal velocity sprint session, and one work capacity sprint session per week. This additional training was consistent among all subjects. The University of Guelph Research Ethics Committee approved the study (REB#16FE11), and written informed consent was obtained from all subjects prior to testing.

Table 1. Subject Characteristics within the Resisted Sprint Training and Un-Resisted Sprint groups.

<table>
<thead>
<tr>
<th>Subject Characteristics</th>
<th>RST</th>
<th>URS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>20.6 ± 2.3</td>
<td>19.7 ± 1.6</td>
</tr>
<tr>
<td>Number of Subjects M/F</td>
<td>6 / 5</td>
<td>5 / 4</td>
</tr>
<tr>
<td>Mass M/F (kg)</td>
<td>75.4 ± 8.7 / 61.2 ± 4.4</td>
<td>78.3 ± 8.1 / 58.8 ± 7.3</td>
</tr>
<tr>
<td>Best 60m time M/F (s)</td>
<td>6.75 - 7.24 / 7.59 - 7.77</td>
<td>6.87 - 7.19 / 7.62 - 8.04</td>
</tr>
</tbody>
</table>

1080 Sprint Resistance and Data Collection Tool

All data was recorded using a 1080 Sprint device (1080Motion, Sweden), which uses a robotic flywheel resistance and simultaneously records velocity, power, horizontal force, distances and time. The error of the 1080 Sprint has previously been examined and is low across all measurements (velocity error = ± 0.5 %, distance error = ± 5 mm, force error = ± 4.8 N)108. Subjects attached a harness to their waist from which a tether cord was run to the 1080 Sprint
device. Baseline and final sprints were measured using the “isotonic” function of the 1080 Sprint with the minimum functional load of 1 kg, which is required to maintain tension on the cord.

Given that a minimal load is required for the device to function, it has been suggested that sprint times reported using timing gates may not be comparable to those obtained using the 1080 Sprint. Since this is the first study to simultaneously use the 1080 Sprint as a training and data collection tool, we performed fifty sprint trials while measuring 0-10 m, 10-20 m and 20-30 m splits concurrently with a Freelap timing system (Freelap, California, USA), a Stalker Pro II Radar system (Applied Concepts, Texas, USA) and the 1080 Sprint (1080Motion, Sweden).

Sprint times obtained using the 1080 Sprint were practically identical compared with the other two devices (see Table 2 for time comparisons).

Table 2. Comparative sprint analysis between 1080 Sprint, Freelap timing gate system and Radar system.

<table>
<thead>
<tr>
<th></th>
<th>0 - 10 m</th>
<th>10 - 20 m</th>
<th>20 - 30m</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Freelap - 1080 Sprint</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pearson Correlation</td>
<td>0.87</td>
<td>0.99</td>
<td>0.98</td>
</tr>
<tr>
<td>Coefficient of Variation % (s)</td>
<td>4.75</td>
<td>2.03</td>
<td>2.19</td>
</tr>
<tr>
<td>(~0.002)</td>
<td>(~0.003)</td>
<td>(~0.007)</td>
<td></td>
</tr>
<tr>
<td><strong>Radar - 1080 Sprint</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pearson Correlation</td>
<td>0.87</td>
<td>0.94</td>
<td>0.99</td>
</tr>
<tr>
<td>Coefficient of Variation % (s)</td>
<td>5.11</td>
<td>4.32</td>
<td>1.51</td>
</tr>
<tr>
<td>(~0.015)</td>
<td>(~0.008)</td>
<td>(~0.002)</td>
<td></td>
</tr>
</tbody>
</table>

Procedures

**Determining Population Variability**

Thirty unloaded sprint trials were used to determine typical inter-sprint variability within a varsity level sprint-trained subject. Subjects performed 3 maximal 20 m sprints from sprint blocks, in track spikes, on an indoor polytan track surface, with outcomes measured using the
1080 Sprint device. Data was stored online for later analysis. This protocol was performed on two separate days to determine individual within and between day inter-sprint variation.

**Testing Protocol**

Subjects performed five maximal 20 m sprints. The first was used as the “baseline sprint”, following which, subjects in the RST group performed three resisted sprints (Sprint 2 - Sprint 4), while subjects in the URS group performed three un-resisted sprints. Sprint 5 was the final sprint and was un-resisted for both groups. A minimum of 3 minutes was given between each sprint to ensure full recovery while not exceeding the 10 minute time span in which an acute performance enhancing effect is likely to be observed following a potentiating stimulus. Subjects performed either the RST or URS protocol on four separate occasions to account for daily fluctuations in performance.

**Statistical Analysis**

A factorial 2(Group) x 2(Test) x 4(Day) repeated measures ANOVA was used to compare baseline and final sprint times for the RST and URS groups. An alpha level of p < 0.05 was selected, *a priori*. As previously stated, a magnitude-based inferences approach was concurrently used to account for changes in performance which may have been missed using null-hypothesis testing. The coefficient of variation (CV) of the testing population was determined using a sub-group of sprinters as described above, and the smallest worthwhile change (SWC) in performance was determined for 5 m and 20 m sprints using 0.2 of the group standard deviation. Results are presented as mean ± SD.
RESULTS

No significant changes in sprint times over 0 – 5 m (Δ URS = -0.003 s ± 0.03 s, RST Δ = 0.0008 s ± 0.03 s, p=0.63) or 0 – 20 m (URS Δ = -0.01 s ± 0.04 s, RST Δ = -0.003 s ± 0.04 s, p = 0.33) were observed in either the RST or URS groups (Figure 1). Average individual CV was 1.82 % (-0.02 s) at 0 - 5 m and 1.19 % (-0.04 s) over 0 – 20 m. The SWC in performance for 0 – 5 m was 0.01 s and 0.03 s over 0 – 20 m. The average changes in sprint times observed between Sprint 1 and Sprint 5 under both RST and URS conditions, and the variation in these measures (which perfectly matched the calculated individual CVs, which were very low), demonstrate the reliability of this population. The mean group change in performance did not exceed the SWC after performing the RST intervention over 0 – 5 m or 0 – 20 m. Therefore, RST using moderate loads did not improve post-exposure sprint performance in highly trained sprinters after being analyzed using a null-hypothesis or magnitude-based inferences statistical approach.

DISCUSSION

A major strength of the current study was the highly-trained nature of the participants. This population had an average individual CV over 5 m and 20 m sprints of less than 2 %, which equated to our subjects repeatedly achieving sprint times within 0.04 s. Thus, even if a small effect occurred, it would have been detected. This consistency is similar to the variation (~2 %) seen in professional athletes used in other training studies and is an essential quality often neglected in the field of sprint research which allows outcomes to be confidently attributed to the intervention under examination.

In seeking to determine whether resisted sprints elicit a performance enhancing effect in varsity level track, no performance enhancing effect was observed following the RST intervention over
0 – 5 m or 0 – 20 m. This outcome is consistent with the results of Whelan et al. 25 who showed no acute enhancement of sprint velocity after performing resisted sprints in physically active men. Therefore, even when sprint-trained subjects with low inter-sprint variability are studied, measurement error is reduced, loading parameters are consistent, variable environmental conditions are controlled for, and a statistical approach specifically designed to evaluate changes in this population is employed, we did not observe an immediate performance enhancing effect after performing resisted sprints with moderate resistive loads.

Although the resisted sprint literature has historically refrained from using resistive loads greater than ~40 % body mass due to the belief that heavy loads negatively impact sprint mechanics, two recent studies have assessed the performance enhancing ability of resistive sprint with loads as high as 150 % body mass 9,11. Both studies reported improvements in sprint times over 15 – 20 m after performing weighted sled sprints with ~75 % body mass loads but decrements in sprint performance when using loads of 125 % and 150 % body mass 9,11. Both groups also used trained rugby athletes as their subjects, making it plausible that the 75 % body mass loads were optimal for this population due to the strength-oriented nature of their training. A previous investigation of post activation potentiation suggests that stronger individuals (1RM squat > 160 kg) have a greater improvement in vertical jump performance (+ 4.01 %) compared with those who had a 1RM squat of < 160kg (+ 0.42 %) following a potentiating protocol 40. This suggests that subjects must have a specific baseline strength to benefit from a potentiating protocol, and was a rationale for our hypothesis that lighter loads may yet be effective for sprinters, who possess explosive power, but are not typically defined as strength-based athletes per se.

Figure 1. Changes in Sprint Time Over 0 – 5 m and 0 – 20 m
Individual differences between baseline (Sprint 1) and final (Sprint 5) sprint times over 5 m (a.) and 20 m (b.). Individual points represent an average change in sprint time for subjects over the four trials with error bars representing individual SD. A meaningful change in performance was determined to be 0.01 s over 0 – 5 m and 0.03 s over 0 – 20 m.

While training status of a subject may dictate the extent of potentiation, new research focusing on determining optimal loading parameters to exert maximal horizontal power may provide an additional consideration. Using both recreational and elite level sprinters, Cross et al. \(^{20}\) very recently demonstrated that both populations produced maximal horizontal power at resistive loads of \(~80\%\) body mass. If these loads consistently allow subjects of various athletic backgrounds and training status to achieve maximal horizontal power, perhaps the potentiating effect seen by Winwood \(^{11}\) and Seitz et al. \(^{9}\) was a result of their subjects performing sprints in this optimal zone, rather than solely due to their training status. This would suggest that performing resisted sprint training as a potentiation technique requires athletes to use loads of \(~80\%\) body mass, or more specifically, loads which allow the individual to produce maximal...
horizontal power. To accommodate both potential explanations of how resistive sprint loads of ~80% body mass improve sprint performance, future research should incorporate strength testing into their design to categorize subjects based on strength levels while additionally monitoring whether subjects are producing their maximal horizontal power.

CONCLUSION

Resistive sprint loads of 15% body mass using a 1080 Sprint do not elicit an immediate performance enhancing effect in varsity level sprinters. Athletes with highly reproducible results, such as the sprint-trained athletes used in the current investigation, offer the greatest chance of observing small, but meaningful, alterations in performance and are recommended for future investigations in this area. Future research should also determine whether performing resisted sprints with a load that allows subjects to achieve maximal horizontal power is the determining factor when desiring a performance enhancing effect.

PRACTICAL APPLICATIONS

Sprint-trained athletes are capable of highly reproducible results, and are thus optimally suited for examining potentially small changes in sprint performance. After controlling for this (and other sources) variation, the results did not support a potentiation effect following resisted sprints with moderate loads. Therefore, it is not recommended that coaches use these loading parameters as an acute performance enhancing method. We additionally showed that the 1080 Sprint device can be used as a reliable timing system in addition to being used as a training tool. This tool represents a viable option for research and training that can accurately control and measure resisted sprint training loads.
ACKNOWLEDGEMENTS

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Study 2: Ischemic Pre-Conditioning Does Not Influence Maximal Sprint Acceleration Performance


Authors: Kyle M.A. Thompson, Alanna K. Whinton, Shane Ferth, Lawrence L. Spriet, Jamie F. Burr

ABSTRACT

Ischemic pre-conditioning (IPC) was initially developed to protect the myocardium from ischemia through altered cardiocyte metabolism. Due to the observed effects on metabolism and oxygen kinetics, IPC gained interest as a potential ergogenic aid in sport. Limited research evaluating the effects of IPC on maximal short-duration activities has been performed and of the existing literature, methodological limitations may have clouded the efficacy of this technique for enhancing sprint performance. Therefore, the current study employed a randomized repeated-measures crossover design with IPC, placebo (SHAM), and control conditions while using sprint-trained athletes (n = 18) to determine the effect of IPC (3 x 5 min occlusions, with 5min reperfusion), concluding fifteen min prior to maximal 10 and 20 m sprinting. A visual analogue scale was used in conjunction with the sprint trials to evaluate any possible placebo effect on performance. Despite a “significantly beneficial” perception of the IPC treatment compared with the SHAM trials (P < 0.001), no changes in sprint performance were observed following either the IPC or SHAM conditions over 10 m (IPC Δ = <0.01 s ± 0.02 s, SHAM Δ = <0.01 s ± 0.02 s) or 20 m (IPC Δ = -0.01 s ± 0.03 s, SHAM Δ = <0.01 s ± 0.03 s) compared to control. Thus, an IPC protocol does not improve 10 or 20 m sprint performance in sprint-trained athletes.

Keywords: sprinting, blood-flow occlusion, skeletal muscle, ergogenic aid, anaerobic exercise
INTRODUCTION

Ischemic pre-conditioning (IPC) was originally developed to reduce cell necrosis during prolonged periods of ischemia \(^{56}\). In addition to the cytoprotective effects of IPC, the stimuli from cyclical periods of localized ischemia, which is similar to the ischemia experienced during intense exercise, resulted in physiological changes such as increased phosphocreatine (PCr) availability \(^{83}\), anti-inflammatory effects \(^{111}\), increased muscle perfusion \(^{4}\), and improved oxygen uptake \(^{62,64}\). As these effects protect muscle and other tissues from ischemia, it is likely that IPC may also influence the ability of muscle to work under similar conditions.

Work supporting the use of IPC as an ergogenic technique has primarily used endurance \(^{63,64,66,112}\) and repeated sprint \(^{65,68,70}\) exercise models. Limited work has examined the effectiveness of IPC at improving maximal, short-duration activities lasting <10 s \(^{61,62,69}\). While IPC was demonstrated to enhance force production during maximal leg extensions in strength trained males \(^{62}\) and improved 6s sprint cycling peak power output \(^{61}\), Gibson et al. \(^{69}\) did not observe an improvement in 10, 20, or 30 m maximal sprint time using a group of team-sport athletes. Irrespective of the sprint specific literature, there are a number of more general findings which do not support a performance-enhancing effect of IPC \(^{75,113,114}\). A recent systematic review of the literature \(^{115}\) argued that the specific effects of IPC on numerous quantifiable performance outcomes are highly variable and, at present, a definitive effect on exercise performance remains uncertain.

The outcomes of sport performance intervention studies are heavily influenced by methodological design. In the IPC performance literature, factors such as the timing of IPC prior to the performance test, the number of ischemia-reperfusion cycles, the location of IPC (local or remote), the quantity of muscle mass made ischemic, subject characteristics, and any pre-
conceived expectations of the technique could possibly influence outcomes. With each of these variables having the ability to independently influence the results, it becomes especially important to minimize controllable measurement error, recruit subjects with low inter-test variation, and use statistical methods which are sufficiently sensitive to detect meaningful changes, should they exist.

A major source of potential error in the existing literature may derive from the low-level training status of recruited subjects. For example, in the 30 m sprint model used by Gibson et al. 69, the subjects’ inter-sprint variability may have been too large to observe the smallest worthwhile change in performance, which would have equated to 0.05 s (0.2 times group SD [0.25 s] 93).

Examination of the individual response data provided in this paper 69 reveals that subjects experienced changes in performance as large as 0.30 s over 30 m, which would describe a large change in performance as per their stated effect sizes. (By comparison, the difference in sprint time over 30 m between the world record 100 m performance and the 8th place finisher at the 2009 World Championships was 0.24 s, suggesting that an effect size of this magnitude would mean IPC has the potential to make any world championship finalist a world record holder.) These substantial fluctuations in performance were more likely a result of large inter-sprint variation, which may have masked a small, but meaningful, change in performance.

Therefore, the purpose of the current study was to determine whether a 3 x 5 min IPC protocol, ending 15 minutes prior to exercise influences 10 and 20 m sprint performance in well-trained sprint athletes. We expected sprint performance to improve following the IPC protocol, as the only maximal short-duration IPC performance study using highly-trained individuals saw improvements in peak/average force outputs during leg extensions 62.
METHODS

Experimental Approach to the Problem

A randomized repeated-measures crossover design (n=18) was used to determine the short-term effect of IPC on maximal 10 and 20 m sprint performance. Three randomly ordered protocols were performed prior to the exercise test, with each trial performed in duplicate to account for normal inter-day variability: 1. Control (no IPC), 2. SHAM (3 x 5 min at 20 mmHg) and 3. IPC (3 x 5 min at 220 mmHg). To control for any pre-conceived beliefs regarding the effects of the IPC intervention on sprint performance, subjects quantified their expectations using a visual analogue scale. Testing was conducted over a six-week period during the subjects’ indoor competitive season and all subjects performed similar training programs over the course of the study. For flow chart of Study 2 see page 79.

Subjects

Top varsity level track and field sprinters (male = 10, female = 8) were recruited from the National Champion Canadian University Track team, with further inclusion of select sprinters of similar caliber from other teams (all podium finishers at a national championship). Descriptive subject statistics are presented in Table 1. All subjects had at least three years of previous sprint and

Table 1. Subject characteristics

<table>
<thead>
<tr>
<th>Subject Characteristics</th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Subjects</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Age (years)</td>
<td>20 ± 2.6</td>
<td>21.7 ± 2.6</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>58 ± 6</td>
<td>72.8 ± 6.7</td>
</tr>
<tr>
<td>Best time over 60m (s)</td>
<td>7.44 - 7.92</td>
<td>6.75 - 7.25</td>
</tr>
</tbody>
</table>
resistance training experience and a primary indoor track event ≤ 300 m, which ensured the quality of maximal 30 m sprint ability remained high. No subjects had previously used or had knowledge of IPC. The University of Guelph Research Ethics Committee approved the study, and written informed consent was obtained from all subjects prior to participation.

**PROCEDURES**

*Testing Protocol*

Upon arrival at the testing facility, subjects completed a standardized warm-up and a randomized intervention (Control, SHAM or IPC protocol). Subjects were given 15 min following the SHAM/IPC protocol to ensure they were prepared to sprint maximally. Four 20 m sprints were performed by each participant. Sprints were performed from starting blocks, in track spikes, on an indoor polytan track surface with performance measured using a 1080 Sprint device (with the minimum functional load of 1 kg) and data stored online for later analysis. A minimum of 5 min was provided between sprints to ensure full recovery. After completion of the sprints, subjects indicated their perception of SHAM or IPC interventions on sprint performance using a 1000-pixel visual analogue scale (VAS) with the anchors of “IPC did not influence sprint performance” at the zero end and “Sprint performance improved because of IPC” at the 1000 end.

*SHAM and IPC Protocol*

Subjects were instructed to assume a recumbent position with both legs extended while performing the SHAM/IPC protocol. Both protocols consisted of 3 cycles of 5 min occlusion (SHAM - 20 mmHg, IPC - 220 mmHg) and 5 min reperfusion (0 mmHg) periods. Occlusions were performed using a pneumatic tourniquet system (Delfi Medical, Vancouver, British
Columbia, Canada) with the cuff positioned around the proximal aspect of the upper right thigh. A pressure of 20 mmHg was chosen for the SHAM protocol as it provides a sensation of cuff inflation with no vascular occlusion \(^{62,66,74}\). To reduce subject expectations, subjects were told that the purpose of the study was to compare the effects of different levels of occlusion on subsequent sprint performance.

**Statistical Analysis**

Using repeated measures ANOVA, we compared mean sprint times from each condition with significance set *a priori* at \( P < 0.05 \). A paired *t*-test was used to determine whether there was a difference in the athlete’s perception following the SHAM and IPC protocols using the VAS scores. A magnitude-based inferences approach was concurrently applied to account for changes in performance which may be meaningful, but not detectable using null-hypothesis testing. This approach has been recommended for sport performance and clinical studies, in which a reported P-value does not necessarily describe the magnitude or importance of change in a context-specific manner; for a full review of the rationale, the reader is directed to \(^{91,92}\). The coefficient of variation (CV) and the smallest worthwhile change in performance (0.2 times the between subject SD) were derived using the control sprint trials. Mean changes in sprint times (individual and group) were reported with 95% confidence intervals.

**RESULTS**

The average individual CV within subjects was 1.3 % over 10 m (~0.03 s) and 1.1 % over 20 m (~0.04 s). The smallest worthwhile change in performance was 0.02 s and 0.04 s for 10 and 20 m sprints, respectively. The SHAM and IPC protocols had an unclear trivial effect on 10 (Figure 1) and 20 m (Figure 2) sprint time. No differences were detected between control
Figure 1. Individual (circles) and group (diamond) changes in sprint time over 10 m.

Error bars indicate 95% CI. The smallest worthwhile change in performance (0.02 s) is indicated in the center with left and right areas indicating a beneficial and harmful effect, respectively.

Figure 2. Individual (circles) and group (diamond) changes in sprint time over 20 m.

Error bars indicate 95% CI. The smallest worthwhile change in performance (0.04 s) is indicated in the center with left and right areas indicating a beneficial and harmful effect, respectively.
(10 m = 2.07 ± 0.11 s, 20 m = 3.37 ± 0.20 s), SHAM (10 m = 2.07 ± 0.11 s, 20 m = 3.37 ± 0.19 s) or IPC (10 m = 2.08 ± 0.11 s, 20 m = 3.37 ± 0.19 s) sprint times over 10 m (P = 0.55) or 20 m (P = 0.91) (Table 2). A significant difference in the perception of how the SHAM (mean VAS score = 276 ± 159) and IPC (mean VAS score = 525 ± 251) protocols affected performance was observed (P < 0.001). The significantly higher VAS score following the IPC sprints indicated the subjects believed IPC improved performance. The average change in sprint times between conditions, and the variation of the subjects, demonstrated the consistency of this population. The mean group change in sprint performance did not exceed the smallest worthwhile change for either the SHAM or IPC for 10 or 20 m and confidence intervals demonstrated a range across a harmful, trivial and beneficial effect. The magnitude of the change across all conditions was, therefore, deemed trivial and the effect was described as “unclear”.

Table 2. Mean sprint times over 10 m and 20 m

<table>
<thead>
<tr>
<th>Condition</th>
<th>10m Sprint Time (s)</th>
<th>95% CI</th>
<th>20m Sprint Time (s)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>2.072 ± 0.11</td>
<td>2.02-2.13</td>
<td>3.374 ± 0.20</td>
<td>3.28-3.46</td>
</tr>
<tr>
<td>IPC</td>
<td>2.075 ± 0.11</td>
<td>2.02-2.12</td>
<td>3.372 ± 0.19</td>
<td>3.28-3.46</td>
</tr>
<tr>
<td>SHAM</td>
<td>2.069 ± 0.11</td>
<td>2.02-2.13</td>
<td>3.369 ± 0.19</td>
<td>3.28-3.46</td>
</tr>
</tbody>
</table>

**DISCUSSION**

A major strength of the current study was the well-trained status of the subjects and the repeated-measures study design, which allowed us to confidently attribute changes (or lack thereof) to the intervention. Also, using the VAS to determine subject perceptions following each testing day provided insight into the overall influence of the placebo effect on this population. Despite subjects believing they had performed better after the IPC treatment, there was no change in performance compared to the SHAM or control conditions, suggesting that highly-trained sprinters (CV for 10 and 20 m <1.5 %) did not experience a “functional” placebo effect from
these protocols. Further analysis showed IPC “believers” (reported VAS score >600) displayed an average decrement in sprint time over 20 m of -0.01 s from their control sprints, further indicating a lack of benefit from the placebo effect.

In opposition to our hypothesis, no performance enhancing effect was observed following IPC or SHAM protocols in the current study. This finding supports the conclusions of Gibson et al. 69, who also used a maximal sprint test as a performance outcome, and importantly clarifies that a null finding was not simply an artefact from “normal” participant variation and traditional statistical approaches, which would serve to reduce statistical power and the chances of observing small effects. This finding does, however, appear contradictory to work that found improvements in maximal and average force outputs following IPC using maximal leg extension exercise 62. It is plausible that IPC influences specific muscle actions differently, allowing movement-controlled (and concentric-dominant) modalities such as cycling or leg extensions to benefit more than open-chain, dynamic activities like sprinting, wherein coordination and skill may play a more important role. However, no currently published data adequately provides a strong rational for why IPC would improve peak force production during leg extensions 62 or during the first 6 s of a maximal cycling performance 61 in humans.

While making a thorough comparison of the methodological differences between positive and negative IPC performance-related study findings is outside the scope of this article, it is worth noting that two recent investigations suggest IPC timing 79 and the repeated use of IPC 80 may play a large role in affecting the performance outcome. In a study by Lisbôa et al. 79, competitive swimmers performed maximal 50 m swim sprint trials 1, 2, and 8 hours following a 4 x 5 min IPC protocol. Sprint times displayed clear beneficial improvements at 2 and 8 hour intervals after IPC, whereas no improvement in sprint time was seen at 1 hour. Similarly, Lindsay et al. 80
reported large improvements in peak power output (~11 %), average power output (~4 %), and maximal aerobic capacity (~10 %) after performing a 7-day consecutive IPC protocol. Of note, both studies employed performance tests lasting much longer than the ~3.5 s duration sprint test used in the current study, making it difficult to identify whether similar factors would play as important a role in anaerobic sprint performance. Despite the clear differences in exercise duration between the 50 m swim sprint, repeated 30 s Wingate tests, and the VO$_2$ max test with the current short-duration 20 m sprints, the results of Lindsay et al. 80 and Lisbôa et al. 79 suggest a need for future research to continue to focus on protocol optimization. The importance of IPC timing relative to the performance test and the lack of repeated IPC exposure do, however, provide simple plausible explanations as to why no improvements in sprint times were observed in the current study.

**PRACTICAL APPLICATIONS**
The findings of this study suggest three sets of 5 minute occlusions performed prior to sprinting do not provide an adequate stimulus to improve acceleration ability. This suggests that track and field coaches aiming to improve short-distance sprint performance should not use ischemic preconditioning as a pre-race performance enhancing protocol. Despite no observed change in performance, the change in athlete perception may be of utility to coaches.

**CONCLUSION**
A standard, three by 5 minute IPC protocol, completed 15 minutes prior to exercise, did not elicit a performance enhancing effect over distances of 10 or 20 m in sprint-trained athletes. The trained nature of the subjects used in the current investigation allowed small changes in performance to be observed due to their consistency in performance. Future research in this area should evaluate the accepted methods used in IPC performance related studies to determine
whether other factors such as the number of ischemia-reperfusion cycles, or the quantity of muscle mass made ischemic play a critical role in study outcome.
Chapter 5: Discussion and Acknowledgements
Discussion

A major strength of the studies presented in this thesis was the fact that we recruited highly-trained athletes who were sufficiently reliable to ensure we could observe even small changes in performance resulting from the interventions, if they occurred. The display of individual subject data (graphs in manuscripts) also allows for the interpretation of whether specific individuals within the subject pool are “responders”, that is, they respond to the intervention more frequently than do subjects who do not respond to the intervention – “non-responders”. From a practical standpoint, this form of “analysis” is invaluable, as it can dictate the implication of any performance-enhancing strategy. Additionally, performing repeated measures in both studies allowed us to account for normal, between-day variation and be more confident that findings were not by chance. Both studies fill gaps in their respective fields.

Previous findings 25, using similar loading conditions, showed a lack of an effect of resisted sprints on acceleration performance. However, when accounting for the characteristics that commonly predict the magnitude of improvement in this type of study such as subject training status, resistive load, volume of sprints, and recovery time 44,45, it was unclear whether the resistive load was too low to observe a positive effect, or if previous subjects were under-trained. The resisted sprint study within this thesis confirmed that moderately heavy resistive loads do not elicit an acute performance enhancing effect on 0 – 20 m sprint ability, even when using a subject cohort that is highly trained and has little variation about their normal performance.

Similarly, in previous work investigating the effects of ischemic pre-conditioning on acceleration ability 69, it was apparent that the variability of subjects likely would have masked any changes in performance. When avoiding large subject variation by using a group of sprint-
trained athletes, the IPC study within this thesis supports the lack of effect previously observed 
69. This is the first study using highly-trained athletes that did not report an improvement in 
exercise performance following IPC. This either suggests that the limited IPC performance 
research using highly-trained athletes has repeatedly (3 cases 62,77,78) observed improvements due 
to chance, or that the performance measures used in those studies are in some way metabolically 
or neurally different than the performance measure used in the current study, allowing the 
performance to be enhanced by IPC. As the performance outcomes of these three studies were 
quite different (100 m and 200 m swim 77; maximum underwater swimming distance and 1 km 
rowing time 78; 5 x 5 maximal leg extensions 62), the latter hypothesis seems unlikely.

Limitations

While it would have been more informative if both studies had used multiple protocols 
(to account for loading differences in Study 1, and protocol timing differences in Study 2), it was 
not feasible at present owing to the large time commitment of the recruited athletes and their 
coaches. Even though testing was designed in such a way to be minimally disruptive to the 
training of the recruited competitive athletes, focus is still diverted from the coaches’ training 
plan, making it impossible to answer all performance related research questions within a short 
timeframe. Additionally, repeated measures as were performed in both studies within this thesis 
allow for outcomes to be more reliable, as they account for normal, between-day subject 
variation and would have required weeks of additional data collection for each protocol under 
examination. Moving forward in both areas of research, it will only be through the continued 
experimentation within these fields that we determine the precise protocols necessary to induce 
acute changes in exercise performance.
Future Directions of Resisted Sprinting Performance Research

Despite the remaining ambiguity in the IPC performance literature, it is now more clear that resisted sprinting used to acutely enhance acceleration performance requires a load greater than 15% body mass using the 1080 Sprint, or ~ 40% body mass if using a weighted sled. Based on findings by Winwood 11, Seitz et al. 9, and Jarvis et al. 26, a minimal resistive load of ~50% body mass may be required to observe an acute performance enhancing effect, and more research should aim to confirm this. The new resistive and data collection tool used in the current studies (1080 Sprint) allows for a variety of different loading parameters to be independently controlled. Future work that manipulates these parameters independently, will allow for a more precise understanding of how concentric and eccentric loads, and the rate at which athletes are being resisted by the 1080 Sprint influences acceleration performance.

Future Directions of Ischemic Pre-Conditioning Performance Research

Although some research supports the ability of RST and IPC to acutely influence exercise performance, it is possible that the most effective use of IPC to enhance sport performance has been overlooked. For example, Beaven et al 67 demonstrated the ability of IPC to attenuate reductions in exercise performance following an exhaustive series of exercise tests (squat jump, countermovement jump, leg press, 40 m sprints). IPC may, therefore, allow athletes to recover more quickly from training sessions, allowing them to perform greater volumes of high-intensity training over a longer period. The smaller drop off in performance after an intense bout of exercise also suggests that IPC should be used prior to and throughout major competitions, in which there are multiple heats, games, or trials over the course of a few days. As the discussion of IPC as a recovery tool is outside the focus of acute performance enhancing protocols, it is
simply suggested that future research investigate the ability of this technique to influence performance in ways other than directly prior to competition.

**Discussion of Mechanisms and General Limitations Within Performance Literature**

When examined mechanistically, factors that support the used of resisted sprints as an acute performance enhancing method are far more developed than factors that support the use of ischemic pre-conditioning for the same cause. Of the performance studies examining the effects of IPC on short-duration activities, Paradis-Deschênes et al.\textsuperscript{62} attempted to provide mechanistic evidence supporting the improved power outputs observed during maximal leg extensions. However, their choice to monitor blood flow and oxygen consumption during an activity lasting <15s was confusing, since maximal force production during a leg extension is likely unrelated to oxygen utilization. It was, however, useful in providing a rationale for the improved recovery between sets, as recovery would most likely be related to oxygen availability.\textsuperscript{84} but again, this mechanism does not explain why an immediate improvement in peak power was observed during the first set, and very likely one of the first repetitions. Mechanisms that would support the observed improvement in peak power during the first set of leg extensions are likely of neuromuscular origin because maximal force production capabilities of a muscle, in a rested state, will not be limited by metabolic demand. Specific explanations for improvements in power generation such as, alterations in resting membrane potential, greater motor unit recruitment and firing frequency, increased calcium handling rates, inhibition of antagonistic muscles, and phosphorylation of myosin light chains are deserving of further attention. Therefore, future work should examine how IPC influences these different mechanisms, which contribute to muscle contraction and force production capability.
Within the field of exercise science, and specific to the pre-exercise protocols examined within this thesis, it appears that the rationales put forth by authors are mostly based on past exercise performance studies. The habit of citing a single mechanism to explain an observation is especially prevalent in studies examining the performance-enhancing effect of overloading exercises on dynamic exercise performance. A review of post-activation potentiation by Hodgson et al. \(^{44}\) published in 2005 is the most cited article discussing PAP as the potential reason behind the observed improvements in sprint and jump ability following an overloading exercise. Upon performing a thorough review of the literature in an attempt to uncover alternative hypotheses behind these improvements, it appears that there are several shortcomings to the PAP hypothesis that are infrequently discussed. Therefore, it is suggested that performance research be based upon understood physiological mechanisms to reduce the amount of trial and error needed to develop a true performance-enhancing protocol. In addition to developing sound principles upon which to base performance-related pre-exercise protocols, another area within the field that can be improved upon is in characterizing individual subjects. Within the manuscripts presented in this thesis, it was more applicable to provide individual subject variation data rather than providing group characteristics, which do not provide any information regarding the consistency of a cohort. Providing individual subject variation data also allowed for the quantification of subject reliability, and as previously discussed, for the practical interpretation of which athletes do and do not respond to the intervention. It is suggested that future research provide individual subject characteristics, especially in regards to variability, so that the ability of a cohort to observe an effect can be clear. Adopting a magnitude-based inferences statistical approach will also allow future exercise performance studies to effectively discuss their findings, with the end goal being to help influence a coach’s
decision. Finally, as one of the main goals of exercise performance research is practicality, the studies presented within this thesis suggest that;

1) RST, using loads of 15% body mass (using a 1080 Sprint) are insufficient to elicit an acute performance enhancing effect. This finding suggests that coaches looking to gain a “race-day” performance-enhancing edge should use greater resisted sprint loads, with other work suggesting this may need to be as high as ~ 50 - 70% body mass.

2) IPC performed prior to sprint performance does not acutely enhance acceleration ability. This finding suggests that coaches should not use IPC prior to a major performance, unless, as supported by other work, it is imperative that the athlete recover quickly for a succeeding match, game or race.
Conclusion

Sprint performance did not acutely improve following either a resisted sprint or ischemic pre-conditioning protocol. It is presently unclear whether a sufficient pre-exercise stimulus was applied in either study, as the optimal pre-exercise prescription is currently unknown. Furthermore, it is debatable if a sufficiently strong mechanistic basis for IPC use in sprint activities currently exists, despite reports of efficacy for improving exercise performance in the literature. Based on the in-depth reporting of recruited subject variability, it is clear that sprint-trained athletes exhibit an above average ability to perform at a consistent level. This level of individual subject analysis was essential to the interpretation of findings, allowing the lack of observed changes in the two studies to be more confidently attributed to a lack of effect rather than between-test variation. It is recommended that future exercise performance research include more information regarding individual subject variability, as using a highly variable athletic population causes results to become questionable, particularly null findings. In addition to reporting variability characteristics, it seems appropriate and more informative to continue providing interpretative results using a magnitude-based inferences statistical approach, especially for sports performance where a small effect size can have a large impact on success. Finally, as all types of error should be limited in research, a novel data collection device was tested against commonly used devices, and the perceptions of subjects were accounted for. In conclusion, the findings of the studies within this thesis suggest that resistive sled loads of ~40%, and ischemic pre-conditioning performed prior to sprinting, do not enhance performance in sprint-trained athletes. The precise volume and intensity of resisted sprinting needed to enhance sprint ability requires further investigation, and the understanding of how and if ischemic pre-conditioning influences short-duration exercise remains unclear.
Acknowledgements

After having a taste of the research experience, I am hooked. In retrospect, the questions “answered” in my MSc. thesis were rudimentary, but I believe the past two years have allowed me to develop a skill set that will permit me to answer far more complex questions in the future, especially in the context of sports performance.

Moving forward, I will be travelling through Canada, to the USA, Costa Rica, Panama, Columbia, Spain, Croatia, Montenegro, Italy, and France with my sweetheart to gain a worldlier perspective (and the perspective of the coach/practitioner rather than researcher) on applied athletic training, and life. A major aim of the trip is to gain an understanding of how well-known training facilities, known for their implementation of specific scientific approaches utilize these methods in practice. I expect I will return to reality with more questions than answers, which I hope to answer back under academic scrutiny.

At this point I would like to take the time to acknowledge all the support I have had from my family and friends over the exciting 26 years I have been breathing.

To my family, Momma and Poppa, thank you for always signing me up for things even when I initially was reluctant. I have had so many unique experiences, which at the time seemed forced but now contribute to who I am today, that you made sure I was exposed to. Having the two of you as role models has allowed me to appreciate every aspect of life and has taught me to really immerse yourself in what you love (Momma – returning to U of T to complete a MSc. degree in an extremely niche area, Poppa – climbing your way up the rankings at work while somehow coaching your locally founded badminton club and a college team simultaneously) regardless of time commitment and what others believe possible. To young master Thompson (GT), thank you
for helping me learn how to coach and being willing to test out all the crazy ideas of your brother
and his friends, to help you run faster. Please continue to work hard because one day soon it will
pay off and you will get where you need to.

I would like to thank my close friends: Harrison – for your perspective on continued personal
growth and your ability to take “far out” ideas and make sense of them, Emcee Steveo – for
helping me get this research opportunity and always being available for a “sick time”, Grant –
for being my “superbro” (defined as: a friend who you can always count on in any situation), and
Alanna – for always having my best interests at heart, having the ability to undoubtedly put the
feelings of others before her own, and sharing many exciting ideas, laughs, chats, and
experiences with me.

As my research was all done with varsity athletes at the University of Guelph, I would like to
thank the coaches for their time and effort in entertaining my data collection as well as all the
athletes who volunteered to be part of my research.

Lastly, I would like to thank my supervisors – Dr. Jamie Burr and Dr. Lawrence Spriet, for all
the time and effort they have put into each conversation we’ve ever shared. I appreciate your
immediate feedback, ability to juggle real-life scenarios, senses of humor, and the guidance you
have provided me over the past two years. I will be forever grateful, and if you ever need any
help with sprint mechanics or training ideas I will be the first one to volunteer my time.
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Chapter 6: Appendices
INFORMATION and CONSENT to PARTICIPATE in RESEARCH

Sprinter Variability, Resisted Acceleration and Ischemic Preconditioning in Varsity Level Sprinters

Investigators

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This research is funded by the Natural Sciences and Engineering Research Council of Canada.

Introduction

You are being asked to participate in a research study conducted by the Department of Human Health & Nutritional Sciences at the University of Guelph. Several conditions specific to sprinting performance and sprint performance measurement are being explored in which you may choose to participate. Each of the conditions are referred to herein as “Phases”. Participation in one Phase does not require participation in the other. This consent form will provide an overview of the different phases; if further information is desired, please contact either Kyle Thompson or Dr. Burr – contact information above.

In order to understand if changes as a result of training, or other variables represent meaningful alterations in performance, we first need to understand the normal day to day alterations that would be expected. Variability of varsity level track and field sprinters over 30m has not been reported in the literature and will be measured prior to both the Acceleration Phase and Blood Flow Manipulation Phase of the study.

Phase 1: Acceleration

The Acceleration Phase of the study will examine the effects of resisted sprint training on maximal 30m sprint times. The general scientific consensus is that heavy resistive loads cause athletes to improve during the initial phase of acceleration from 0m-10m, whereas medium resistive loads cause improvements from 10m-20m. Using a new device called a 1080Sprint, loads can be manipulated mid sprint, effectively allowing both a heavy and medium load to be
used within a single sprint. Through this study, I hope to examine whether a 1080Sprint device can enhance a sprinters 0m-20m using the variable load setting.

High level track and field sprinters will be recruited to perform two variability training sessions and nine training acceleration sessions consisting of resisted sprints and un-resisted sprints during Phase 1.

Phase 2- Ischemic Preconditioning (performance changes from blood flow restriction)

The phase of the study will examine the effects of blood flow manipulation on maximal 30m sprint times. The technique known as ischemic preconditioning (IPC), has demonstrated potential for improving the performance of already well-trained athletes. Despite this being an experimental technique, preliminary work has shown a 1-3% improvement in performance in elite athletes. However, only one study has been performed regarding the effects of IPC on maximal sprint performance. This phase will examine whether the performance benefit from IPC are also seen in high level sprinting athletes during maximal sprints.

This will be a cross over study investigating the effects of different IPC procedures to the upper leg, prior to maximal sprinting. Healthy, high level track athletes will be recruited to complete a total of 6 sprinting tests consisting of 3 30m maximal sprints. The participants will perform the IPC procedure prior to the sprints during 4 of the 6 sessions and will perform only a regular warm up prior to the sprints in the remaining 2 sessions.

Procedures

These studies will be performed at the University of Guelph, in the Indoor Fieldhouse.

Phase 1 will involve the participation in eleven training sessions (2 variability sessions and 9 resisted sprint training sessions). Each variability session will include 3-4 30m sprints, while each resisted sprint training session will include 3-4 resisted sprints and a maximal 30m sprint performed before and after. Resisted training will mimic typical resisted training (sled) sessions, wherein your sprints will be performed against a resistance. In this case, the resistance will be provided by the 1080 Sprint machine, tethered to your back by way of a sprint belt with a hook. As previously indicated, the amount of resistance experienced by you, the participant, will change while sprinting, from 15%-10% bodyweight. A quick release (at the point of the athlete) and an emergency stop (on the device) will be included in the event that a sprint ever needs to be stopped quickly.

Phase 2 will involve the participation in six training sessions (2 variability sessions, 2 medium pressure blood occlusions, 2 high pressure blood occlusions). The protocol for each day is as follows: regular dynamic warm up, either no IPC, medium pressure IPC or high pressure IPC (3x5min blood occlusion with 5min reperfusion) followed by 3 maximal sprints.

The length of time between sessions will be approximately 1 week but will vary depending on the individuals’ training schedule since high level athletes are being recruited. The length of time between phases is dependent on the participant. The Phases can operate independently of one another and Phase 2 is only concerned with an acute effect of IPC on sprint performance.

After your completion of Phase 1 and each training session within Phase 2 you will be asked to
indicate how you perceived the effects of the resisted sprints and IPC on sprint performance using a visual analogue scale. 2 questions are asked regarding your perception of the protocol. This will take no longer than 2 minutes.

Prior to beginning the study you will be asked to thoroughly read and sign this consent form. All sessions will be performed on days which your regular training session allows this to be done.

Example of Phase 1
Pretest Sessions (2 sessions)
Session 1: standard warm up, 3-4 30m maximal sprints (Variability)
Session 2: standard warm up, 3-4 30m maximal sprints (Variability)

Training Sessions (9 sessions)
Session 1: standard warm up, 30m maximal sprint, 3-4 resisted sprints, 30m maximal sprint
Session 2: standard warm up, 30m maximal sprint, 3-4 resisted sprints, 30m maximal sprint
Session 3: standard warm up, 30m maximal sprint, 3-4 resisted sprints, 30m maximal sprint
Session 4: standard warm up, 30m maximal sprint, 3-4 resisted sprints, 30m maximal sprint
Session 5: standard warm up, 30m maximal sprint, 3-4 resisted sprints, 30m maximal sprint
Session 6: standard warm up, 30m maximal sprint, 3-4 resisted sprints, 30m maximal sprint
Session 7: standard warm up, 30m maximal sprint, 3-4 resisted sprints, 30m maximal sprint
Session 8: standard warm up, 30m maximal sprint, 3-4 resisted sprints, 30m maximal sprint
Session 9: standard warm up, 30m maximal sprint, 3-4 resisted sprints, 30m maximal sprint

Sessions: Each session will last approximately 1 hour or the length of your typical training session. Prior to your arrival for the training session, you will be asked to avoid recreational drugs, alcohol for 12 hours prior, and caffeine immediately prior. You will be asked to wear your regular training clothing.

Example of Phase 2
IPC training: IPC training uses blood flow restriction that is based on the compression of vasculature of the upper leg muscles by an external compression device. In this study, blood flow restriction will be accomplished using an automated tourniquet system or blood pressure cuff. We will apply blood pressure cuffs to both your upper legs and inflate these cuffs for 5 minutes (to a maximum pressure of 220mmHg) and then deflate the cuffs for 5 minutes. We will do this cycle three times (~30mins). The cuff will be inflated to a higher pressure or medium pressure depending on your session. The 30 minutes of IPC will begin after your regular warm up.

Sprinting Test: You will first undergo a regular track warm up. This will immediately be followed by no IPC, medium IPC or high IPC. Following the warm up and initial protocol participants will perform 3 maximal 30m sprints. Runs will be measured using a 1080Sprint device.

Example:
Session 1: Warm up, no IPC, and 3 30m maximal sprints (Variability)
Session 2: Warm up, Medium pressure IPC, and 3 30m maximal sprints
Session 3: Warm up, High pressure IPC, and 3 30m maximal sprints
Session 4: Warm up, no IPC, and 3 30m maximal sprints (Variability)
Session 5: Warm up, Medium pressure IPC, and 3 30m maximal sprints  
Session 6: Warm up, High pressure IPC, and 3 30m maximal sprints

Each of the conditions will be performed twice as shown above.

Sessions: Each session will last approximately 1-1.5 hours. Prior to your arrival for the training session, you will be asked to avoid recreational drugs (any substances that blunt the senses; opium, morphine, belladonna etc), and alcohol for 12 hours prior and caffeine for 24 hours prior. You will be asked to wear regular athletic clothing for the testing sessions.

A visual example of Phase 1 and Phase 2 is given below:

Potential Risks and Discomforts

Sprinting: During all sprint training there is always the risk of acute injuries – hamstring strain, groin strain, achilles strain, etc. To the knowledge of the researchers, no data has been reported suggesting a greater risk of injury due to resisted sprint training.

Belt: The belt which attaches the resistance cable to the participant can be uncomfortable if worn too tightly. The belt will be adjusted on an individual basis.
**Upper leg cuff inflation:** The upper leg will experience cuff inflations. The inflations are at pressure levels commonly used in doctor’s offices and the risk of soft tissue damage is very low. The inflation of the cuff can be uncomfortable for some people, and if you experience pain from the inflation cuffs, they will immediately be deflated and removed. If preferred, thin clothing can be worn under the cuff to avoid skin irritation, or the research team can provide you with a cloth liner.

**Ischemia:** Blood flow restriction of the upper leg causes a lack of blood supply to all the leg muscles, introducing a state of lowered oxygen known as ischemia. Commonly associated with ischemia are feelings of numbness, tingling, or mild burning. These feelings are completely normal and will not harm you. There is a slight chance of soreness in the upper leg for one to two days afterwards but this is rare in most participants and should subside without intervention. There is a theoretical possibility that particularly stressful exercise can result in excessive muscle breakdown known as rhabdomyolysis. This condition is extremely rare and occurs with extensive effort far beyond what is being asked of you. This condition presents with obvious signs such as: intense muscle pain and darkening of urine. If you experience these symptoms at any point you must inform the researchers immediately. Theoretically there is also a risk of a blood clot during IPC which could come loose and travel to the lung, causing a blood clot in your lungs. These risks are extremely low and no reported cases of either scenario have been reported.

**It should be noted that there will be no required medical personnel present during the training or testing. In case of injury discovered following a training session contact your regular health care provider. All injuries sustained during the course of research must be reported to your coach, research staff and appropriate athletic therapy staff.**

**Potential Benefits**

During Phase 1 you could directly benefit from participating in this study as research has shown significant improvements in acceleration capabilities following resisted sprint training; however, your data will contribute to advancing our knowledge into the optimal usage of resisted sprint training, which may lead to the improvement of athletic performance.

During Phase 2 you will benefit directly from participating in this study by determining whether a short 30min protocol causes you to have an increased performance in maximal speed; your data will also contribute to advancing our knowledge into the optimal usage of IPC, which may lead to the improvement of athletic performance.

**Data**

You may also request to receive a form of aggregate results of the study. Every effort will be made to ensure confidentiality of personal information that is obtained in connection with this study. Data will be kept on a password-protected computer and all written material secured indefinitely in a locked cabinet on site.

Data will be retained for 5 years for possible use for future analysis for the lab group in the case the project may be expanded upon (i.e. the student investigator may pursue a 4 year PhD expanding on this project). All data will be stored electronically in databases with access only
granted to investigators involved in the use of the data. All personal identifiers will be destroyed following completion of the entire study. Jamie Burr, PhD, Assistant Professor will be in charge of data stewardship.

**Participation and Withdrawal**

You may choose whether to be involved with this study or not. If you volunteer, you may withdraw at any time without consequence. You may exercise the option of removing your data from the study. You may also refuse to answer any questions you don’t want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise that warrant doing so.

The researchers wish to be inclusive in their recruitment process. This project could require:

- Interaction one on one with a male researcher
- The placement of blood pressure cuffs on the upper leg

The student investigator and primary investigator – Kyle Thompson and Dr. Burr, have a dual role in this study in that they are also members of the training group/integrated support team.

If for any reason you may feel uncomfortable taking part, please contact the researcher to discuss these requirements and possible modifications to the procedure to address your concerns. Your decision to participate or not participate in the study will not affect your relationship with the student investigator, the care/service provided by the team’s exercise physiologist (Dr. Burr), your relationship with your coaches, or your participation in the Guelph Gryphons track and field team.

**Rights of Research Participants**

This project has been reviewed by the Research Ethics Board for compliance with federal guidelines for research involving human participants.

If you have any further questions regarding your rights and welfare as a research participant in this study (REB 16FE011), please contact: Director, Research Ethics; University of Guelph; reb@uoguelph.ca; 519-824-4120 ext. 56606. You do not waive any legal rights by agreeing to take part in this study.
SIGNATURE of RESEARCH PARTICIPANT

I have read the information provided for the study “Sprinter Variability, Resisted Acceleration and Ischemic Preconditioning in Varsity Level Sprinters” as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

__________________________________________
Name of Participant (please print)

__________________________________________  ________________
Signature of Participant                               Date

SIGNATURE OF WITNESS

__________________________________________
Name of Witness (please print)

__________________________________________  ________________
Signature of Witness                                Date
Ethics Approval

RESEARCH ETHICS BOARDS
Certification of Ethical Acceptability of Research Involving Human Participants

APPROVAL PERIOD: April 5, 2016
EXPIRY DATE: April 5, 2017
REB: NPES
REB NUMBER: 16FE011
TYPE OF REVIEW: Full Board
PRINCIPAL INVESTIGATOR: Burr, Jamie (burj@uoguelph.ca)
DEPARTMENT: Human Health & Nutritional Sciences
SPONSOR(S): NSERC Discovery Grant (RG)
TITLE OF PROJECT: Optimizing the use of blood flow restriction for preconditioning & recovery of human performance.

The members of the University of Guelph Research Ethics Board have examined the protocol which describes the participation of the human participants in the above-named research project and considers the procedures, as described by the applicant, to conform to the University's ethical standards and the Tri-Council Policy Statement, 2nd Edition.

The REB requires that researchers:
- Adhere to the protocol as last reviewed and approved by the REB.
- Receive approval from the REB for any modifications before they can be implemented.
- Report any change in the source of funding.
- Report unexpected events or incidental findings to the REB as soon as possible with an indication of how these events affect, in the view of the Principal Investigator, the safety of the participants, and the continuation of the protocol.
- Are responsible for ascertaining and complying with all applicable legal and regulatory requirements with respect to consent and the protection of privacy of participants in the jurisdiction of the research project.

The Principal Investigator must:
- Ensure that the ethical guidelines and approvals of facilities or institutions involved in the research are obtained and filed with the REB prior to the initiation of any research protocols.
- Submit a Status Report to the REB upon completion of the project. If the research is a multi-year project, a status report must be submitted annually prior to the expiry date. Failure to submit an annual status report will lead to your study being suspended and potentially terminated.

The approval for this protocol terminates on the EXPIRY DATE, or the term of your appointment or employment at the University of Guelph whichever comes first.

Signature: [Signature]
Date: April 5, 2016

A. Papadopoulos
Chair, Research Ethics Board-NPES
Visual Analogue Scale

- 1000 – Pixel visual analogue scale with the 0 anchor being “IPC did not influence sprint performance” and the 1000 anchor being “Sprint performance improved because of IPC”
Flow Chart of Both Study 1 and Study 2

Phase 1: Variability and Resisted Sprinting

Day 1
Recorded Sprint
Recorded Sprint
Recorded Sprint

Day 2
Recorded Sprint
Recorded Sprint
Recorded Sprint

Days 3-9
Recorded Sprint
Resisted/Un-resisted Sprint
Resisted/Un-resisted Sprint
Resisted/Un-resisted Sprint
Recorded Sprint

Regular dynamic warm up precedes all days in both Phase 1 and Phase 2
At least 5min of rest between all sprints in both Phase 1 and Phase 2
At least 72hrs between all experimental days

To determine variability

~75min-105min

~75min-105min

~75min-105min

~75min-105min

Phase 2: Acute Effects of Ischemic Preconditioning on Sprint Performance

Medium pressure protocol: 3x5min of medium pressure blood occlusion with blood pressure cuff on upper thigh following regular dynamic warm up. 5min of reperfusion between each occlusion.

Day 1
No IPC
Recorded Sprint
Recorded Sprint
Recorded Sprint

Day 2
Medium pressure IPC
Recorded Sprint
Recorded Sprint
Recorded Sprint

Day 3
High pressure IPC
Recorded Sprint
Recorded Sprint
Recorded Sprint

Day 4
No IPC
Recorded Sprint
Recorded Sprint
Recorded Sprint

Day 5
Medium pressure IPC
Recorded Sprint
Recorded Sprint
Recorded Sprint

Day 6
High pressure IPC
Recorded Sprint
Recorded Sprint
Recorded Sprint

High pressure protocol: 3x5min of high pressure blood occlusion with blood pressure cuff on upper thigh following regular dynamic warm up. 5min of reperfusion between each occlusion.

~75min-105min

~75min-105min

~75min-105min

~75min-105min

~75min-105min

~75min-105min

~75min-105min

~75min-105min
1080 SPRINT

- Orange yachting line recoils around drum and is attached to subject via a waist belt
1080 SPRINT INTERFACE

- View of 1080 Sprint interface while collecting data, alternative views allow for plotting of force, power, acceleration and velocity.