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‘Effects of Local heat pre-conditioning of the arms on strength performance’

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ABSTRACT

Introduction: Repeated Strength performance is a highly important factor for sports performance and physical improvement. Athletes are constantly trying to improve strength capabilities in order to improve performance. Performing maximal strength exertion requires appropriate warm up preparations in order to achieve maximal force contractions. Heat stress has been shown in research to increase muscular and peripheral blood flow as well as increase the temperature of the muscle itself. Therefore, it is proposed that an increase in local temperatures of the performing muscles may enable an increase repeated strength performance. It is unknown whether the thermoregulatory system plays a detrimental or enhancing factor in anaerobic strength performance. This study examines whether localised increases in skin temperature can affect repeated bicep strength performance. **Methods:** Eight male recreationally strength trained university students (8 male; 20.75 ± 1.25 years; body mass 79.2 ± 18.4kg; height 180.9 ± 12.6cm) took part in the study. Test protocols included three laboratory based visits, including a single One Repetition Maximal (1RM) test and two Multiple Repetitions (MR) tests completed on separate occasions. Each MR test had been completed under differing controlled peripheral skin temperature conditions. **Results:** The results, analysed using Pearson's 2-tailed correlational analyses on SPSS showed a significant positive relationship correlation existed ($r = 0.903; p < 0.05$). An increase in MR performance was observed (*Mean MR Non-heat stress = 12.875; MR Heat Stress = 14.125*) as a result of an increase in peripheral skin temperature via heat stress. **Conclusions:** Therefore, it is right to say that it is possible that the application of heat stress can directly improve strength performance. However, other factors such as psychological inhibitors, muscle potentiation and electrical stimulation during maximal voluntary contraction need to be taken into consideration. Drawing from this study, more advanced research is necessary within this area of physiological performance in order to obtain the true degree of influence heat stress has on strength performance.

CHAPTER I

INTRODUCTION

1.1 *Introduction*

Strength performance and power are essential physiological attributes in a host of sports. Sports such as Olympic weight lifting, 100/200m sprinting and sprint cycling where great muscular strength is a requirement, tests the muscle to perform to the limits of its maximal output. Sports such as this force muscles to exert maximal strength output (Gamble, 2010) over short durations. As repeated strength output is so crucial to success within these sports, effective performance is accompanied by pre-performance preparation and training (Baechle & Earle, 2008). Therefore identifying methods of achieving the greatest possible strength performance can be the difference between success and failure in competition.

Thermoregulation in its physiological definition is the biological control of temperature within the body (Kurz, 2008). Heat balance plays a pivotal role within the body, the importance of heat balance is enhanced prolifically when exposing the body to exercise (McArdle, Katch & Katch, 2010). When considering thermoregulatory effects on performance, short-term strength performance typically is not associated. However, physiologically there are many factors that occur during strength performance that are affected by thermoregulation. When performing maximal strength exercise blood flow is essential in order to initiate vasodilation and the transportation of Nitric Oxide as a result of muscular contraction (Bagchi, Nair & Sen, 2013). Vasodilation is important in order to account for increased blood flow to the working limbs during repeated muscular contraction. Heat stress causes vasodilation to dissipate heat by diverting blood to peripheral areas like the skin. Furthermore, Sampaio-Jorge *et al*, (2014) explained that increasing the heat of the muscle initiates increases in contractility as well as increasing the elasticity of the muscle and surrounding joint of the muscle in question. This has positive effects on muscle performance by enabling more efficient contractions and reducing the risk of muscle tear particularly under heavy load stress.

In order to exert explosive maximal force the muscle needs to be ready to complete the stress that is to be placed upon it. Ensuring that muscle contractile function, muscle fibre recruitment and force development are all performing at maximal capacity will provide an enhanced performance. Pre-performance muscle heating has been shown to increase force development in performance (Marshall, Cross & Lovell, 2015). When an athlete is able to utilise maximal amounts of muscle fibres more force, torque and power can be exerted, resulting in improved sprint times or even increasing mass lifted in Olympic weight lifting competition.

Using this knowledge and improving it can be a vital asset in competition, as exercising pre-performance heat stress preparations may enable athletes to perform with increased levels of force and strength output. This can not only improve singular performance but if consistently utilised in a training program, muscle strength performance will become consistently more efficient. Very little research has been conducted in this area, making any form of breakthrough within this field useful for future research to take place.

CHAPTER II

LITERATURE REVIEW

2.1 *Introduction*

As outlined in the previous chapter, this chapter shall explore the current literature of the topic under investigation. Previous physiological studies covering adaptions to heat stress, muscle function, strength performance and warm up importance shall be included.

2.2 *Warm up*

The purpose of a warm-up is to steadily raise and activate a number of physiological occurrences within the body in preparation for exercise. A warm up is physiologically designed to raise heart rate, muscle temperature, stretch the joints and neurologically prepare the brain and body for exercise, with injury prevention and performance readiness both physically and psychologically in mind (Hedrick *et al*, 1992). A warm up is considered a pivotal preparation process in all aspects of exercise and sport. Studies such as Brunner-Ziegler *et al,* (2011) and Ingjer & Strømme (1979) have found clear evidence that an active warm up directly improves performance and reduces risk of injury because steady state is achieved earlier. This is due to tissue warming that occurs during a warm up, contractions create friction within the muscle filaments, alongside dilation of the blood vessels creating increased blood flow (Hedrick *et al*, 1992). These physiological changes help to prepare the muscles and body for further stresses. Increased heart rate and blood flow are products of a warmup, this causes vasodilation within the blood vessels allowing more blood to pass through to the working muscle tissue (Hedrick *et al*, 1992). A hyperemic state is initiated and more oxygen is able to be transfused from the blood to the active muscle tissue (Wittekind *et al,* 2012). Further to this when exercise is initiated blood supply to the vital organs drops in favour of the working muscle resulting in oxygen becoming more readily available through more directly flowing blood to the working muscles. Previous research has shown just how important a warm up can be to improving performance. However, there are ranges of differing warming techniques that can achieve varied physiological outcomes. With tissue temperature increase at the forefront of a warm up it is important to consider the most effective method of achieving the desired outcome.

2.3 *Muscle Contraction*

The muscular contraction is the most important aspect of strength performance that dictates force production, power & strength exerted (Beachle & Earle, 2008). Therefore a more efficient contraction results in improved strength performance. When considering multiple repetition high intensity muscular performance, a most effective form of muscular contraction is one that produces a high rate of force development eccentric contraction (Young & Bilby, 1993). Biomechanically, a high rate of force development will provide a quicker contraction, therefore ensuring the correct technique is utilised accordingly, more repetitions will be exerted before muscular fatigue is initiated.

Marshall, Cross & Lovell (2015) showed that pre-performance muscle temperature increases of around 3ºc accounted for a 20-30% increase in voluntary torque development of the muscle and highlighted that this was due to improved rate dependent muscle contractile function. Exercising the theory that voluntary torque directly affects muscle contractile function and in turn muscular strength performance. This theory follows the hypothesis that heat stress could improve the participant's voluntary torque and muscle contractile function, resulting in prolonged strength performance. Alongside this, research by Sampaio-Jorge *et al*., (2014) studied the effect heat stress has on joint and muscular elasticity. Sampaio-Jorge found that under heated conditions muscle and joint elasticity improve and muscle stiffness is reduced (Rubini *et al*, 2007). A muscle and joint that is more flexible is able to initiate muscular contraction activation more effectively, resulting in improved strength and power performance. Church *et al*, (2001) showed that pre vertical jump performance warm up and stretching improved flexibility and significantly improved plyometric jump performance. Linearly Lutjemeier *et al*, (2005) witnessed a clear correlation between increased muscle blood flow and power output. Suggesting that if skin and muscle temperature can be increased effectively, muscle blood flow will increase alongside power and strength output.

2.4 *Muscle Temperature*

Muscle temperature is a key part of both the preparation for exercise and exercise itself. Muscle temperature can be affected by both cutaneous and sub-cutaneous factors causing fluctuations (Detry *et al*, 1972). The muscular work during exercise, combined with dilation of the blood vessels, increased blood flow and the metabolism of energy cause muscle temperature to rise (Hedrick *et al*, 1992). Externally the muscle can be heated by increased skin temperature as a preparation for exercise. Pearson *et al.* (2011) showed that heating the skin directly raises the local muscle temperature and induces vasodilation within the muscle and skin vasculature. Deep muscular vasodilation such as this enables increased muscular blood flow that enables the muscular contractions to continue to occur. Pearson *et al*, (2011) also showed that heat stressing local peripheral skin and muscle (38-39ºC) does not cause any rise core temperatures. Therefore, these findings suggest it is possible to target specific primary muscle groups with localised heat stress in order to achieve a state of performance readiness before exercise without having to initiate warm up activity. During skin hyperthermia conditions, Pearson *et al,* (2011) witnessed a 4.2 ± 0.4 ^{o}C increase in skin temperature, however the muscle temperature increased by only around 1.7 ± 0.3 ^{o}C. Although significant muscle temperature had been witnessed, it suggests that much greater increases in skin temperature are required in order to greatly increase muscle temperature. Hedrick *et al,* (1992) explains that a 2-3 ^{o}C increase in muscle temperature occurs when exercising, beyond this point muscle performance can begin to decline and thermoregulatory responses will begin to occur in order to dissipate heat. Morrison *et al*, (2004) showed that significant increases in whole body skin temperature and core temperature greatly decreases voluntary contraction and force production within the muscle. However, relating to the findings of Pearson *et al,* (2011) core and whole body temperature will not rise when heating local limb temperature.

2.5 *Peripheral Heat Stress*

When considering the application of heat stress upon the peripheral skin, there are a number of physiological occurrences that begin to see change. Some of the cardiovascular changes that occur under heat stress include changes in blood pressure, skin blood flow, vasodilation and muscular blood flow (Johnson *et al*, 2010). Crandall (2008) showed that whole body heat stress of a non-exercising individual can cause blood pressure and heart rate to rise in the same fashion that exercising inhibits**.**

Niimi *et al*, (1997) explored the idea that when skin temperature is heated muscular blood flow will be reduced due to the redistribution of blood flow to the peripheral areas of the skin in order to dissipate heat, therefore declining muscular performance. He found that skin blood flow significantly increased under heated stress as well as a decrease in blood pressure and an increase in cardiac output. A similar earlier study (Rowell *et al*., 1969) also identified that the thermoregulatory system even at rest will respond to acute heat stress by redirecting blood volume to the skin to reduce any sub-cutaneous heating. Opposed to this, studies by Hendrick *et al,* (1992) & Pearson *et al*, (2011) found that muscle blood flow increased under localised heat stress conditions as well as an increased in skin blood flow. This research more directly applies to this particular study as localised heat stress is used as opposed to full body heat stress under aerobic conditions. Rowell (1983) furthered his research by testing his theory under exercising conditions and found that fatigue was induced earlier under whole body heat stress as a result of the redistribution of blood away from the working muscles to the skin in order to dissipate the heat stress placed upon it (Johnson & Proppe, 1996). This literature may argue against the study hypothesis, as a decrease in muscular blood flow could negatively affect the strength performance under a heat stressed condition. Although there is little in the current literature that suggest these physiological changes will occur in enough volume to affect acute high intensity strength performance. Further to this the detrimental effects to performance witnessed in Rowell *et al*, (1983) where under whole body heat stress conditions, therefore affecting core temperature and cardiovascular conditions. It is more likely that under localised heated conditions a rise in skin and muscle temperature, will result in increased muscular blood flow as in the study of Pearson *et al*, (2011).

2.6 *Gap in the Literature/Aerobic Concentration*

Thermoregulation is a subject within physiology that is becoming more researched constantly, with athletes performing in multiple regions around the world each providing differing challenging foreign environments for sporting competitors to overcome. Research (Hom *et al.,* 2004) has proved just how valuable thermoregulatory control can be for performance when exercising. Increases in heat in particular have been widely researched and it is now known that even slight increases in core body temperature can be seriously detrimental to performance (González-Alonso *et al*, 2012). The main focus of research exhuming heat stress however has come within aerobic performance due to its naturally longer duration. Continuous forms of aerobic performance such as marathons and cycling were originally studied so that the findings could be directly applicable to athlete's performance (Cable *et al*., 2004). This research shows that working under increased heat conditions deteriorates performance excessively, due to increased fatigue (Kitzing *et al.,* 1972). Further research (González-Alonso, 2012) explored interval training under heated conditions and examined significantly lower exercise intensity levels in a heated state in comparison to an ambient environment. Ely *et al*., (2007) established that running performance in a heated state induced earlier fatigue, opposed to this running in a chilled state prolonged exercise performance. Following research such as this, it is now inherently proved just how much of a pivotal role heat balance can play while exercising. Moving forward with this it is important that research continues to find the specific effects the thermoregulatory system has on all types of exercise performance, including strength performance.

The main focus of studies that have included the strength of the performer under heat stress have been on the intensity that the individual has managed to achieve to exhaustion (Akimov *et al.,* 2011). Akimov found that when the skin is heated and individuals are exercising under intense conditions the thermoregulatory system applies urgent adaptions in order for the intense muscular work to continue. Some of the adaptions that take place as a result of heightened skin temperature include increased muscle oxygen saturation and haemoglobin levels to help prevent rises in fatigue (Hom *et al*., 2004). Solely strength performance under heat stress is yet to be tested. It is highly possible that similar and different physiological occurrences will take place when performing strength exercise. The question is whether this will have a positive or negative affect on the strength output under a locally heat stressed condition.

2.6 *Aims*

The main objective of this study is to penetrate a relatively secluded area of research. Thermoregulation and temperature control both sub-cutaneously and peripherally is highly researched aerobically, due to its vital nature when attempting to maintain long duration aerobic performance. However, acute duration strength performance is considered less important when considering the thermoregulatory components. Therefore, this study has been set in place to uncover some potentially crucial information that may show that altering peripheral skin temperatures can affect strength performance.

In particular, this study is focused on identifying whether increasing local skin temperature of the active muscle can improve maximal strength exertion. If sufficient data can be found that show significant improvements in strength performance, it will open the pathway for future research to focus on the most specific physiology adaptions that occur which result in the enhanced muscular performance.

2.7 *Hypothesis*

It is hypothesised that muscular strength performance would be significantly greater under localised heat stressed conditions in comparison to non-heat stressed conditions.

CHAPTER III

METHODOLOGY

3 METHODS

3.1 *Ethical Approval & Informed Consent*

Before any test protocols occurred ethical approval was granted to ensure the safety of all subjects that agreed to take part in this study. Eight young, healthy and recreationally strength-trained individuals (8 male; 20.75 ± 1.25 years; body mass 79.2 ± 18.4kg; height 180.9 ± 12.6cm) volunteered from Cardiff Metropolitan University to take part in this study. Participants reported to the lab for their first session, before any exercise or testing began each individual were presented with a participant information sheet, outlaying the details, requirements and process of the study they are volunteering to undertake. Once read, both a Physical Activity Readiness Questionnaire (PAR-Q) and consent form were completed to ensure the participants were physically healthy enough to complete the study and that they were willing to cooperate with the contribution to this research.

3.2 *Testing Procedures*

3.2.1 *One Repetition Maximal Protocol*

Beginning this visit, baseline measurements were taken of height (cm) using a fixed Stadiometer (Holtain Ltd, Crosswell, Crymych, Pembs,UK) and body mass (kg) using Seca scales (Vogel & Halke, Hamburg, Germany).

Participants began by undergoing an incremental one repetition maximum (1RM) bicep curl test as conformed by the standardised protocol set out by the National Strength & Conditioning Association (NSCA) (Miller, 2012). Three differing stretches lasting a duration of 8 seconds per arm were used in alliance with a light-weight 10kg bicep curl 12 repetition warm up using an Olympic EZ-bar, weight plates and clips. As set out by the NSCA, a two-minute rest period had been granted to the participant post warm up before the first single repetition lift was completed at approximately 80% of the participants' predicted 1RM. A single repetition lift, defined as a lift where the muscle reaches full contraction and the inner angle surpasses the acuteness of 45º, anything less is defined as a failed attempt. Each successful lift was followed up with a two-minute rest period and a 2.5kg increase for the next lift. A failed attempt was defined as a single repetition where the correct technique could not be completed. Upon two failed attempts the previous successful lift weight were recorded as the final 1RM of the individual.

3.2.2 *Multiple Repetitions Non-Heat vs Heat Stress Procedure*

70% of 1RM results were calculated post preliminary testing in order to find the multiple repetition mass to be lifted by each individual. On this visit, warm up protocol was not changed before any exercise testing began. With multiple eight second arm stretches used combined with a 12-repetition 10kg bicep curl warm up followed by a two-minute rest period. Once rested, a single set of multiple repetition lifts were initiated following the same successful lift criteria as the 1RM preliminary testing. Participants back and arms had to be flat to the wall and each successful lift whereby the bar was curled from a resting position (> 160^{o} inner arm angle) to a fully contracted position (<45^{o} inner arm angle) were counted. Participants continually lifted the weight until they were no longer able to perform a successful curl and the final number of repetitions counted by the researcher was noted. Upon completion participants were immediately sat down for approximately 5-6 minutes while necessary measurements were recorded post exercise, two and five minutes. Visit two followed the exact same protocol as visit one. However after completion of warm up activities, individuals were sat down and controlled heat stress was applied to the arms (heat increase = 8^{o}c ± 1.2) using custom-made water perfused arm sleeves (Cardiff Metropolitan University, Custom Made) lined with silicone tubing connected to a water circulator (model F34; Julabo, Seelbach, Germany). Temperature within the sleeves could then be controlled using a temperature-control unit attached via an auxiliary pump. This process lasted approximately 7-10 minutes. Upon obtaining appropriate skin temperature, blood pressure (BP) and skin temperature measurements were taken immediately after the removal of the sleeves. Followed by immediate multiple repetition performance in order to ensure minimal peripheral heat is lost from the limbs before exercising. From this point test protocol and measurement recordings followed in the same fashion as visit one. Both multiple repetition testing was completed in a randomised order to account for any physiological variations in performance that could affect validity. A minimum of 72 hours rest period was granted between each visit in order to allow for sufficient recovery time between high muscular strain activities.

3.3 *Blood Pressure Measurements*

BP measurements were taken at five stages during each of the two multiple repetitions testing visits using a manual Yamasu 535 sphygmomanometer (Yamasu, Tokyo, Japan) and stethoscope. At each measurement point two BP were taken and averaged for clearer results. First measurements were taken pre-exercise before any warm-up activity had been initiated; in order to account for any activity that may cause fluctuations in BP participants were rested for 10 minutes in a seated position upon arrival. Following the warm-up, BP was recorded again, followed by measurement of BP immediately post exercise, two and five minutes post exercise. Identically timed BP measurements were taken for both visits, apart from a further BP recording taken immediately post applied heat stress in that particular visit.

3.4 *Skin Temperature Measurements*

Skin temperatures were measured in unison with BP using skin thermistors (Grant Instruments, Cambridge, U.K.). Skin temperature measurements were taken placing the sensors at the midline horizontal and vertical meeting point of the bicep and the inner midline of the forearm. Sensors were tapped directly onto the skin in order to ensure consistent measurements were obtained with the sensor face fully contacting the skin. Before the first skin temperature was measured participants were given a 10-minute skin acclimation period of room temperature. The third and final measurement of skin temperature was recorded immediately post exercise, measurements were not taken during the two and five minute post exercise BP recordings. As with BP recordings the measurements were taken at coordinated timings between the two multiple repetition visits. Apart from an extra skin temperature recording that was taken immediately post applied heat stress during the multiple repetition heat stress visit.

3.5 *Statistical Analyses*

A Dependent (Paired Samples) T-Test was used to determine differences between the heat stress and non-heat stress conditions for multiple repetitions. For parameters that were measured repeatedly a 2-Way Repeated measures ANOVA was used to determine differences in BP and skin temperature under differing heated conditions. All data was analysed using a Software Package for Social Sciences (IBM SPSS Statistics). Data are reported as mean ±SD.

CHAPTER IV

RESULTS

4. *Results*

4.1 *Repetition Maximum*

Maximal strength output (MSO): The amount of force the participant could exert in a singular concentric contraction ranged from 30-60 (kg) was 43.4 ± 10.2 kg. MSO was calculated using the final successful lift attempt (Mean No. Attempts = 5 ± 0.75) of each individual. A broad spectrum of MSO had been observed during preliminary testing due to strength training status, muscle size and anthropometric measurements.

4.2 *Skin Temperatures (Heat Stress)*

Bicep and forearm temperature increased significantly (Table 1.) from 31.1 ± 0.69 to 40.68 ± 58 and 31.81 ± 0.49 to 39.95 ± 0.86^{o} C respectively under heat stress conditions (both $p < 0.05$). No significant increase in bicep and forearm skin temperature occurred (Table 1.) under warm up conditions (30.78 ± 1 to 31.15 ± 0.98 and 31.33 ± 1.02 to 31.75 ± 1.26 ^{o}C, $p > 0.05$).

Table 1. *Mean and Standard deviations of skin temperature (^{o}c) variables of the bicep and forearm pre & post warm-up, heat stress & post exercise under heat stressed and non-heat stressed conditions.* showing significant increases in skin temperature P = <0.05.*

	Bicep Non-Heat Stress	Bicep Heat Stress	Forearm Non-Heat Stress	Forearm Heat Stress
Pre-Warm up	30.78 ±1.00	31.1 ±0.69	31.33 ±1.02	31.81 ±0.49
Post Warm up/Heat stress	31.15 ±0.98	40.68* ±0.58	31.75 ±1.26	39.95* ±0.86
Post exercise	31.34 ±1.06	34.06 ±0.51	32.25 ±1.26	33.06 ±0.88

4.3 *Multiple Repetitions Testing*

Mean number of repetitions significantly increased (Figure 1.) from 12.88 ± 1.46 under non-heat stressed conditions to 14.13 ± 1.64 under heat stressed conditions (p = 0.002, < 0.05) (Table 2.). A strong positive correlation was observed between number of repetitions and heat stress condition as an intervention (r = .903, p < 0.05). This positive correlation suggests that heat stress intervention has played a role in improving the muscular performance of the majority of the participants. Seven of the eight subjects experienced a positive increase in number of repetitions post heat stress, with one subject performance remaining unchanged.

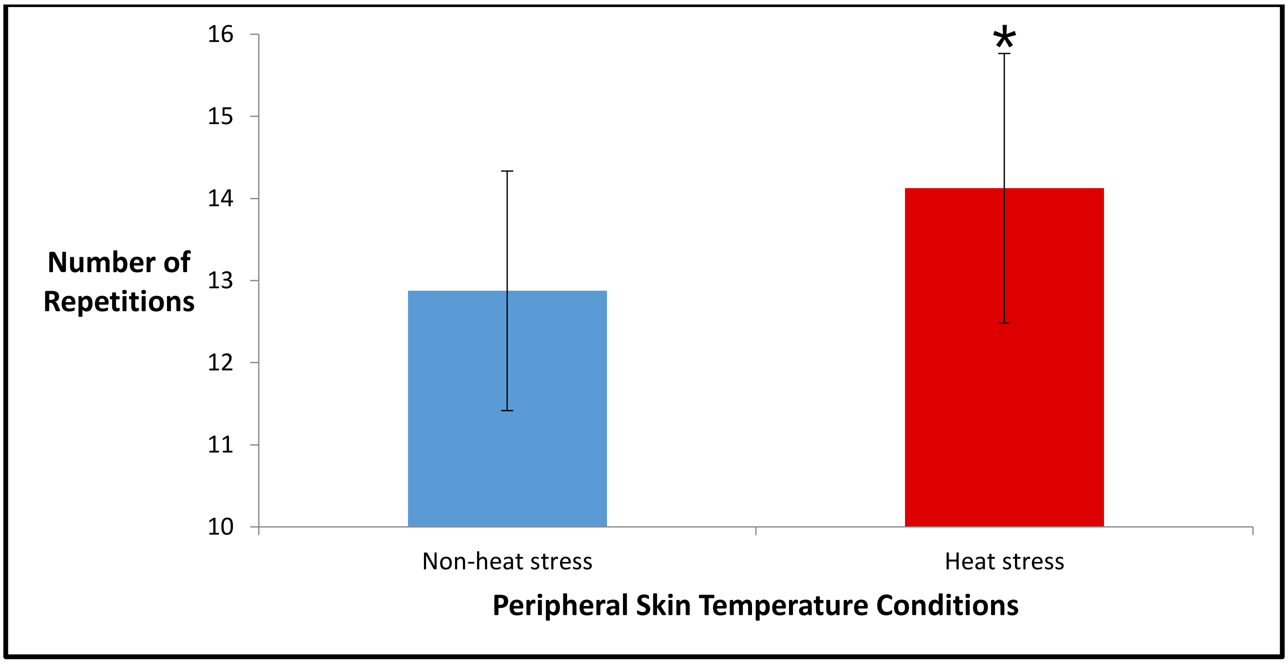

Figure 1. *Mean Number of repetitions achieved under Non-heat stress and Heat stress conditions. * p < 0.05* significant differences compared with non-heat stressed conditions.

4.4 *Blood pressure*

Similar substantial increases in systolic blood pressure were observed post strength exercise performance (Table. 3) in both non-heat stress and heat stress conditions (121.75 ± 5.28 and 121.75 ± 5.39 mmHg, p < 0.05). Systolic pressure did not rise significantly as a result of heat stress intervention (114 ± 4 mmHg, p > 0.05). Diastolic blood pressure was unaffected by time, however saw increases under heat stressed conditions, post heat stress, post exercise, two and five minutes (Table 4.) (68 ± 6.14 mmHg, p < 0.05).

Table 2. *Mean ± Standard deviation Systolic Blood pressure values in Non-Heat stressed and Heat Stressed Conditions*

	Non Heat Stress					Heat Stress				
	Pre-Warmup	Post-warm up	Post Exercise	2 mins PE	5 mins PE	Pre-heat stress	Post-heat stress	Post Exercise	2 mins PE	5 mins PE
MEAN	113.5	115	121.75	119.25	116	113.75	114	121.75	118.5	115.25
Standard Dev.	6.02	5.66	5.28	6.04	6.23	5.06	4.00	5.39	4.50	5.12

Table 3. *Mean ± Standard deviation Diastolic Blood pressure values in Non-Heat stressed and Heat Stressed Conditions*

	Non Heat Stress					Heat Stress				
	Pre-Warmup	Post-warm up	Post Exercise	2 mins PE	5 mins PE	Pre-heat stress	Post-heat stress	Post Exercise	2 mins PE	5 mins PE
MEAN	66.5	66.25	64.5	64.25	66.5	66	68 *	68 *	68.75*	68.75*
Standard Dev.	6.99	6.45	6.12	6.88	5.32	6.14	6.14	4.90	5.44	5.55

CHAPTER V

DISCUSSION

5.1 *Key Findings*

The aim of the study was to find if passively heating local arm skin temperature would have either a positive of detrimental effect on anaerobic muscular strength performance. There were two key findings found in this study that help to provide insight into the role localised heat stress can play on anaerobic strength performance. First, the pre-performance application of localised heat stress resulted in improved strength performance multiple repetitions over non-heat stressed conditions. Mean number of repetitions increased from 12.875 under non-heat stressed conditions to 14.125 under a heat stressed state ($p = 0.002$, < 0.05). Second, the application of heat stress accounted for an increase of diastolic blood pressure but no significant increase in systolic pressure. These findings suggest that localised increases in limb skin temperature pre-anaerobic strength performance initiates sub-cutaneous limb warming that improves muscular function.

In support of the hypothesis of this study, heat stress evoked an increase in the number of repetitions participants were able to continuously lift of their 70% 1RM. With every participant excluding one individual seeing improved multiple lifts, the application of heat stress is shown to have provided enough physiological adaption to improve the outcome of performance. It is inherently apparent that there are various affecting factors that may have influenced an increase in strength ability. Aside from local skin warming, the underlying affecting factors include raised local muscle temperature, increased muscle blood flow and muscle potentiation.

Currently there is very little proven knowledge of the effects of heat exposure and the physiological changes that occur as a result on anaerobic exercise and particularly strength performance. Results of existing studies have found conflicting data on whether heat stress is detrimental or enhancing on anaerobic performance. Studies by Ball *et al,* (1999) and Linnane *et al,* (2004) have demonstrated increases in peak power output during high intensity intermittent exercise following short duration heat exposure (Falk *et al*, 1998). Whereas Drust *et al,* (2005) argued that elevations in core and muscle temperature resulted in decreased power performance over repeated sprints. Earlier studies, theorised that any improvements on performance were a result of increased core body temperature pre-high intensity exercise (Linnane *et al*, 2004). A following study by Lacerda *et al,* (2007) witnessed similar improvements in peak power output over short duration high intensity performance, however the results showed more similarities to the current study. It was found that power output increased due to higher plasma ammonia concentrations within the working muscle, as a result energy charge within the muscle was maintained better, enabling an increased rate of cross bridge turnover. Muscle temperature also had been witnessed during heat stress intervention within the study. Therefore, a suggestion that an increase in pre-performance muscle temperature accounts for higher rates of cross bridge muscle contractions which applies to the current study. Local increases of muscle temperature within the biceps may have increased cross bridge rate within the muscle contractions (Sargeant, 1987) to improve force development during the lifts to enable quicker more explosive lifting over a shorter duration. Combined with this, it is possible that plasma ammonia increased within the muscle resulting in reduced fatigue of muscle activation Lacerda *et al,* (2007). Although the theory in question is apparent, the magnitude of muscle temperature increase, plasma ammonia concentrations and rate of cross bridge contractions is unknown, as these variables were not measured. Although, studies conducted by Webb *et al,* (1992) & Pearson *et al*, (2011) are clear proof that local peripheral temperatures directly influence sub cutaneous muscle tissue temperature.

Secondarily, diastolic blood pressure had also witnessed a substantial rise post heat stress application while systolic pressure did not in the current study. It is known that resistance exercise induces increases in arterial blood pressure due to the strenuous nature of muscular activity and elevations in vascular resistance (Rowell *et al,* 1974). Heat stress has been shown previously to attenuate increases in arterial blood pressure during resistance exercise (Binder *et al,* 2013). Heat stress as an intervention may have accounted for the attenuation of increased systolic pressure, however it does not explain a sustained increase in diastolic pressure. Heat stress evokes an increase in skin blood flow in order to dissipate heat (Wilson and Crandall *et al,* 2011), causing a decrease in vascular resistance, essentially balancing blood pressure as it increases due to the resistance exercise initiated. By diastolic pressure sustaining an increase it suggests that the heat stress attenuation was not sufficient in lowering the diastolic pressure as in the systolic pressure once resistance activity had been completed. Cui *et al*, (2010) reported that body heating (0.7^{o}c) attenuates increases in blood pressure, concluding that the greater the heat stress the greater the attenuation. Therefore, it is possible in the current study that the vascular resistance increase due to high intensity muscular activity outweighed the magnitude of heat stress applied.

5.2 *Muscle Potential*

Muscle potentiation plays a pivotal role within the current study however no variables were measured to suggest the extent. Muscle potentiation, is known to improve muscle contraction performance if the muscle has been exposed to acute contraction stimulus pre-performance (Baudry & Duchateau, 2007). Muscle performance improves due to firstly, stimuli of myosin regulatory light chains, resulting the in the actin-myosin becoming more sensitive to calcium release, therefore force production of each successive twitch contraction increases. Second, muscle work causes synaptic excitation of the spinal cord, increasing post synaptic potentials resulting in increased subsequent force generating capacities (Mettler & Griffin, 2010). As submaximal resistance repetitions were implemented during the warm up phase of the protocol pre-heat stress, a combination of muscle potential and muscle temperature increase could be the primary cause of the observed increase of strength output. Participants activated muscle potential using a light weight high repetition set implemented within the warm up. This warm up exercise could have excited the muscle increasing synaptic potentials, following this heat stress was implemented straight away. Local peripheral heat stress is known to increase sub-cutaneous muscle tissue and effectively increase the rate of cross bridging within the muscle enhancing force development. These two muscular enhancing factors combined could explain the improved performance of the participants under heat stressed conditions. Providing this knowledge is feasible then a combination of submaximal pre-performance exercise and controlled localised heat stress application could enhance muscular performance greatly within competition. Although (Lorenzo *et al,* 2011) argues that muscle potential is more effective when pre-performance excitation is maximal resistance training. These variables were not directly measured during the current study, further studies exploring these variables is necessary to directly identify the magnitude of these strength enhancing variables on performance.

5.3 *Muscular Strength VS Muscular Endurance*

A key question that is raised from this study for future research is whether the application of local limb heat stress helped improve muscular endurance or muscular strength. As researched in Pearson *et al,* (2011) it is proven that muscle temperature rises in correlation with muscle blood flow, therefore the muscle reaches an oxygenated warm state before exercising and sufficient blood flow is accessible during exercise which could help prevent fatigue in muscular endurance. Alternatively, muscular strength could have been improved via increased levels of muscle fibre activation making the load seem less strenuous and enabling more repetitions before fatigue sets in. Consequently, it is highly possibly that a combination of all factors enhanced both muscular strength and muscular endurance.

As previously identified muscle potentiation and sub-cutaneous muscle tissue heating provides a product of increased strength output and force production. These aspects concentrate on strength improvement of the muscle as muscle fibres can be recruited more efficiently as force is improved. When greater numbers of muscle fibres can be recruited the load experienced is less strenuous as the resistance is shared among greater numbers of muscle fibres. In coalition, enhanced rate of force development can be generated to act against a resistance, moving the load more quickly resulting in less time under strain. With a lighter load and more efficient timing of repetitions fatigue will set in later than in a state of non-heat stress where these variables had not been enhanced. Therefore, muscular strength improvement focuses on making the workload easier in order to sustain the workload for a longer duration. Muscular endurance enhancement, is a much more intricate adaption that occurs as a result of localised heat stress. Muscular strength endurance over an aerobic period of between 10-30 seconds can be enhanced through increases in necessary blood and oxygen supply. Fatigue within the muscle during high intensity exercise is a result of an increase in hydrogen ions, lactate, plasma ammonia, ADP and inorganic phosphate (Debold *et al,* 2012) combined with a decrease in ATP and phosphocreatine levels within the active muscle cell. As the number of type IIB muscle fibres used within exercise increases, so does lactate production as fuelled by anaerobic metabolism (Robergs *et al,* 2004). Acidosis caused by lactate accumulation leads to ATP concentrations declining making muscular contractions more difficult. Reduced levels of ATP is a hindrance to calcium recycling creating a build up of calcium through the inability to bind with troponin C (Ferguson *et al,* 2007). Local heat stress however, has the ability to counteract this hindrance in contractual performance and fatigue within the muscle. As explained previously, muscular warming combined with pre performance muscle potentiation stimulates myosin regulatory light chains which results in a sensitivity increase to calcium release (Mettler & Griffin, 2010). This may oppose the negative effect being cause by acidosis within the working muscle helping to recycle calcium build up preventing fatigue from setting in earlier. Currently there is no known knowledge that this will help to prevent acidosis however the current results may suggest it is an area of muscular performance worth investigating further.

5.4 *Strengths & Limitations*

There were a range of strengths and limitations to the process and protocols carried out in the current study. Beginning with the strengths, firstly the intervention of heat stress proved a significant and controlled application. Increases of skin temperature to around -39 to 40^{o}c were achieved in approximately 7-10 minutes' maximum, resulting in short duration discomfort for the participants. Increasing skin temperature by around 4^{o}c is shown to initiate sub-cutaneous warming (Webb *et al*, 1992). Therefore, as heat stress application stood at increasing the skin temperatures of individuals by around 8-9ºc, it is justifiable to say that successful heat stress procedures had been applied. Second to this, timing had been increasingly important within the procedures of the study, as multiple skin temperature and blood pressure recordings had to be taken throughout the protocols. These were controlled well and timed efficiently in order to gather valuable recordings immediately post heat stress and exercise. Furthermore, repetition protocol had been controlled to the conformed practice of repetition lifting set out by the NSCA, resulting in only successful repetitions counting towards the final total.

Heart rate was not measured in the current study, as the nature of the exercise within the study did not provide sufficient reasoning when considering the protocol to record this variable. In light of the results witnessed, heart rate recordings may have helped to improve blood pressure result reliability and provided an insight into the reasoning behind the outcome of the blood pressure recordings. Paired with the reliability of the blood pressure recordings, blood pressure measurements were taken professionally and to protocol however the researcher was overly experienced at recording one hundred percent accurate measurements. This could account for possible discrepancies within the blood pressure recordings validity.

An important uncontrolled variable in this study was the number of repetitions lifted on each encounter was not hidden from the participants. As the background of the study had been provided to them before any exercise had been completed, they were aware of possible heat stress influence that may affect their performance. Although the order of completion between visits were randomised the participants may have been highly psychologically driven to surpass their number of repetitions in the heat stressed exercise visit. A couple of factors that could have initiated a psychological advantage for the heat stress induced exercise is firstly, knowledge of the hypothesis of the study. Participants were aware of the hypothesis and prior expectation that that heat stress would enhance their performance could have effectively enhanced their psychological drive during exercise performance. Secondly, any of the randomised protocols in which lead to the participants performing the heat stress protocol after the non-heat stress protocol could have been psychologically driven to surpass their own exercise performance, as the results were not kept confidential from them.

5.5 *Practical Implications*

The practical implications of the current study open up a large area of physiological knowledge with performance enhancement at the pinnacle of thought. Strength plays a crucial role within anaerobic sports performance whereby successful improvement of strength can be the difference between achieving success in sports performance. The findings in this study combined with previous research suggests that pre-strength performance heat stress application could increase the muscle contraction potential, muscle temperature and muscle blood flow. Exercising this preparation method could provide an inherent advantage in performance and training for athletes. The application of heat stress however is not an easily achievable preparation, with high costs, equipment availability and transportation of equipment posing as potential hindrances.

5.6 *Future Research*

For the purpose of future studies certain factors need to be the concentration in order to identify if heat stress truly can efficiently improve strength performance. Following studies will need to focus on the sub-cutaneous changes within the muscle as a result of heat stress adaption including, temperature and blood flow. Muscle potentiation and rate of force development would also enhance the insight into the theory that muscular strength performance can be enhanced by localised heat stress. A focus on more crucial high intensity performance muscles such as the quadriceps and hamstring would relate any future data gathered more closely to performance capabilities.

CHAPTER VI

CONCLUSION

6.1 Conclusion

This study unveiled an area of physiological study with great potential to improve knowledge by uncovering significant increases in muscular strength performance in high intensity resistance exercise under localised heat stressed conditions. Future studies can develop upon this study by exploring the more intricate physiological adaptions that occur as a result of localised heat stress, including muscle potentiation and muscle temperature that lead to increases in muscle strength performance. Further significant findings could aid in both the lower and elite level performance enhancement of pre-exercise preparations and training programmes.

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APPENDICES

Appendix A. Physical Activity Readiness Questionnaire

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ____

SIGNATURE ____ DATE ____________________

SIGNATURE OF PARENT or GUARDIAN (for participants under the age of majority) ________________________ WITNESS ____________________

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

Appendix B. Participant Consent Form

PARTICIPANT CONSENT FORM

Reference Number:
Participant name or Study ID Number:
Title of Project: EFFECTS OF LOCAL HEAT PRE-CONDITIONING OF THE ARMS ON STRENGTH PERFORMANCE
Name of Researcher: ELLIS DENEGA

Participant to complete this section: **Please initial each box.**

1. I confirm that I have read and understand the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason. ☐

1. I agree to take part in the above study. ☐

The following statements could also be included on the consent form if appropriate:

2. I agree to the performance of all the physical requirements necessary for the completion of this study. ☐

3. I agree to the sampling of data taken from myself in order to aid the aim of the research in question. ☐

4. I agree to the use of anonymised quotes in publications ☐

______________________________ ________________
Signature of Participant
Date

______________________________ ________________
Name of person taking consent Date

____

Signature of person taking consent

Appendix C. Participant Information Sheet

RESEARCH PROJECT

"The effects of local heat pre-conditioning of the arms on strength performance?"

Name of principal investigator: Mr Ellis S Denega

Name of co-investigators: Dr. Eric Stöhr

This document provides information on:

1) The background and aim of the research project

2) The role of the researchers

3) Your role as a participant

4) Benefits of taking part

5) How data will be collected

6) Risks

7) How the results will be used

8) Your rights

IMPORTANT: The purpose of this document is to assist you in making an informed decision about whether you wish to volunteer for this research project by promoting transparency in the research process.

1) Background and aims of the research

- Thermoregulation is a hugely important factor when considering exercise performance.

- Currently aerobic exercise is the main source of research conducted when exploring thermoregulation, due to the longer duration of the exercise the thermoregulatory effects have a much greater impact on performance.

- Very little research has been conducted into the role temperature control can have on anaerobic strength performance.

- It is not known whether there is an optimum local temperature in which the muscles perform more efficiently, and whether the temperature can affect the contractility or utilization of the muscle fibres.

- The aim of this study is to unearth whether local heat stress exposure can have an effect on muscle strength performance & to understand whether an increase in heat is detrimental or beneficial to anaerobic strength performance

2) The role of the researchers:

The researcher (Ellis Denega) will be responsible for conducting and overseeing all stages of the research project. In addition to carrying out the scientific part of the project, we are there to provide you with personal guidance and assistance in relation to any questions or issues you may have. During your first visit, we will explain all the project details so that you feel comfortable with knowing exactly what will be required. We will also assist you with the completion of the health questionnaire and answer any questions you may have in relation to the project.

While our research interest is to collect novel and valuable information on your muscular strength performance when exposed to local heat stress, your health and safety is of primary importance to us and has precedence over our research interests. In relation to this, you will not only be able to ask questions and inform us about issues while in the laboratory but you will also be able to contact Dr Eric Stöhr at any time outside laboratory contact time. We encourage you to talk to us at any time should you feel uncomfortable or have questions related to the project.

3) Your role as a participant:

We are very grateful should you choose to take part in this research project and we will treat you with respect at all times and try our best to explain everything to you so that you have an enjoyable experience. While we need to ensure the scientific quality of our work, we also aim to create a friendly and fun environment in the laboratory during your visits.

Your role is to visit the laboratory on three occasions and enable us to assess your health through completion of a brief questionnaire, assess your current maximal bicep strength performance through a 1RM (Repetition maximum) test, and two multiple repetition strength performance bicep tests using an Olympic EZ weighted bar. Repetitions completed and weight lifted will be recorded along with blood pressure and skin temperature pre and post exercise under normal warm-up conditions and controlled heat stress conditioning of the arm skin temperature (7°c approximate increase).

4) Direct and indirect benefits of taking part:

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

Direct: By participating you will learn your current bicep strength performance levels, of both maximal and repeat repetition performance. You will also experience whether control of heat levels can influence your strength performance and get an insight into how research studies are conducted in a modern exercise laboratory environment.

Indirect: Your participation will contribute to our general knowledge of the affect heat can have on performance. Your participation will inform researchers and clinicians and may help to develop further research into the influence heat stress can have on muscular activity during strength performance. We will be happy to share your personal results from this study with you.

5) How data will be collected:

You will need to attend the laboratory on three occasions for three time points of assessment. The purpose of each assessment and what you will be required to do is outlined below.

Assessment 1 (estimated duration ~30-45 minutes)

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

- Fill out a consent form and a health questionnaire (see both attached). According to the guidelines of the American College of Sports Medicine (ACSM), you will be considered healthy and free to enroll in this study if you do not have more than one cardiovascular risk factors. We will then measure your height and weight. Should the completion of the questionnaire reveal that you do have more than one risk factors, you will, unfortunately, not be able to partake in this research project.

- Perform a 1RM bicep curl test according the NSCA (National Strength and Conditioning Association) standardized protocol. The purpose of this test is to assess your maximal bicep strength performance. In order to complete this you will be asked to stand with your back flat on a wall and to fully contract and curl the weights arranged based on your predicted repetition maximum. This process will then be continually repeated with 2 minutes rest intervals increasing the weight each time until you are no longer able to perform the exercise movement. Once provided with enough recovery time, the first session is completed.

Assessment 2/3 (estimated duration 1 - 1 ½ Hours)

During assessment two, upon arrival we will:

- Measure your height and weight again, before completing a number of stretches and arm focused warm up activities, in order to prepare you for multiple lift repetitions. Participants will be required to wear a short or non-sleeved t-shirt.

- This time blood pressure and two skin temperature measurements will be taken from the arms before and exercises are completed. Using the strength data collected in the first session 70% of your maximal load will be added to the EZ bar, using the same technique for each lift you will be required to perform multiple repetitions continually until you are no longer able to complete another repetition. Upon completion of this exercise, blood pressure and skin temperature will be taken again immediately, two and five minutes post exercise. Upon these measurements being taken, the second session will be completed.

Assessment 2/3 (estimated duration 1 – 1 ½ Hours)

- Upon the third visit to the lab the same protocol shall be followed that was implemented in the second visit. However during this visit a heat stress will be implemented for approximately 10 minutes using water perfused arm suits powered by a water circulator in order to heat the local arm temperature of the skin by approximately 7°c. This will occur before any exercise has been carried out and once completed the same exercise protocol and measurements shall be taken.

Assessment order:

- Note that the order of the second and third session will be randomized in order for the results to be as reliable as possible.

6) Risks

For healthy individuals there are minimal risks associated with this project, the possible risks include.

1) There is a possibility of muscle strain during exercise, during strength lifts the bicep muscle will be under heavy strain due to contracting whilst holding a heavy load, particularly when reaching the point at which the muscle can no longer contract the weight. This can be avoided by there being two spotters at all times during every lift so that when strain begins to increase greatly, spotters will be on hand to release the load from the participant.

2) There is a chance that light headedness or dizziness may occur due to high tension and strain during the exercise. As well as spotters during the activity, we will also ensure a seated rest period immediately after excise, minimizing the risk of dizziness or light headedness.

7) How the data / research will be used:

In agreeing to become a voluntary participant, you will be allowing us to use your results to statistically analyse, interpret and publish the findings according to the principles of scientific conduct. We will not refer to your personal data in any way during conference presentations or in peer-review publication.

8) Your rights

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

Protection to your privacy

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

Contact details

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

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Appendix D. Data Collection Sheet

Participant Performance Sheet:

Participant Name:	
Student Number:	
Height (cm):	
Weight (Kg):	

1 RM TEST:

Weight (kg)	Attempt 1	Attempt 2

Predicted 1RM: 1RM= *w* (1 + *r* / 30)	
Starting weight:	
1 RM Final:	

Multiple Repetitions Test (Non-heat stress)

TOTAL REPS:

	Blood pressure	Skin Temperature °c	
		Bicep	Forearm
Pre-heating			
Post-Heating			
Post-Exercise			
Post Exercise (2mins)			
Post Exercise (5 mins)			

Multiple Repetitions Test (Heat stress)

TOTAL REPS:

	Blood pressure	Skin Temperature °c	
		Bicep	Forearm
Pre-heating			
Post-Heating			
Post-Exercise			
Post Exercise (2mins)			
Post Exercise (5 mins)			