The Effects of Different Thermal Environments on Performance of Manual Handling Tasks

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Abstract

Many people work in uncomfortable thermal environments where the need to perform manual handling tasks is a fundamental requirement. A review of the research into the effects of performing manual handling in these environments revealed design limitations and gaps in knowledge. Current industry guidance merely states that 'extremes of heat and humidity should be avoided'.

The purpose of this thesis was to study participants' physiological and subjective responses while lifting in hot, warm and cold environments. Three studies were conducted using the psychophysical approach where participants self-selected the load in a floor to knuckle-height lift.

For the first study 12 males (mean ± sd), age 25.2 ± 6 yrs, mass 74.9 ± 11.9 kg, stature 1.73 ± 0.1m were recruited and acclimated over five days (1 hr sessions) in an environmental chamber at 38°C, 70% relative humidity (RH). They completed 15x35-min trials on consecutive weekdays in five environments: thermoneutral, 21°C, 45% RH (17°C WBGT); warm-dry, 30°C, 25% RH (22°C WBGT); warm-humid, 30°C, 65% RH (27°C WBGT); hot-dry, 39°C, 22% RH (27°C WBGT); hot-humid, 38°C, 70% RH (34°C WBGT) and three lift frequencies: 1, 4.3 and 6.7 lifts.min^{-1}. Heart rate and aural temperature were significantly higher and maximum acceptable weight of lift (MAWL) significantly lower in the hot-humid environment compared to all others. Ratings of perceived exertion (RPE) were significantly higher in hot-humid compared to both warm-dry and thermoneutral. Although participants reduced workloads in the heat, they did not compensate adequately. There were no significant differences in response between two environments with the same WBGT (27°C).

Secondly, 12 males, age 26 ± 5.6 yrs, mass 75.1 ± 9.2kg, stature 1.77 ± 0.1m were recruited. They completed 15x35-min trials in five environments: thermoneutral, 16°C, 65% RH; 10°C, 55% RH; 5°C, 45% RH; 0°C, 55% RH (standard ensemble); 0°C, 55% RH (enhanced ensemble) and the same three lift frequencies. MAWL significantly decreased at higher lift frequencies. Mean aural temperature was significantly lower at 0°C (standard) compared to thermoneutral. Mean MAWLs were higher than in the heat suggesting that participants increased activity to keep warm possibly placing them at greater risk of musculoskeletal injury. In all environments below thermoneutral the mean end aural temperature was ≤36.2°C when lifting at 1 lift.min^{-1}.

Finally, 10 males, age 28.4 ± 5.1 yrs, mass 79.5 ± 13.1 kg, stature 1.8 ± 0.1 m were recruited to assess the effects of face-cooling on physiological strain and perceived exertion while lifting at 6.7 lifts.min^{-1} in 30°C, 65% RH (27°C WBGT). Face-cooling significantly reduced local skin temperature and heart rate. There were no other significant differences. Face-cooling seems to be limited to mediating RPE (encompassing thermal strain) independent of core temperature which might continue to rise.

The following recommendations are suggested for inclusion in future industry guidance. Workers should not regulate their own workloads in uncomfortable environments. RH does not impose additional strain in air temperatures up to 30°C. At ~39°C care must be taken when RH exceeds 25%. Attention must be paid to workers' clothing ensembles in temperatures below 16°C so that they provide adequate insulation. Finally, face-cooling should not be thought of as a protective mechanism against heat stress.

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List of Abbreviations

α	Alpha (a priori level for rejection/ retention of null hypothesis)
ANOVA	Analysis of Variance
BASES	British Association of Sports & Exercise Sciences
°C	Degrees Celsius
Clo	Clothing insulation rating
d	Effect size for two sample designs
F	F ratio (ANOVA)
Gen η^2	Generalised eta squared
HR	Heart Rate
HSE	Health & Safety Executive
ISO	International Organisation for Standardisation
kcal	kilocalorie
kg	kilogram
$lifts.min^{-1}$	lifts per minute
LoA	Limits of Agreement
MAWL	Maximum Acceptable Weight of Lift
MHOR	Manual Handling Operations Regulations
mOsm	milli osmoles
m	metre
min	minute
$m.s^{-1}$	metres per second
$mu.l^{-1}$	milli units per litre
NIOSH	National Institute for Occupational Safety and Health
ns	not significant
P	Statistical Significance
Prl	Prolactin
RCF	Relative Centrifugal Force
RH	Relative Humidity
RPE	Rating of Perceived Exertion
s	second
t	t statistic (T-test)
T_a	Air Temperature
T_c	Core Temperature
TEM	Technical Error of Measurement
T_{msk}	Mean Skin Temperature
UKAS	United Kingdom Accreditation Service
$\dot{V}O_{2max}$	Maximal Aerobic Power
WBGT	Wet Bulb Globe Temperature
W	watts
$W.m^{-2}$	watts per metre squared

Candidate's Statement

The objective of this thesis was to investigate the effects of uncomfortable thermal environments on individuals performing an intermittent lifting task. Material that has been cited to support statements and arguments put forward in this text has been fully referenced in the appropriate section (chapter 8).

This project was a partial collaboration with the Health & Safety Laboratory (HSL). The industrial site visits and the first two laboratory studies were conducted with their assistance. The candidate was responsible for designing the test protocol, obtaining ethical approval and then conducting the experimental research. HSL provided the candidate's funding, paid for the participants' time and supplied the lifting equipment and clothing worn during the sessions. The candidate was also responsible for the statistical analysis of the results and subsequent writing up.

The third laboratory study was conducted by the candidate without external collaboration.

1 Introduction

1. Summary

This chapter provides a general overview of the topic under investigation. It considers the issues surrounding work in hot and cold environments and identifies the need for research so that these problems are more readily understood.

2. General Introduction

Exercise physiology is defined as the study of how the body responds to physical activity. Research in this area is usually focused on sporting or recreational pursuits but physical activity can also take place in occupational settings. Many people are employed in industries where the need to perform manual handling tasks is a fundamental requirement. Factory employees, health professionals, military personnel and construction workers all perform these tasks as part of their normal working day. In the United Kingdom, the regulation of manual handling is enforced by the Health & Safety Executive's (HSE) Manual Handling Operations Regulations (1992) which are enshrined in law in the Health & Safety at Work Act (1974).

Occupational settings are often uncomfortable places to work in due to the environmental conditions that are typical in different industries. Glassworks, steelworks and bakeries are examples of workplaces that are often uncomfortably warm or hot. Conversely, areas of chilled and frozen foods factories and distribution warehouses may be maintained at very low temperatures. Human beings are described as homeotherms meaning that they attempt to maintain their body temperature within a narrow range irrespective of the surrounding environment. Normal body temperature is approximately 37 °C with a safe range of approximately 2 °C either side of this. Failure to stay within the upper and lower limits of this range can have deleterious and, ultimately, fatal results. Working in uncomfortably hot or cold environments can impose a physiological strain as the body attempts to maintain its core temperature within the safe range despite the ambient conditions. The performance of manual handling tasks can present a similar challenge and when they are performed in uncomfortable hot or cold environments the threat to thermal homeostasis is twofold.

There is a large body of research that has investigated the effects of hot and cold environments on individuals performing sports and exercise activities but much less on those who have to work in such environments. The reader is directed to Doubt (1991) and Toner & McArdle (1988) for reviews of cold research and to Sawka & Pandolf (2002) and Hubbard & Armstrong (1988) for similar work on hot environments. Although some of the findings from the sports and exercise disciplines can be applied to work settings there are quite often differences in the latter area that mean specialised research is necessary. For instance, many working activities are intermittent and involve compound tasks whereas most sports research involves the investigation of an individual's responses whilst performing continuous rhythmic exercise such as treadmill running. Potential exposure to hazardous materials might also mean that the worker has to wear protective clothing thus preventing adequate thermoregulation. Contrast this with the minimalist outfits worn by many athletes, outfits often made from so-called ‘breathable’ materials designed to allow evaporative cooling.

A closer inspection of the limited research into the effects of working in hot and cold environments has revealed gaps in knowledge and highlighted a number of design limitations. Many studies in cold environments have concentrated on investigating the effects of cold on the fingers and hands (see Bensel & Lockhart, 1974 and the reviews by Havenith *et al.*, 1995; Heus *et al.*, 1995). Others have examined the effects of cold together with windy and wet conditions; environments especially likely to be encountered outdoors (McCaig & Gooderson, 1986; Weller *et al.*, 1997; Weller *et al.*, 1998). Research studies into the effects of hot environments on manual handling performance have failed to examine the effects of different levels of relative humidity on human performance. The Manual Handling Operations Regulations (MHOR) guidance issued by the HSE (HSE, 1998) merely states that ‘extremes of heat and humidity should be avoided’. For these reasons it would appear that there is a need for systematic, controlled studies of the effects of uncomfortably hot and cold environments on individuals performing industrial tasks.

3. Conclusions

Whilst it is accepted that conducting manual handling tasks in uncomfortable hot and cold environments increases the risk of injury, there is currently no guidance on how important these risk factors are or on how to identify and control these risks. There is also a lack of guidance on the effects of relative humidity on performance of these tasks. Previous research in these areas has been almost non-existent with regards to cold environments and those studies concerned with work in the heat have not adequately investigated the effects of relative humidity on performance and safety.

The purpose of this thesis is to investigate the physiological and subjective responses of individuals performing manual handling tasks in a range of uncomfortably hot, warm and cold environments. It aims to address gaps in the literature related to manual handling performance in the heat and the cold; the effects of relative humidity and of wearing different clothing ensembles.

2 Main Concepts & Review of Literature

1. Summary

This chapter provides a more detailed overview of the main areas of interest, notably the human thermal environment, thermoregulatory responses and manual handling tasks. There follows a critical overview of the current state of published literature in the areas under investigation.

2. Main Concepts

2.1 The Human Thermal Environment

The human thermal environment is generally described as comprising six basic variables (Parsons, 2003); four environmental and two personal. The most commonly referred to variable is air temperature, indeed this variable is quite often the *only* variable considered when describing an environment. The other three environmental variables are radiant temperature (usually from the sun but also from localised heat sources such as furnaces and ovens), relative humidity (the amount of moisture held in the air expressed as a percentage of totally saturated air) and air velocity. The two personal variables are metabolic heat production and clothing insulation. The interaction of the six variables is important since adjustment of one or more of them will generally result in a different human response to a given situation. Collins (1983) cited in Parsons (2003) describes a situation where an adult skier descended a slope with a child on his back. At the end of the run the adult was warm and perspiring yet the child was hypothermic. Both had experienced the same air temperature and air velocity and both were similarly clothed but the adult's metabolic heat production from skiing had compensated for the heat loss experienced during the descent. The adult and child had in effect experienced two different thermal environments.

Air temperature describes the degree of hotness or coldness of the air surrounding a person. Temperature is a measure of the average kinetic energy of the particles in a sample of matter (Parsons, 2003) and is usually, in environmental studies, measured in degrees Celsius (°C). Measures of air temperature are usually taken in the shade to avoid the effects of radiant heat such as that from solar radiation. A mercury-in-glass thermometer is often used for measurement. This and other measurement methods will be detailed in chapter 3.

Radiant temperature is a measure of heat transferred by radiation between one body and another. Virtually all life on Earth depends on the radiant heat of the sun reaching this planet. When someone is outside they may be exposed to solar radiation in a variety of forms, whether direct from the solar disc, diffused through clouds, reflected off walls, ground or water or a combination of these factors (Parsons, 2003). Indoors, radiant heat is emitted from various sources such as ovens and industrial kilns. Mean radiant temperature is also expressed in °C and can be measured using a thermometer inside a matte black globe.

Humidity is defined as the moisture content of the air. Absolute measures of humidity usually expressed as a ratio of grams of water vapour to kilograms of air are available but in environmental studies it is often more meaningful to use measures of relative humidity. Relative humidity is expressed as a percentage and represents the ratio between the current partial vapour pressure to the saturated vapour pressure at a given temperature (Parsons, 2003). High levels of relative humidity are of great importance to anyone working or exercising in a warm or hot environment because of the effect on the body's ability to cool itself by sweating. Cooling by sweating is brought about by the evaporation and subsequent convection away of perspiration. The evaporation of sweat requires a vapour pressure gradient to exist between the skin and the surrounding air. As relative humidity rises the gradient will decrease, reducing the ability of the sweat to evaporate until, at a relative humidity of 100%, the gradient disappears and evaporative cooling becomes impossible. Relative humidity can be measured using a hygrometer of which there are a variety of designs.

The fourth and final environmental factor is air velocity which is defined as the movement of air across the body. Most people will have experienced the pleasure of a cool breeze on a summer's day and suffered the effects of a cold draught in a poorly insulated room. The movement of air disturbs and carries away the air immediately surrounding our bodies. In hot environments it can facilitate evaporative cooling but in cold environments it can disturb the barrier effect of warm air close to the skin. Air velocity can be measured by a device known as an anemometer and is expressed in units of $m.s^{-1}$.

An individual's metabolic work rate can greatly affect their personal thermal environment. Energy is released in the body to perform mechanical work although due to the body's inefficiency over 75% of this energy may be dissipated as heat (Powers & Howley, 1997). This heat originates in skeletal muscle and is dissipated to the skin's surface by conduction or convection through the adjoining tissues and blood via the cardio-vascular system. The increase in core body temperature contributes greatly to the individual's perception of the surrounding environment (consider the previously described example of the skier). Metabolic heat production can be measured directly in laboratories using specially constructed rooms or 'pods' for instance but this is impractical for most 'real-world' applications. In these cases indirect measurement methods are used and an international standard (International Organisation for Standardisation [ISO], 8996, 1990) document is available for estimation of metabolic work rate in a wide variety of manual tasks. Work rate is expressed in watts (W) but a standardised measure of $W.m^{-2}$ may be used if the body's surface area is estimated using an equation such as that proposed by Mosteller (1987).

The second personal variable and last of the six components of the human thermal environment is clothing insulation. Clothing covers the body to a greater or lesser extent and in certain industrial environments a particular protective ensemble may be mandatory. In cold environments the clothing ensemble will insulate the body from the surrounding air by trapping a layer of warm air next to the skin. This will be beneficial but if the worker is required to perform any manual labour it may become a hindrance as evaporative cooling is prevented. Bulky clothing might also prevent ease of movement and execution of tasks requiring a high degree of precision; a phenomenon known as the 'hobbling effect'. In warm or hot environments the clothing ensemble might again interfere with evaporative cooling. The thermal insulation of clothing is often expressed in units of Clo and was first proposed by Gagge *et al.* (1941). In everyday terms, 1 Clo is the level of clothing insulation (roughly equivalent to a standard business suit) required to keep a sedentary person comfortable in an air temperature of

21° C. Another ISO document (ISO 9920, 1994) provides tables of Clo values for individual items of clothing and various clothing ensembles.

2.2 Human Thermoregulatory Responses

Human beings are described as 'homeotherms', that is they attempt to maintain a constant body temperature despite changes in the surrounding environment (Powers & Howley, 1997). Temperature regulation is controlled by the thermoregulatory centres in the hypothalamus which receive afferent inputs from both peripheral and central thermoreceptors (Marieb, 1998). Peripheral thermoreceptors monitor the temperature of the skin whilst central thermoreceptors (some of which are located in the hypothalamus) are sensitive to changes in the temperature of the blood (Marieb, 1998). Any perturbations are corrected by appropriate regulatory and feedback mechanisms described below.

2.2.1 Control of Heat Loss

An increase in core temperature above 40-41° C can cause dysfunction of the central nervous system and there is a risk of death above 43-44° C (Powers & Howley, 1997). Heat loss is achieved by four methods: radiation, conduction, convection and evaporation. In common with other examples of energy transfer, heat will be lost from the body if it is warmer than the surrounding environment (Powers & Howley, 1997). This temperature difference between the body and the environment is known as the thermal gradient. Where a thermal gradient exists in the opposite direction, a cold body will absorb heat from a warm environment.

In the event of a rise in core temperature, the hypothalamus activates the heat-loss mechanisms. Vasodilation of the cutaneous blood vessels occurs as a result of an inhibition of vasomotor tone (Marieb, 1998). This allows more blood to flow at the skin's surface allowing heat loss via radiation, conduction and convection. Sweat glands are activated and the individual begins to perspire leading to evaporative cooling. This method of cooling is the most effective during physical activity (Powers & Howley, 1997) but it is severely compromised in very humid conditions as previously described. This danger is recognised by many of the world's sports governing bodies who issue guidelines on whether events should take place or not depending on the prevalent conditions. The American College of Sports Medicine have published a position stand on the prevention of thermal injuries during distance running for instance (ACSM, 1985).

2.2.2 Control of Heat Promotion

Cold stress is a major risk to the health of an individual and the body attempts to counteract this by using a number of mechanisms to promote heat. This phenomenon is known as thermogenesis and takes two forms, shivering and non-shivering. Vasoconstriction of the cutaneous blood vessels occurs first in order to restrict the flow of blood to the skin's surface thus reducing heat loss. Noradrenaline is released, increasing the metabolic rate and also heat production (Marieb, 1998). This is known as non-shivering thermogenesis. If this is not sufficient to maintain core temperature then the body will invoke a shivering response. This initially takes the form of asynchronous firing of muscle fibres but then graduates onto synchronised firing of the muscle fibres of the neck (Parsons, 2003). Other muscle groups are then recruited, the neck being first so that the temperature of the brain can be maintained. Heat production can be increased six-fold over short durations and doubled for longer periods when compared to resting levels (Parsons, 2003).

2.2.3 The Heat Balance Equation

The heat balance equation describes the mechanisms of heat production and heat loss in humans:

$$M - W = E + C + K + R + S$$

Where M = metabolic rate
W = mechanical work
E = evaporative heat loss
C = convective heat loss
K = conductive heat loss
R = radiative heat loss
S = heat storage

(Parsons, 2003)

So for heat storage equalling 0, the equation can be rewritten thus:

$$M - W - E - C - K - R = 0$$

2.3 Manual Handling Tasks

Manual handling tasks are generally described as the transport or support of any load, including the use of lifting, putting down, pushing, pulling, carrying or moving techniques (HSE, 1998). Tasks such as these are commonplace in a wide range of industrial settings and they have been identified as a major contributor to reported workplace injuries. In 2000/01 manual handling tasks accounted for 36% of reported industrial accidents requiring more than three days off work in the UK (HSE, 2001). Of these, injuries to the lower-back accounted for 49% of the reported injuries and the upper-limbs were also identified as areas at increased risk. These injuries may have been the result of an acute event or the culmination of years of poor manual handling technique (Dickinson, 1995).

Investigators have used a variety of methods to assess manual handling tasks and set safe limits for industrial workers. These assessment methods are reviewed in detail in the forthcoming section. As previously stated the term 'manual handling tasks' covers a wide range of activities and it would be impractical to attempt a study of them all considering the constraints of a typical PhD time-schedule. For this reason a decision was made early on in the project to concentrate on the lifting task and, more specifically, the lift from floor to knuckle-height. This lift is one of three that are traditionally studied; the other two being knuckle to shoulder-height and shoulder-height to arm-reach. The floor to knuckle-height lift is common throughout industry and has been extensively studied in laboratory settings. It commonly imposes the largest physiological strain of the three lifts because of the involvement of the large muscle groups in the legs, buttocks and lower-back.

3. Review of Literature

3.1 Current UK Manual Handling Guidelines

On January 1st 1993 the Manual Handling Operations Regulations (MHOR, 1992), came into force under the Health & Safety at Work etc Act (1974). In the same year the HSE published a guidance document (L23: HSE, 1992 subsequently revised as the 2nd. Edition, 1998) aimed at employers and employees across all industries. The guidance document identifies four main factors when assessing the risk of injury associated with manual handling operations, namely: task, load, working environment and individual capability.

With the exception of working environment, these factors are considered in detail. Tasks, for example, are analysed in 23 separate paragraphs which deal with the implications of subtle variations such as load distance from the trunk and trunk-twisting. The section on working environment however merits only seven paragraphs, of which only one deals with extremes of temperature or humidity. Although compliance with the guidance document is not compulsory, it is generally used by health and safety inspectors as an example of good practice. For the sake of clarity, compliance with regulations is mandatory, compliance with guidance is not.

The guidance recommends that, where possible, manual handling tasks should be avoided. Where this is not possible, a risk assessment should be conducted taking into consideration the task, load, working environment and individual capability. It is noted that all of these factors are interrelated and cannot be considered in isolation (HSE, 1998). It is acknowledged that tasks conducted in uncomfortable thermal environments are likely to result in a greater chance of injury but there is no detailed guidance on how to assess the increased risks. Paragraph 94, for example, states that "high temperatures or humidity can cause rapid fatigue" and that "work at low temperatures may impair dexterity" (HSE, 1998). In paragraph 156 it is stated that "there is less risk of injury if manual handling is performed in a comfortable working environment" and that "extremes of temperature, excessive humidity and poor ventilation should be avoided where possible". The magnitude of the risks and range of environmental temperatures outside of which the injury risks increase have not been determined.

The L23 document (HSE, 1998) includes guidelines on weight limits that are recommended for relatively infrequent operations (30 operations per hour or one every two minutes) (see figure 1). If the hands move through more than one box then the lower or lowest value is recommended as the weight limit. The guidance recommends reducing the limit by 30% if the operation is repeated once or twice per minute and by 50% for five to eight repetitions per minute.

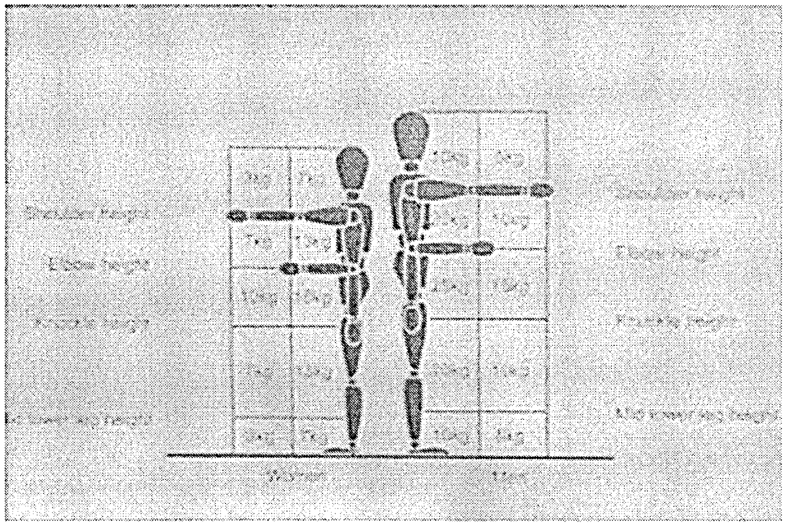

Figure 1. Manual Handling Operations Regulations guidance on weight limits for infrequent lifting and lowering tasks. Reproduced from HSE document L23.

3.2 Methods of Assessing Manual Handling Tasks

What is the best way of assessing manual handling tasks and what is the importance in doing so? The second question is answered by the accident and injury data. Consider the previously reported UK figures from 2000/1 where 36% of injuries requiring three or more days off work were attributable to manual handling. Of these, 49% were injuries to the lower back. Data from the United States of America (USA) also paint a similar picture but here the problem is more clearly quantifiable probably because of the differences in health service provision and insurance. From a sample of 883,015 workers' compensation claims, 37% were found to be attributable to injuries incurred during manual handling activities (Leamon & Murphy, 1994). It was estimated that the total workers' compensation costs in 1989 for lower back pain were $11.4 billion (Webster & Snook, 1994). Clearly not all of these costs were incurred by manual handling tasks but it can be assumed that they comprise slightly over one third of the overall figure; a staggering amount of money.

When considering how manual handling tasks are assessed it should be remembered that the tasks vary considerably so no single method will be universally appropriate. Even if one confines oneself to lifting, as in the case of this study, it should be evident that a physiological assessment using mean heart rate for example would glean very little useful information if the lifting frequency was extremely low (<1 lift every hour). Snook & Irvine (1967) identified seven variables that are important when considering lifting tasks. These are age, sex, training, fitness level, size of object, height and frequency of lift. Because of this a number of assessment methods have been used in the literature but the three principal ones are based on biomechanical, physiological and psychophysical factors.

3.2.1 The Biomechanical Approach

Biomechanical assessment is primarily aimed at preventing musculoskeletal injuries by measuring the tolerance limits of human tissue. Joint injuries, particularly at the lumbosacral (L5/S1) junction are a major risk when undertaking manual handling tasks. Analysis of the forces acting on the joints and surrounding musculature is used to set limits of maximal safe lifts for various population subsets. Compressive forces on the spine have typically been measured in cadaver studies using prepared *in vitro* spine specimens. Adams (1995) has published a review of these studies and highlighted some of the limitations of these designs. Analysis of the surrounding musculature is usually performed on live participants. Granata & Marras (1995), for example, collected electromyography (EMG) data from the trunk muscles and kinematic data from a force platform to assess trunk-loading during isokinetic and dynamic lifting tasks. Jorgensen *et al.* (1999) measured lumbar motion using an external monitor and tape measure along with EMG data from the surrounding musculature during a standardized lifting task. These data, together with heart rate, were used to determine a maximum acceptable weight of lift at a fixed frequency of 4.3lifts.min^{-1}. Limits defined by the biomechanical approach are set with the intention of avoiding acute injuries (i.e. tissue failure) caused by excessive forces. As such, they are generally most applicable to low-frequency, high-intensity tasks.

The biomechanical approach has its limitations as do all of the assessment methods. Can a prepared specimen of an *in vitro* spine really perform in a similar fashion to an *in vivo* spine for example? The cumulative loading of the spine may also be important when considering injury prevention (Kumar, 1990) and Dempsey (1998) has suggested that cadaver studies may be unable to assess this. Dempsey (1998) also indicates that there has been no real examination of the effects of shear forces experienced during manual handling.

3.2.2 The Physiological Approach

The physiological approach assesses markers of physical strain such as heart rate, oxygen uptake and energy expenditure so that working limits can be set that avoid the onset of excessive fatigue. Absolute limits that have been recommended include oxygen consumption of 1 l.min^{-1} or energy expenditure of

5 $kcal.min^{-1}$ (Dempsey, 1998). According to Dempsey (1998) these absolute limits roughly equate to 33% of maximal oxygen uptake for an ‘average’ person. Absolute limits of heart rate have been variously recommended in the range of 110 to 130 $beats.min^{-1}$ (Snook & Irvine, 1969). Limits are usually set so that the loads selected can be lifted for extended periods (e.g. eight-hour shifts) without undue fatigue and, as such, are generally most applicable to high-frequency, low-to-medium intensity tasks.

When considering relative limits it should be remembered that $\dot{V}O_{2max}$ measured on a person while running or cycling will be different from $\dot{V}O_{2max}$ recorded during lifting. Khalil *et al.* (1985) reported that values of maximal oxygen uptake during lifting tasks using various weights, heights and frequencies were between 57% and 91% of that for cycling. These findings are similar to those of Petrofsky & Lind (1978) who reported values of between 54% and 80% compared to cycling. The differences are most likely due to the variable contribution of different muscle groups used to perform the task at hand. This will mean that a relative limit imposed using a $\dot{V}O_{2max}$ measurement from a running or cycling protocol will be an overestimate and might result in the onset of fatigue while lifting.

Using physiological limits in the workplace is obviously impractical except for the possible use of heart rate as a method of preventing the onset of undue fatigue. There is also the issue of applying generalized limits to a heterogeneous working population. Because of this the appropriateness of using physiological limits for manual handling tasks is to a large extent unknown.

3.2.3 The Psychophysical Approach

The science of psychophysics examines the relationship that exists between subjective perceptions and physical stimuli or strain (Ayoub & Dempsey, 1999). The underlying theory is that the strength of a subjective sensation is directly related to the intensity of a particular stimulus by means of a power function. The relationship is described thus:

$$S = kI^n$$

Where S = perception of the stimulus
I = strength of the stimulus
k = constant (determined by units of measurement used)
n = the exponent which varies depending on type of stimulus

(Stevens, 1960)

The exponent n has been investigated for many of the stimuli that affect humans and the value of 1.6 for muscular effort and force is of particular interest in manual handling research. In the area of exercise science, Borg (1970), has used this particular exponent to produce a rating scale of perceived exertion that is in widespread use today. When considering manual handling tasks, psychophysics makes three assumptions:

1. An individual is able to rate perceived effort in a lifting task.
2. They are able to produce an individually acceptable level of performance on their task.
3. This level of performance will be safe from manual handling injuries.

(Gamberale *et al.*, 1987)

However, as Karwowski (1996) argues, the validity of these assumptions has never been fully examined.

In manual handling research using the psychophysical approach, participants are asked to perform a specified lifting task (or carry, pull, lower etc.) at either a prescribed frequency or load. One of the variables is held constant by the researcher while the participant adjusts the other until they arrive at a workload or frequency that they deem acceptable to perform for a set period of time (usually eight hours). This is known as the tracking and adjustment strategy. Usually it is the lift frequency that is controlled by the researcher and the load that is free to vary. This is achieved by the participant adding or removing weight (usually ball-bearings that are either loose or bagged) to and from the box being lifted. The time allowed to make changes to the box weight is known as the adjustment period and this can vary, usually from 20 to 40 minutes.

The theory that an individual can accurately gauge an acceptable workload for an 8-hour day from a much shorter adjustment period underpins much of the research using the psychophysical approach. This theory is largely supported by studies where the relationship between workload selected during a short adjustment period and actual workloads recorded over 4-hour and 8-hour sessions has been investigated. It appears that the theory is valid for lower lifting frequencies: Ciriello *et al.* (1990) reported consistency between the two measures up to 4.3 lifts.min^{-1} after a 4-hour session for example. Over 8 hours, Mital (1983) reported similar findings up to a frequency of 6 lifts.min^{-1} after which MAWL started to decline.

Lengths of adjustment periods have varied between 15 and 40 minutes since research in this area began in the 1960s. A 40-minute adjustment period was used in the early work by Snook & Ciriello (1974) but more recent studies (Chen, 2003; Mital, 1987; Wu & Chen, 1997) have found that between 20-25 minutes is an adequate length of time to establish MAWL. The length of the adjustment period is necessarily governed by the lift frequency with very low frequency lifts (<0.1 lifts.min^{-1}) requiring a much longer time to establish. Part of the problem when examining the literature is the various terminologies used when describing lift frequencies. In the context of this study the 1 lift.min^{-1} frequency would be considered low frequency but this would not be the case in studies where lifts as infrequent as 0.1 lifts.min^{-1} and slower have been used.

Research on manual handling using the psychophysical strategy was pioneered by Stover Snook in the 1960s on behalf of the Liberty Mutual Insurance Company in the USA. In 1978 Snook published tables of maximum acceptable weights and forces for lifting, lowering, pushing, pulling and carrying (Snook, 1978). The tables were produced from data collected in six studies and provided information for males and females, accounting for many of the task variables known to affect the weight handled. For example the lifting tables provide maximum acceptable weights based on width of load, height and type of lift and lift frequency. Values are reported for the 10th, 25th, 50th, 75th and 90th percentiles representing the percentage of the working population for whom the weight should be acceptable. Based on epidemiological data collected by the Liberty Mutual Insurance Company, Snook (1978) suggested that workers performing a task involving a weight that is acceptable to less than 75% of the population were three times more susceptible to low-back injury. The results of four further studies were used subsequently to revise and augment the tables (Snook & Ciriello, 1991). They are now freely available in an interactive format on the world wide web (Liberty Mutual, 2006) although some readers will be frustrated by the adherence to imperial weights and measures therein.

In a comprehensive review of the area of psychophysics and manual handling, Ayoub & Dempsey (1999) identified a number of advantages and disadvantages associated with the psychophysical assessment approach. In its favour, the authors cited its ability to assess realistic work tasks and the fact that a large amount of data has been collected using industrial workers as subjects. It can also be used to assess intermittent tasks and can integrate both biomechanical and physiological factors. The main limitations are that it is a subjective approach and that the assumption that selected loads are below injury thresholds has not been extensively validated. Furthermore, at low and high lifting frequencies, the selected loads may exceed limits imposed by biomechanical and physiological assessment alone. This assumes, of course, that limits set using biomechanical and physiological data are 'correct' but this assumption remains unproven.

Psychophysics seeks to bridge the gap that exists between biomechanical and physiological assessment methods. The weights in Snook & Ciriello's (1991) tables have been found to exceed certain 'safe' spinal compression loads (NIOSH, 1981) at low lifting frequencies. At the other end of the continuum it is acknowledged that weights for high-frequency lifts may not be valid for eight-hour shifts because they incur undue physiological strain. Mital *et al.* (1993) have published modified tables, incorporating biomechanical and physiological data, in an attempt to overcome the problems encountered at the high and low ends of the lift-frequency spectrum.

3.2.4 The NIOSH Equation

In addition to the tables published by Snook & Ciriello (1991) and Mital *et al.* (1993) there is another widely used tool for the assessment of manual handling tasks. The NIOSH equation was developed by the National Institute for Occupational Safety and Health (NIOSH, 1981), incorporating biomechanical, physiological and psychophysical criteria. The equation was revised in 1991 and again in 1993 to address some of the limitations in the original; notably its ability to assess lifts in the sagittal plane only and its inability to assess asymmetrical tasks, variations in load couplings (e.g. handles), temperature, work duration and lifting frequency. The revised NIOSH (1993) equation is thus:

RWL = LC x HM x VM x DM x AM x FM x CM

Where

- RWL = Recommended weight limit
- HM = Horizontal multiplier
- VM = Vertical multiplier
- DM = Distance multiplier
- AM = Asymmetric multiplier
- FM = Frequency multiplier
- CM = Coupling multiplier

(Waters *et al.,* 1993)

The recommended weight limit is defined as ‘a load value that nearly all healthy workers could perform over a substantial period of time’ (Waters *et al.*, 1998). The revised equation was reviewed by the same authors and was deemed to be of greater protective benefit to workers than the original equation. Amongst the limitations identified however was the inability to account for a working environment outside of the temperature range of 19 – 26 °C or a relative humidity range exceeding 35 - 50%.

Hidalgo *et al.* (1997) subsequently proposed a comprehensive lifting model that built on the revised NIOSH equation and incorporated, amongst other things, an environmental variable (wet bulb globe temperature - WBGT). This variable, known as the heat stress multiplier, was developed using data from Hafez (1984) but it only applies to environments ranging from 19 – 40 °C WBGT. The effects of cold stress are not addressed nor the other factors responsible for thermal comfort (air velocity and clothing). Interestingly, the heat stress multiplier only affects WBGT values above 27.0 °C (from 19 to 27 °C the multiplier is 1) suggesting that the authors believe that environments up to this value all impose the same physiological strain. The multiplier decreases linearly to a value of approximately 0.69 at 40 °C.

3.3 Thermal Stress

In extreme environments the body's internal control mechanisms may prove to be inadequate and the core temperature may rise or fall outside the 'safe' range. If this departure from the safe range is large enough death is inevitable but lesser deviations are also problematic, providing a continuum of heat or cold illnesses of increasing seriousness.

3.3.1 Heat Stress

As previously described, in the event of an increase in core temperature (hyperthermia) the body will activate its heat-loss mechanisms. Vasodilation and sweating will occur, providing heat-loss pathways to the surrounding environment. The second law of thermodynamics states that heat will travel spontaneously from a warmer to a cooler environment so the body must be warmer than its surroundings for heat loss to occur. Conversely, there will be a net heat gain in cases where the environmental temperature exceeds body temperature. Such environments are described as uncompensable and pose a serious risk to health.

Armstrong (2000) has classified heat illnesses into four main categories when considering athletes and workers:

- Heat Exhaustion
- Exertional Heatstroke
- Heat Cramps
- Heat Syncope

Of these, heat exhaustion is probably the most common, occurring at a rectal temperature of or exceeding 39 °C. Work or exercise cannot be continued, sweating is heavy and there may be some minor mental impairment. Exertional heatstroke on the other hand is a medical emergency and typically occurs at a rectal temperature of 40 °C or higher.

3.3.2 Exercise in the Heat

During exercise blood is diverted to working muscles thus providing oxygen and removing waste products (Powers & Howley, 1997). In the heat, as has been stated, blood flow is redistributed to the skin's surface through vasodilation, allowing heat loss to the surrounding environment. Exercise in the heat therefore poses a twin challenge to the cardiovascular system.

High sweat rates can lead to dehydration if fluid loss is not balanced by an appropriate rehydration regime. Sweat rates of 0.8 – 1.4 $l.hr^{-1}$ are not uncommon and in extended exercise sessions individuals will experience a concomitant decrease in body mass (Armstrong, 2000). Sawka *et al.* (1992) demonstrated that a 5% reduction in body mass due to dehydration significantly reduced plasma volume, decreased sweat rate and led to a higher heart rate during exercise in the heat. Time to exhaustion was also massively reduced (121 mins v 55 mins) and this occurred at a significantly lower core temperature.

Investigations into the effects of thermal environments on exercise performance are widespread and a comprehensive review of the relevant literature is beyond the scope of this thesis. Many of these studies have been conducted using continuous running or cycling protocols that are inapplicable to the manual handling environment. In addition to the papers cited in the previous chapter, the reader is directed to these selected reviews for further information in this area (Aoyagi *et al.*, 1997: Cheuvront & Haymes, 2001; Febbraio, 2001; Lindinger, 1999; Noakes, 2000).

3.3.3 Cold Stress

In cold environments where the body's heat generation processes are unable to prevent net heat-loss the risk of cold injury and death is very real. Should the core temperature fall below 35 °C then the individual is defined as being hypothermic (Holmer, 1994b). At this temperature the muscles stiffen and the viscosity of the blood increases further (Parsons, 2003). There is a clouding of consciousness, confusion and apathy leading to a loss of sensory information (Parsons, 2003). At 30-31 °C the individual will lapse into unconsciousness and any further fall in core temperature will probably result in death due to ventricular fibrillation. Parsons (2003) identified considerable inter-individual variation in the ability to withstand extremely low core temperatures, citing a case where complete recovery was achieved in an accidental hypothermia victim who had experienced a core temperature of 18 °C.

Of particular interest in manual handling studies are the effects of cold on the hands. Situated at the body's extremities, the hands are affected immediately by the reduction in blood flow caused by vasoconstriction resulting in decreased net heat loss. A gradual loss of dexterity is experienced as hand temperature falls due to a number of factors. There is a reduction in nerve conduction velocity (De Jong *et al.*, 1966) which drops strongly at a nerve temperature below 20 °C and is effectively blocked at 10 °C (Vangaard, 1975). There is also a loss of sensibility in the surface sensory receptors at a local skin temperature of around 6-8 °C (Morton & Provins, 1960) and a decrease in joint mobility as the synovial fluid becomes more viscous at lower temperatures (Heus *et al.*, 1995). Psychological factors such as loss of attention due to pain or discomfort may also play a role (Teichner, 1957). Loss of dexterity is accompanied by a loss of maximal force output and a reduced time to exhaustion on dynamic power tasks (Heus *et al.*, 1995).

Periodic vasodilation of the blood vessels in the hands has been reported when they are locally exposed to prolonged cold temperatures (Burton & Edholm, 1955). This phenomenon has been variously described as 'cold-induced vasodilation', 'hunting reflex' and the 'Lewis effect' (named after the first person to investigate it). Lewis (1930) reported that when the fingers were immersed in ice-water, finger temperature dropped quickly to 0 °C but rose after approximately 10-15 minutes to around 5-6 °C. There then followed a cycle of temperature fluctuation which the author concluded was due to variations in local blood flow. Most of the work in this area has concentrated on cold-water immersion of the hands but some studies have noted a similar, though less pronounced, response in cold air environments (Kramer & Schulze, 1948; Blair, 1952).

Cold injuries to the extremities can occur, of which frostbite is the most severe. Frostbite is a condition that occurs when tissue fluids freeze, possibly leading to cell death and necessitating amputation of the affected area. Non-freezing cold injuries due to exposure to temperatures between 1-15 °C may lead to nerve damage (peripheral vasoneuropathy) (Parsons, 2003). In addition to these injuries, workers may be at risk from 'contact injuries' where the skin sticks to extremely cold surfaces. The type of materials handled and their surface temperatures determine when these contact injuries will occur (Parsons, 2003).

3.3.4 Exercise in the Cold

During exercise, metabolic responses to cold exposure (compared to a thermoneutral environment) include reduced lipid mobilisation and higher levels of blood lactate (Doubt, 1991). Glucose use may be slightly higher (Doubt, 1991) and Blomstrand *et al.* (1986) reported greater use of glycogen in muscle cooled to 28-29 °C compared to muscle at 35 °C. Burton & Edholm (1969) also identified an increase in urinary output in the cold, a phenomenon known as cold-induced diuresis. The increase in urine production is accompanied by a decrease in plasma volume (and a concomitant increase in blood viscosity). These changes have been reported to lower physical work capacity (Gronberg, 1991).

3.3.5 Acclimation

Human beings have an ability to adapt in a limited fashion to extended exposure to hot (though, it appears, not cold) environments. When this adaptation takes place in a 'natural' environment (e.g. a tropical country) it is known as acclimatization. When it occurs in an artificial environment such as a laboratory it is termed 'acclimation' and this latter term will be used in the original studies reported in this thesis. It is common practice nowadays for athletes and military personnel to be relocated to a hot environment prior to commencement of competition or operations. The British Olympic team set up a holding camp in Cyprus prior to the Athens Olympics in 2004 and coalition troops engaged in exercises in the Middle East before deployment in both Iraq wars.

The adaptation response to hot environments manifests itself in an earlier onset of sweating and a higher sweat rate. These changes contribute to an enhanced ability to stay cool by increasing evaporative heat loss. Mineral concentration of sweat is lowered, blood volume increases by 10 – 12% and the core body temperature falls slightly (Parsons, 2003).

The time-course for the onset and decay of acclimation is well documented. Pandolf (1998) reviewed the main studies conducted in this area from the 1940s onwards and concluded that almost complete acclimation occurs within 7 to 10 days of exposure and that two-thirds of the adaptation takes place in the first 4 to 6 days. Acclimation decays rapidly within the first week of removal from the environmental stimulus with almost total cessation after four weeks.

Whether humans can adapt to the cold is much less clear and Parsons (2003) states that the results of investigations in this area are inconclusive. The author describes the apparent ability of Australian aborigines to allow body temperature to fall during the night for example. This suppresses shivering allowing them to sleep whereas a person from a temperate climate would find this impossible. The possible causes of this phenomenon are unclear as is the time factor for any onset or decay of adaptation.

3.4 Indices of Thermal Stress

Over the years attempts have been made to develop indices of heat stress that take account of the interactions between the variables that comprise the human thermal environment. Goldman (1988) reported that there may more than 60 such indices in use, many tailored to specific situations.

3.4.1 Wet Bulb Globe Temperature

Probably the most widely used index is the WBGT which is usually attributed, slightly inaccurately, to Yaglou & Minard (1957); a paper which documented the control of heat casualties at three US Marine Corps (USMC) training camps during the summer of 1954. The WBGT scale was introduced in the text as a method 'recently developed' but the source material was not referenced. An article on the World Wide Web provides a clue to the scale's origins however:

"The original work which served as the basis of this standard has been lost. A prominent exercise physiologist of our acquaintance has been looking for the seminal "Technical Paper" by Yaglou for more than one year, but it has disappeared."

(Zunis Foundation, 1998)

What seems certain is that sometime in the early 1950's the US Navy commissioned research into measurements of heat stress after suffering a particularly high number of heat casualties at a USMC training camp in South Carolina. The development of the WBGT scale appears to have arisen from this research and, despite these hazy origins, gained widespread acceptance. It has even been given its own international standard (ISO 7243, 1989). The scale is calculated as follows:

Inside buildings and outside without solar load:

$WBGT = 0.7t_{nw} + 0.3t_g$

Outside with solar load:

$WBGT = 0.7t_{nw} + 0.2t_g + 0.1t_a$

Where t_{nw} = natural wet bulb temperature

t_g = globe temperature

t_a = air temperature

(ISO 7243, 1989)

For the purposes of this study, where research was conducted indoors, only the first formula will be discussed. WBGT is expressed in °C and takes account of measures of natural wet bulb and globe temperature although in situations where there is no radiation component, a simple measure of air temperature replaces globe temperature. It has been reported that use of the index may be inappropriate for environments exceeding 33 ˚C WBGT (Westman, 1999).

Consider the following two environments with equivalent WBGT:

WBGT 27.2 ˚C (dry bulb=30.5 ˚C, RH=68%)

WBGT 27.1 ˚C (dry bulb=38.7 ˚C, RH=22%)

The first, with a relative humidity of 68% may be termed 'warm-humid': the second 'hot-dry'. Environments with the same WBGT may vary considerably (as above) but it is assumed that the different conditions will impose the same thermal load on a human subject if the WBGT remains constant. Recently this assumption has been called into question as it is believed that heat stress is greater in more humid environments for a given WBGT. Kellett *et al.* (2003) reported that heat strain was greater when subjects exercised on a treadmill in a warm-humid environment (WBGT 32.1 ˚C, dry bulb=33.4 ˚C, Globe Temp=34.1 ˚C, RH=88%) compared to a hot-dry environment (WBGT 32.3 ˚C, dry bulb=45.6 ˚C, Globe=46.3 ˚C, RH=20%). Rectal temperatures, heart rates and fluid loss were all significantly higher after 60 minutes of continuous walking in the warm-humid environment. Conversely, a study by Keatisuwan *et al.* (1996) found that heat strain was greater in hot-dry conditions (Hot Dry, dry bulb=40 °C, RH=30%, WBGT=32 °C vs. Warm Humid, dry bulb=31 °C, RH=80%, WBGT=32 °C). Rectal temperature, mean skin temperature, heart rate and fluid loss were all significantly higher after a mixed protocol on an exercise ergometer culminating in 60 mins of pedalling at 40% of $\dot{V}O_{2max}$. Why this investigation yielded such unexpected results is hard to explain as it runs contrary to the received wisdom (i.e. that the humid environment will impose a greater strain). A possibility is that the sample, consisting of eight Japanese men and eight Japanese women, exhibited some sort of hereditary response. Average relative humidity levels in Tokyo exceed 85% throughout the months of June to September (WashingtonPost.com, 2006) so it would be expected that anyone indigenous to the region would have formed a habituation to the conditions.

3.5 Subjective Assessment of Thermal Strain and Comfort

A convenient and inexpensive method of assessing an individual's perception of the environment is to use a subjective assessment ratings tool of which there are a number. Two popular ratings tools of this type are the Bedford comfort scale (1936) and the ASHRAE sensation scale (1966). Both are seven-point scales with verbal anchors for each point ranging from 'much too cool' and 'cold' (1) to 'much too warm' and 'hot' (7). Individuals are asked to indicate 'how they feel now' by pointing to a number on the scale.

The usefulness of such scales is questionable in research of the type included in this thesis however. The purpose of this body of work was to examine the effects of heat and cold on lifting performance so responses regarding the individual's perceptions of the environment were of limited value. It was anticipated that participants would report feeling 'hot' in many of the sessions during the first study for example. There was also concern that the scales themselves did not provide a sufficient range of responses. The ASHRAE and Bedford scales accommodate both hot and cold in one seven-point scale, severely limiting the range of possible responses. In a warm environment for example the ASHRAE scale would only allow for responses of 'slightly warm', 'warm' and 'hot'.

The Borg RPE scale (Borg, 1970) is a subjective assessment tool that is widely used in exercise science. If used correctly the scale should produce ratings of perceived exertion based on the individual's integration of all of the 'signals, perceptions and experiences' felt during exercise (Borg, 1982). It seems reasonable therefore to assume that signals from thermal afferents such as peripheral and central thermoreceptors will be integrated into the overall rating of exertion making the RPE scale an appropriate tool for use in thermal research. The RPE scale is described in greater detail in chapter 3.

There are limitations and potential pitfalls inherent in the use of any subjective assessment tool. It is essential that thorough training in the use of such scales is provided for both the researcher and participant. This is necessary to avoid the possibility of the researcher influencing the rating given and to ensure that the participant provides consistent responses. Care must also be taken to ensure that factors such as ego, pride and competitive instincts are not allowed to influence the ratings provided.

3.6 Manual Handling and Heat Stress

An early study was conducted by Kamon & Belding (1971) who assessed the physiological cost of carrying loads in temperate and hot environments. Subjects were asked to carry cartons weighing 10, 15 and 20 kg whilst walking on a treadmill at two different speeds and gradients. Each session consisted of three five-minute exercise bouts separated by five-minute rest periods. The temperature ranged from 20 – 45 °C dry bulb. Wet bulb temperatures were reported but the environments were considered to be 'warm-dry' or 'hot-dry'. Radiant heat was not considered but air velocity was measured at ~75m.min^{-1} (1.25 m.s^{-1}). Heart rate was monitored continuously and expired air collected in Douglas bags during the final two minutes of each test to measure metabolic cost. Of particular interest was the finding that a steady state heart rate was achieved in an air temperature (T_a) of 20° C and this remained consistent throughout the exercise bouts. At 35° C (T_a), the attainment of steady state heart rate was delayed and increased as the bouts progressed. Steady state was not achieved during the final two bouts at 45° C (T_a). Compared to the measurements at 20° C (T_a), heart rate was approximately 10 beats.min^{-1} higher at 35° C and 20 beats.min^{-1} higher at 45° C. These findings indicate that temperature has an independent effect on heart rate. The significance of these findings is greatly diminished by the fact that only three subjects participated however.

Snook & Ciriello (1974) investigated the effects of heat stress on lifting, pushing and carrying tasks using a sample of sixteen male industrial workers. In particular the authors were interested in how much workers compensated for increased heat stress by modifying their lift frequency and work load. The WBGT was used to measure the working environment, as opposed to merely measuring ambient air temperature in the Kamon & Belding (1971) study. This gave a more detailed description of the components of heat stress (ambient, radiant and wet bulb temperature) that the workers were exposed to. Two environments were studied, moderate (17.2 °C WBGT) and hot (27 °C WBGT) and the subjects selected were all unacclimatized to work in hot conditions. The relative humidity was 45% (15 °C natural wet bulb) in the moderate environment and 65% (25.5 °C natural wet bulb) in the hot environment. The lifting task consisted of lifting an industrial tote box from floor level to knuckle-height and the investigators utilised a motorized frame which automatically lowered the box to the starting position again. Subjects self-selected lift frequency or load weight (psychophysical approach) during the sessions depending on which groups they were assigned to. Heart rate and rectal temperature were monitored for all subjects and oxygen consumption for nine subjects. It was found that in the hot environment, self-selected workload was significantly reduced by 20% for the lifting task and that heart rate and rectal temperature were significantly increased by 9-10 beats.min^{-1} and 0.2 – 0.3° C respectively. It was noted that the reduction in workload was not sufficient to reduce heart rate and rectal temperature to levels found in the moderate environment. It was speculated that subjects may have had a level of tolerable heat stress that they were prepared to work at and that heart rate and rectal temperature increases may be used to define this limit.

It has been widely reported that an individual's ability to tolerate heat stress can be improved by acclimatization (Buskirk & Bass, 1974). An acclimatized individual can work in a hot environment whilst maintaining a lower core temperature and heart rate. Evaporative cooling is improved by an earlier onset of sweating and a higher sweat rate (Sato *et al.*, 1990). Hafez & Ayoub (1991) tested six male subjects who performed a lifting test similar to the protocol described in Snook & Ciriello (1974). There were three environmental conditions (22 °C, 27 °C and 32 °C WBGT) which the subjects were acclimatized to over ten consecutive days. The precise environmental variables are described in table 1 below.

WBGT (°C)	***22***	***27***	***32***
Wet Bulb (°C)	20	24.5	29.4
Dry Bulb (°C)	26.7	33	38
RH (%)	53	49	52

Table 1. Environmental variables (Hafez & Ayoub, 1991)

Heart rate, rectal temperature and oxygen consumption were recorded throughout testing. Mean heart rate increased by 3 beats.min^{-1} from 22 to 27 °C WBGT and by 7 beats.min^{-1} between 27 and 32 °C WBGT. Mean rectal temperature increased by 0.1 °C and 0.3 °C respectively between the three environments. When plotted, the increase in heart rate and rectal temperature in the three environments described a curvilinear relationship. There was a significant interaction between environmental temperature at a given lift frequency and amount of weight selected to lift. The most pronounced reductions in workload occurred between 27 and 32 °C WBGT and at lift frequencies of 3 $lifts.min^{-1}$ and 6 $lifts.min^{-1}$. At a frequency of 3 $lifts.min^{-1}$ there was an 18.3% reduction in weight lifted (25.6 kg vs. 20.9 kg) between 27 and 32 °C WBGT. At 6 $lifts.min^{-1}$ there was a 21.2% reduction in weight lifted (20.37 kg vs. 16.06 kg) between the same environments. Reductions in the amount of weight selected to lift at 27 °C WBGT were smaller (7.7% vs. 20%) than those reported by Snook & Ciriello (1974). The authors speculated that the younger subject sample and their acclimatization status may have contributed to some of the differences in results. The authors concluded that acclimatized individuals can work at the same rate in a hot environment up to 27 °C WBGT as in a moderate environment (22 °C WBGT). Individuals working in hotter environments (specifically 32 °C WBGT) should reduce the amount of load lifted or take longer rest periods. Further research was recommended in order to identify the precise temperature at which reductions in workload should occur. It was suggested that work/rest schedules at elevated temperatures should also be investigated.

Research into the effects of uncomfortable warm and hot environments on lifting performance has been limited to a few studies. Acclimation status has varied and hydration status prior to participation has not been assessed. A particular limitation has been the absence of any investigation into the effects of relative humidity and how it interacts with the other environmental variables.

3.7 Manual Handling & Cold Stress

The literature reviewed on cold stress has been limited to conditions likely to be encountered in UK industrial settings and to what it would be possible to replicate in the laboratory. This excludes investigations conducted at extreme low temperatures (<0 °C) and those concerned with an individual's responses to cold water immersion. Many of the deleterious effects of a cold environment can be avoided by simply wearing more layers of clothing and by insulating the extremities with gloves and suitable footwear (Holmer, 1994a). Hats can also reduce a significant amount of heat lost from the head. Unfortunately, a worker dressed for thermal comfort at rest or for working at light intensities may be overdressed when working at high intensities (British Occupational Hygiene Society, 1990). In this case, the additional layers of clothing may prevent heat loss and lead to a rise in core temperature.

Investigations into the effects of cold environments on manual handling tasks have been extremely limited, especially at temperatures encountered in the chilled food industry for example. Emmett & Hodgson (1993) compared the cardiovascular responses of ten males whilst shovelling snow in thermoneutral, cold (4.9 ± 1.3 °C) and cold with wind (4.8 ± 1.3 °C and $1.9 m.s^{-1}$) environments. Heart rate was significantly lower in the cold/wind environment compared to the thermoneutral environment and post-shovelling systolic blood pressure was significantly higher. The authors hypothesized that the reduction in heart rate may be a protective mechanism against excessive cardiovascular strain caused by the increase in systolic blood pressure. It was noted however that subjects with higher body fat percentages exhibited higher mean cardiovascular responses. This may be due to the greater insulative effect of body fat resulting in less efficient heat loss.

To the author's knowledge there have been no studies conducted on the effects of cold environments on lifting performance and physiological strain. One of the aims of this thesis is to begin to address this gap in the literature.

3 Materials and Methods

1. Summary

This chapter describes the design and procedures used in the investigations into the effects of different thermal environments on the performance of manual handling tasks. This covers temperature measurement of the environment and of the individual with respect to current international standards and methods. The calibration of the measurement equipment is also detailed. The protocol used to produce the Maximum Acceptable Weight of Lift (MAWL) is described and reliability of the results reported with statistical analyses. The details of a pilot study used to validate the MAWL procedure are also included. There is also a section dedicated to the statistical tests chosen, the reasons for their use and their underlying assumptions and limitations.

2. Measurement of the Environment

The 'environment' described throughout these studies refers to the environmental chamber in the Centre for Sport & Exercise Science at Sheffield Hallam University. The chamber was commissioned in 2000 and has a temperature range of -20 °C to +45 °C with relative humidity adjustable up to 95%. The main chamber measures 3.9 m x 3.9 m and is accessible from the external environment through an intermediate room where the temperature can be independently controlled. This arrangement allows participants to move both in and out of the main test area into a relatively comfortable 'halfway house' environment. The equipment used to adjust the environmental parameters is housed in a control room adjacent to the main chamber. Two double-glazed glass panels allow investigators to observe events in the chamber and insulated service hatches provide access for any required test cables.

3. Assessing the Characteristics of the Chamber

Between November 2002 and April 2003 eighteen trials were conducted in the chamber at various environmental settings. The purpose of these trials was to identify the characteristics of the chamber with respect to the four environmental variables of the human thermal environment. To recap these are; air temperature, radiant temperature, relative humidity and air velocity. Conditions were also monitored in different parts of the chamber so that a determination could be made on the homogeneity (or otherwise) of the environment.

Air temperature was measured using a temperature probe (general purpose thermistor CS-U, Grant Instruments, Cambs., UK), accurate to ±0.2 °C between 0 °C and 70 °C. The probe is approximately 100 mm long and shielded from radiant heat sources. Radiant temperature was measured using a temperature probe insulated inside a 15 mm matte black globe. Relative humidity was measured using a humidity sensor (Rotronic Hygroclip humidity and temperature sensor, Rotronics Instruments UK Ltd., West Sussex, UK); accurate to ±1.5% RH between -40 °C and 85 °C. Air velocity was measured using an anemometer (Air Velocity Transducer 8455-300, TSI Inc., MN, USA). All sensors and probes were connected to a data logger (Squirrel 1021, Grant Instruments, Cambs. UK) which was set to sample every 10 seconds and record a mean of the samples once a minute.

The main findings arising from these trials were as follows:

- There was an absolute technical error of measurement (TEM) of 0.26 °C between air temperature and radiant temperature when the two probes were situated adjacent to one another. The relative TEM was 0.84%. The mean bias and 95% limits of agreement (Bland & Altman, 1986) were 0.06 °C ± 0.7 (see appendix F). This meant that there was no appreciable radiant heat component in the chamber and therefore black globe measurements were unnecessary.
- Air velocity was in excess of 1 $m.s^{-1}$ in the upper regions of the chamber near the vents but fell to less than 0.3 $m.s^{-1}$ at a height of approximately 1.8 m. This demonstrated that air flow near head height was barely perceptible.
- There was an absolute TEM of 0.02 °C in air temperature between two areas in the centre of the chamber separated by a distance of approximately 1.5 m. The relative TEM was 0.05%. The mean bias and 95% limits of agreement (Bland & Altman, 1986) were 0.001 °C ± 0.05 (see appendix F). This meant that two participants could be tested simultaneously in almost identical environmental conditions.
- Mean measurements of air temperature and relative humidity taken simultaneously at heights of 0.1 m, 1.1 m and 1.7 m were practically uniform (differences of less than ±5% in accordance with ISO 7726, 1985). Therefore the environment was considered homogeneous allowing a future single reading of each variable to be taken at a height of 1.1 m.
- The chamber demonstrated good stability during prolonged operation although best performance was at higher air temperatures. Over a three hour period set at 34 °C and 60% RH the chamber maintained a mean

(SD) temperature of 33.9 (0.2) °C and a relative humidity of 61.4 (1.1) %. Over four hours set at 5 °C, 45% relative humidity, a mean temperature of 4.8 (0.5) °C and a relative humidity of 50.8 (13.5) % were achieved. The second trial illustrates the difficulty of maintaining relative humidity in a low air temperature. This is because air is able to hold more moisture at higher temperatures. Air that is completely saturated at 5 °C holds only around 5.5 grams of water vapour per kilogram of dry air (known as the mixing ratio), depending on the ambient atmospheric pressure. The mixing ratio required for a relative humidity of 45% at 5 °C is therefore approximately 2.5 $g.kg^{-1}$. Compare this with an air temperature of 40 °C which has a saturated mixing ratio of around 49.3$g.kg^{-1}$ and a mixing ratio of 22$g.kg^{-1}$ at 45% RH. The greater absolute concentrations of moisture at higher temperatures appear to present less of a challenge to the control and feedback mechanisms in the chamber resulting in better stability.

As a result of these trials it was decided that measures of air temperature and relative humidity would be taken from directly behind each participant at a height of 1.1 m from the floor in accordance with the recommendations of ISO 7726 (1985) for homogeneous environments. Measurements of radiant temperature and air velocity were deemed to be unnecessary.

4. Measurement of the Participants

4.1 Core Temperature

Although it is an oft-quoted term, core temperature defies easy description because core tissues are not defined (Parsons, 2003). The term is usually used to describe the internal temperature of the body particularly the temperature of the vital organs including the brain. ISO 9886 (2000) defines the core as "all of the tissues located at a sufficient depth not to be affected by a temperature gradient through surface tissue". Measures of core temperature can therefore be taken at various sites in the body, seven of which are detailed in ISO 9886 (2000):

- Oesophagus
- Rectum
- Gastro-Intestinal Tract (GI tract)
- Mouth
- Tympanum
- Auditory Canal
- Urine

The selections of method and site are dictated by practical considerations but these have to be balanced with what is acceptable to the participant. In the studies presented herein it was essential for safety reasons to monitor and record temperature throughout testing. The temperature sensor had also to work continuously while located somewhere on a working participant. For these reasons, measurements at the oesophagus, mouth, tympanum and of the urine were rejected. The use of ingestible temperature transducers in the GI tract was rejected on grounds of cost. Of the two remaining methods, rectal measurements were rejected partly due to the propensity of the probe to become displaced when exercising and partly because of participants' traditional aversion to the procedure. It was therefore decided to use the temperature of the auditory canal as a measure of core temperature.

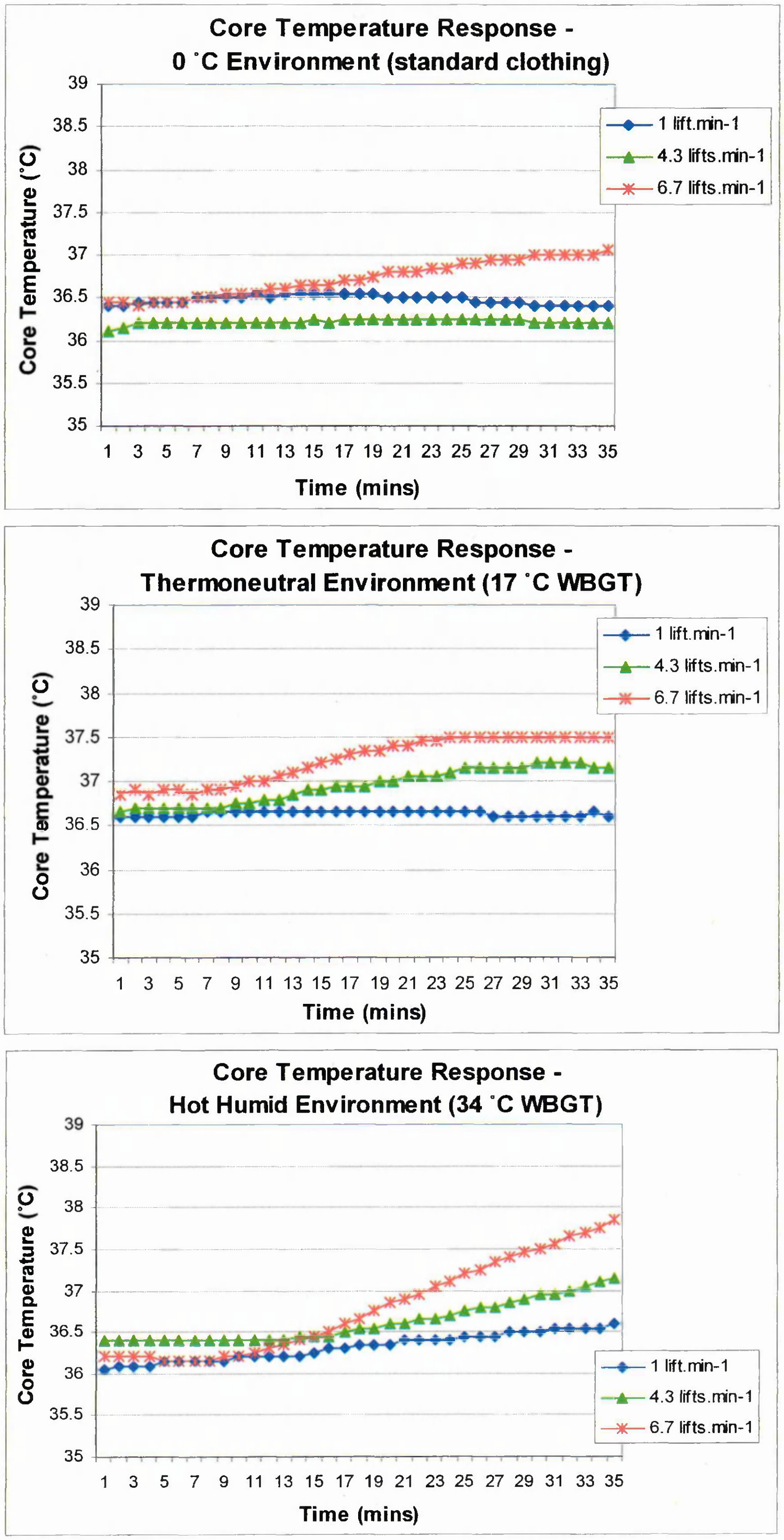

Figure 2. Individual core temperature response at three lifting frequencies in three different environments. Top: In 0°C wearing standard clothing ensemble. Centre: In 17° C WBGT. Bottom: In 34° C WBGT. Data are from one participant recorded over 35 minutes of box-lifting.

Temperature of the auditory canal or 'aural temperature' is usually lower than rectal temperature. Muir *et al.* (2001) for example reported a mean difference of ~1.2 °C between the two sites prior to an exercise bout. Temperature rose at both sites during subsequent exercise though more quickly at the aural site resulting in a gradual convergence of the two values. This finding reflects the second characteristic of aural temperature; changes are more rapid than those seen at the rectum because of the heat storage capability of the tissue surrounding the latter. It has also been speculated that aural temperature may be a better indicator of brain temperature because of the sensor's proximity to the hypothalamus and the blood vessels that perfuse it (ISO 9886, 2000).

Temperature of the auditory canal or 'aural temperature' was measured by a sensor inserted into the ear to a depth of approximately 8 mm. The sensor took the form of a bead thermistor which was affixed to a plastic ear-shaped moulding. Once inserted it was taped into position and insulated with cotton wool. Finally, a pair of ear-defenders were donned to fully insulate the internal environment (only one ear was covered to allow the participant to communicate with investigators). A period of not less than twenty minutes was then allowed to elapse prior to testing so that the aural environment could stabilise.

4.2 Skin temperature

The skin is the largest organ in the body, providing climatic protection and a first line of defence against infection. With a surface area of between 1.5 and 2 m squared (Marieb, 1998) it also facilitates heat transfer with the surrounding environment. Skin temperature varies greatly depending on location and clothing worn so measurements are usually taken at a number of sites and converted to a measure of mean skin temperature using a weighted equation. One such popular and practical equation is that proposed by Ramanathan (1964) which uses four skin sites. Measurements are taken at the chest, upper arm, thigh and shin and a weighted mean is calculated from the equation:

$$\text{Mean Skin Temperature} = 0.3t_{chest} + 0.3t_{arm} + 0.2t_{thigh} + 0.2t_{shin}$$

(Ramanathan, 1964)

4.3 Data Loggers

The temperature and humidity sensors were all connected to data loggers (Squirrel 1021, Grant Instruments, Cambs. UK). The channel configuration was as follows:

Chan 1	Core Temp
Chan 2	Chest Temp
Chan 3	Arm
Chan 4	Thigh
Chan 5	Shin
Chan 8	Air Temp
Chan 14	Relative Humidity

The loggers were located outside of the chamber because of their inability to work in high humidity environments. They were set to sample every 10 seconds and record a mean of the samples once a minute. After each session the data were downloaded onto a PC via the serial port and exported into Microsoft Excel for analysis.

4.4 Heart Rate

Heart rate was measured and recorded using digital monitors (Polar S610, Polar, UK). The data from the monitors were downloaded via infra-red link onto a PC after each session and analysed in Microsoft Excel.

4.5 Urinalysis

The review of literature highlighted the fact that hydration status is rarely, if ever, assessed prior to manual handling studies in different thermal environments. It was important to ensure that the participants were euhydrated prior to testing as the exercise protocol and the hot environment would pose a twin challenge to thermoregulation. Hydration can be assessed by a number of methods, some more invasive than others (blood analysis for instance). A simple and acceptable method is the measurement of urine osmolality which is defined as the number of osmoles (Osm) of solute particles per kilogram of pure solvent (Chadha *et al.,* 2001). The kidneys can dilute or concentrate urine depending on the body's need to excrete or retain water (Shirreffs, 2000) so urine concentration can give an indication of hydration status. In a dehydrated person for example the kidneys will reduce urine production so the solute concentration will be higher. Most adult humans are capable of concentrating urine from 50 – 1400 $mOsm.kg^{-1}$ and much debate exists as to the optimum range for euhydration. Shirreffs & Maughan (1998) have suggested that urine osmolality greater than 900 $mOsm.kg^{-1}$ can be used as an indication of hypohydration. They have also recommended that a sample of the first urination of the day provides the best estimate. Obviously this would present a problem especially when test sessions were conducted later in the day. The 900 $mOsm.kg^{-1}$ concentration was nevertheless adopted as an indicator of hypohydration and anyone presenting with a urine osmolality at this level or higher was asked to drink copiously for the 20-30 minutes prior to commencement of lifting.

Osmolality was assessed by an osmometer (Advanced Micro Osmometer Model 3300, Advanced Instruments, Norwood, MA) which utilises the principle of freezing-point osmometry. Briefly, this technique exploits the fact that when a solute is dissolved in a pure solvent the freezing point of the solvent is lowered (or depressed). The depression of the freezing point varies depending on the amount of dissolved solute. By supercooling the solvent and measuring the temperature at which it froze, an estimate can be made of the solution's concentration (Dufour, 1993).

5. Measurement Equipment – Calibration

This project necessitated the purchase of a range of thermal monitoring equipment including sensors and loggers. The equipment was calibrated at the Health & Safety Laboratory (HSL), Sheffield using their United Kingdom Accreditation Service (UKAS) accredited thermal equipment. UKAS is the agency responsible for calibrating, amongst other items, thermal equipment for industry and HSL are required to send their equipment away every 12 months for certification. Their thermal equipment is therefore one generation removed from the UKAS 'gold standard'.

The skin and aural thermistors were measured in a stirred water bath at 36 °C, 28 °C, 19 °C and 5 °C. A reading was taken from the reference mercury thermometer once a minute for 30 minutes at each temperature and compared to readings from the purchased equipment. The air thermistors and humidity sensors were measured in an oven at 40 °C, 80% RH; 22 °C, 45% RH and 0 °C. Readings were taken from the reference equipment (Rotronic A1 Hygrometer, Rotronics Instruments UK Ltd., West Sussex, UK and Hanna Instruments H193510 microcomputer thermometer) once a minute for 20 minutes and compared to the purchased equipment. The results were analysed using Bland

Altman 95% limits of agreement (Bland & Altman, 1986) and are reproduced in full in appendix F. A summary of these results is presented below in table 2:

Sensor Type	Bias	±95%	Range	Test Environment
Air Temp	0.71 °C	0.33	+0.38 to +1.04 °C	40 °C, 80% RH
Skin Temp	-0.24 °C	0.08	-0.32 to -0.16 °C	19 °C
Relative Humidity	-1.16%	0.87	-2.03 to -0.29%	0 °C

Table 2. Worst performing sensor (by type) compared to reference equipment.

6. Procedures for Obtaining a Maximum Acceptable Weight of Lift

During the initial stages of the project it was envisaged that an automatic lifting platform similar to that used by Snook & Ciriello (1974) and other similar studies would be built but its design and construction were delayed by health and safety considerations. In the middle of 2003 the automatic platform idea was ultimately discarded in favour of a static shelf unit. This decision meant that another person would have to return the box to its starting position after each lift.

The lifting protocol used throughout this thesis was essentially the same in each of the studies. It has been used extensively in published studies since Snook & Irvine (1967) with very minor modifications. What follows is a detailed description of the lifting task as it was performed during the first two studies herein. There were some minor changes made for the face-cooling study and these are explained in the relevant chapter.

6.1 Shelving Unit

Two industrial shelving units were obtained for the study and assembled in the environmental chamber at the Centre for Sport and Exercise Science in

Sheffield Hallam University. The requirements were that it should allow for varying shelf heights and be robust enough to bear the anticipated loads. With the inclusion of a set of custom-made aluminium spacers it was possible to set shelf heights with an accuracy of ±2 mm compared to knuckle height. Each shelf in the unit was rated by the manufacturers to bear a weight limit of 135 kg, well in excess of the loads anticipated.

6.2 Box design

The box chosen was of sturdy construction and made of grey plastic. It measured 600 x 390 x 410 mm and had handle holes on each side 20mm below the top. The depth of the box allowed for a dead space at the bottom which was used to secrete bags of ball-bearings. The space was created by using polystyrene packing blocks and then a thin wooden board was used to hide the contents (see figure 3).

a b

Figure 3. (a) False bottom containing weight bags. (b) The box at the end of a session with bags of weight loaded by the participant.

6.3 Lifting protocol

The lifting task chosen for each of the studies in this thesis was the floor to knuckle height lift. This task is widely performed in industry and tables of acceptable weights have been published (Snook & Ciriello, 1991) allowing easy comparison with the collected data. Knuckle height was measured from the floor to the second metacarpo-phalangeal joint on a standing participant with arms relaxed at the sides. The shelf height was then set so that the top of the shelf was level with this height (see figure 4a).

The procedure for determining the maximum acceptable weight of lift (MAWL) was as follows. A pre-determined amount of weight was secreted in the false bottom of the box so that the starting weight of the box was always different. The wooden board ensured that the participant was blind to the starting weight and that they could not select a box-weight by merely counting weight-bags in and out. The box was then placed at the starting position in front of the shelf unit. The starting position was indicated by marker tape on the floor ensuring that the horizontal distance of the lift was always approximately 0.7 m.

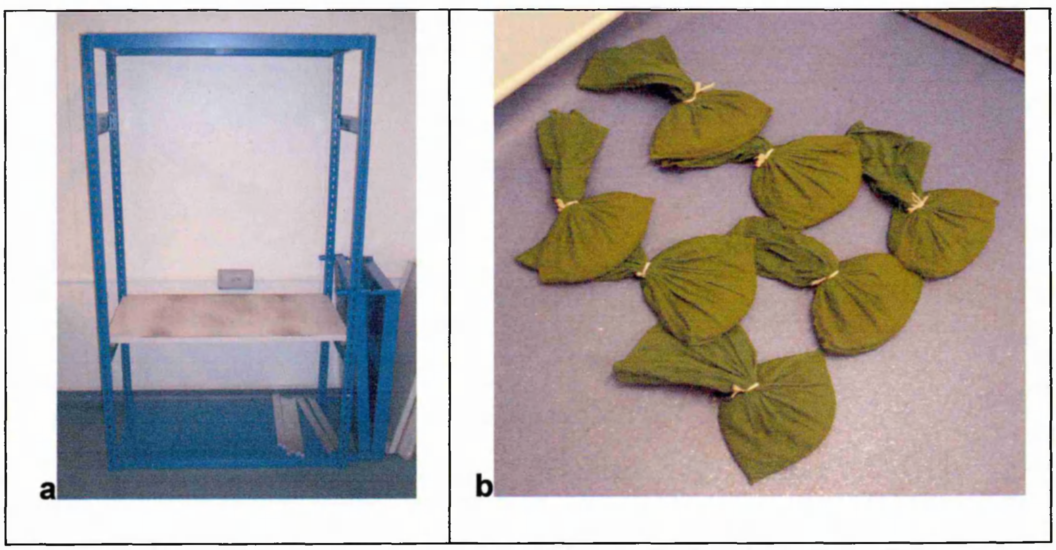

Figure 4. (a) Lifting frame with adjustable shelf. (b) Bags of ball-bearings.

The investigator's instructions to the participant were then read out in the form of a standardised script (see appendix E). After receiving his instructions the participant took up his starting position behind the box and commenced lifting in time with an audible tone from a cassette tape. The first, non-experimental, session was used to habituate the participant to the protocol and was called the MAWL stabilisation session. The participant lifted the box onto the shelf at 4.3 lifts.min^{-1} for 20 minutes in a thermoneutral (21° C, 45% RH) environment. An assistant returned the box to its starting position on the completion of each lift. During the 20-minute session the participant adjusted the box weight by either adding or removing bags of ball-bearings (figure 4b), the object being to arrive at a box weight that they thought they would be able to lift comfortably throughout an eight-hour period at work. The lift-cycle is depicted in figure 5.

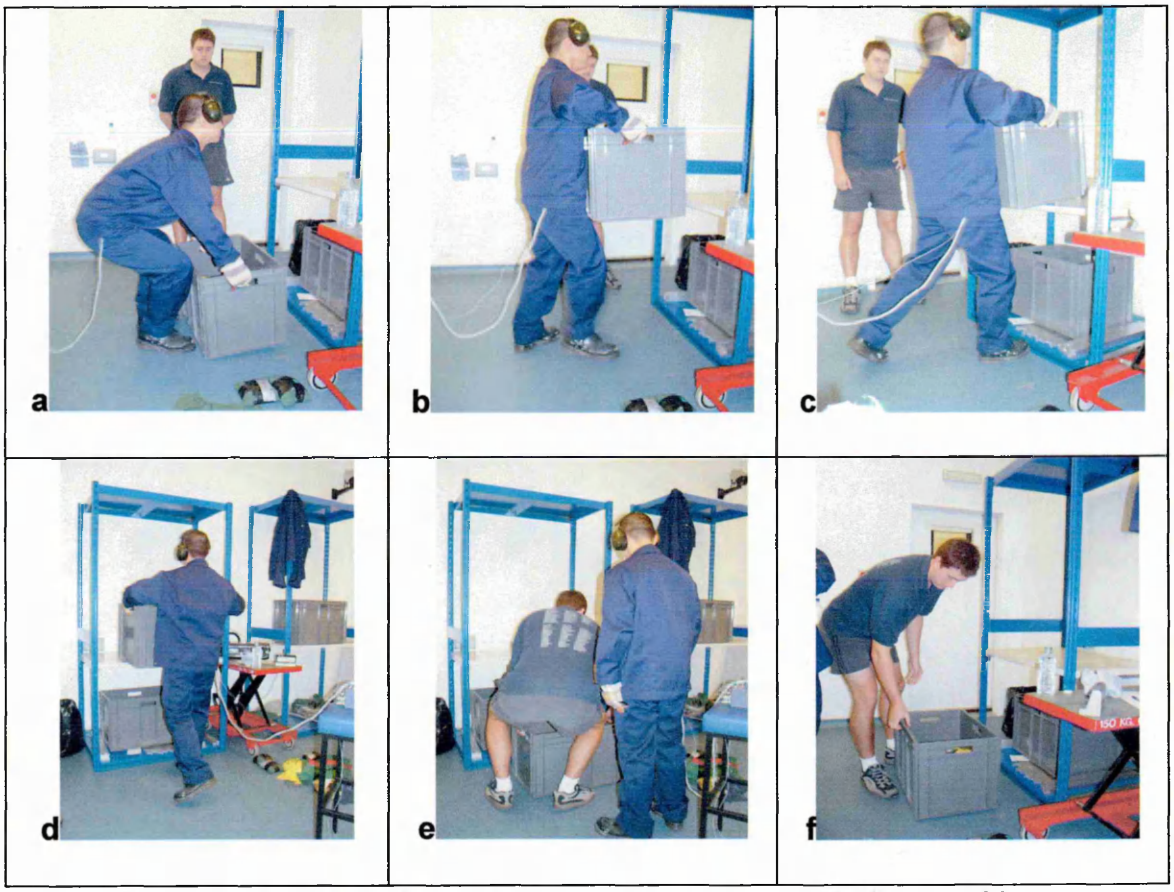

Figure 5. (a-d) Lift phase. (e-f) Box is returned to starting position.

After 20 minutes the participant was instructed to stop lifting and the box weight was recorded. The participant rested for 10 minutes outside the chamber while the box was emptied and a new starting weight was selected. A second 20-

minute session was then conducted and the new final box weight recorded. If the two values were within 15% of each other then the participant was deemed to have consistently selected an acceptable weight. If the two values differed by more than 15% then the participant would have been asked to return on another occasion to repeat the test (in practice this didn't occur). The 15% limit was used previously as a cut-off point for acceptability by Snook & Ciriello (1991).

After MAWL stabilisation the main experimental sessions were conducted on 15 consecutive weekdays. During these sessions the participant lifted for one period of 35 minutes. The first 20 minutes were again used as an adjustment period for the MAWL after which they continued to lift for another 15 minutes at the selected box weight. Three different lifting frequencies were employed: 1 $lift.min^{-1}$, 4.3 $lifts.min^{-1}$ and 6.7 $lifts.min^{-1}$. There were also five test environments making 15 unique test conditions.

7. Pilot Study

A pilot study was conducted early in the project to investigate whether or not the MAWL stabilised after two 20-minute bouts. This was important as the ability to use the MAWL protocol was expected to be unfamiliar to the participants and they were expected to experience a learning effect. This may have resulted in increased acceptable loads over time and it was essential to eliminate this effect prior to introducing the environmental variables. The literature has shown that two or three trials are generally required to 'stabilise' the MAWL and eliminate the learning effect (Snook & Ciriello, 1991).

Five male participants (age, 25.5 ± 7.1yrs) gave written informed consent and conducted two 20-minute trials separated by 10 minutes rest in a thermoneutral (21 °C, 45% RH) environment. They lifted a box from floor to knuckle height at a frequency of 3 lifts.min^{-1}. In the first trial the box was started at a low weight and in the second trial the box was started at a heavy weight. The results are summarized in the table 3 below.

Participant No.	*Box Weight Trial 1 (kg)*	*Box Weight Trial 2 (kg)*	*% Difference*
1	17	18	5.9↑
2	17.3	17.3	0
3	16.3	18.3	12.3↑
4	21.3	20.3	4.7↓
5	16.3	17.3	6.1↑

Table 3. Summary of Results from Pilot Study.

It can be seen that the percentage difference between trials was within the 15% recommended by Snook & Ciriello (1991) in all cases. This provided evidence that the individuals tested could reliably reproduce MAWL after two trials thus determining the MAWL stabilization protocol used in the main studies.

8. Subjective Measures - Ratings of Perceived Exertion

It may not always be possible to take objective measures of physiological strain, especially in a busy or confined workspace. For this reason it was important to collect data on the participants' subjective feelings of exertion during the lifting task. As noted earlier, Borg (1970) has produced measures of perceived exertion the most popular probably being the 6-20 Rating of Perceived Exertion (RPE) scale (see figure 6). The category scale is linear and the numbers roughly equate to heart rate when multiplied by ten (e.g. 13 ≈ 130 beats.min^{-1}) although Borg (1982) counselled against the rigid interpretation of this relationship. During exercise the participant is asked to rate their current perceived exertion level by quoting a number from the left-hand side of the scale. The descriptions on the right are designed to help with rating selection. The participant must be given a thorough orientation prior to use of the scale and it is important that the rating given reflects an overall feeling of exertion, integrating all of the "signals, perceptions and experiences" that are felt (Borg, 1982).

6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

Figure 6. The Borg 6-20 Rating of Perceived Exertion Scale (Borg, 1970).

9. Statistical Analysis

The collected data were analysed using the Statistical Package for the Social Sciences (SPSS for Windows version 13: SPSS UK Ltd, Woking, UK) and Microsoft Excel 2003.

9.1 Hot & Cold Studies

The design for the hot and cold studies (detailed in chapters 3 and 4 respectively) was essentially the same; only the air temperatures and relative humidities varied. There were two independent variables, environment and lift frequency which had five and three levels respectively. This yielded 15 unique test conditions and the participants completed all of them in a fully within-subjects design. There were five dependent variables: heart rate, core temperature, mean skin temperature, rating of perceived exertion and maximum acceptable weight of lift. Finger surface temperature was also measured in the cold study. Heart rate and core temperature were a mean of the last two minutes of measurements during the 35-minute lifting protocol. Rating of perceived exertion was a mean of the last three values reported by the participants. Maximum acceptable weight of lift was the weight of the box at the end of the session.

The null hypotheses that stated that there were no significant differences in the dependent variables across treatments were each tested using a two-factor Analysis of Variance (ANOVA) with repeated measures on both factors. An ANOVA is a parametric test used to compare three or more means. The requirements for this test are that data are from a random subset of the population; they are independent (i.e. they are not influenced by any other subjects), normally distributed (ratio or interval scale) and spherical (i.e. exhibit sphericity). Sphericity is defined as the equality of variances of the differences between treatment levels (Field, 2000). Where this condition is violated, SPSS provides corrections (Greenhouse-Geisser, Huynh-Feldt and lower-bound) where a value (the ε statistic) is used to adjust the degrees of freedom and, consequently, the reported probability. The Greenhouse-Geisser correction was used in these analyses wherever the assumption of sphericity was violated.

The ANOVA is sometimes referred to as an 'omnibus F-test' because it tests for differences across all treatments and produces a statistic (F) with an associated probability. The test described above produces three F ratios, one for each of the two main effects (environment and frequency) and one for the interaction between the two. There were five dependent variables in each study so five separate ANOVA tests were planned. Alpha (α) was originally set at 5% (0.05) but adjusted to take account of the five planned tests (0.05 / 5 = 0.01). This commonly used technique, known as the Bonferroni adjustment (Huck, 2000), makes the null hypotheses more difficult to reject (due to the lower value of α) thus reducing the chances of committing a Type I error.

A significant F ratio only indicates that there is a significant difference somewhere, not where the difference or differences may be. Post-hoc tests, usually in the form of pairwise comparisons, are then conducted to pinpoint the location of the differences. For a significant frequency effect for example where there are three levels, three pairwise comparisons would be performed (1 vs. 2, 1 vs. 3 and 2 vs. 3). SPSS does not allow post hoc tests to be performed after a within-subjects ANOVA. This limitation can be worked around by ticking the 'compare main effects' box in the options menu and selecting a comparison method such as Bonferroni or Least Significant Difference. This work-around is generally not recommended however because the tests may lack the power to find any significant differences in the case of the former or massively inflate the type I error rate as in the latter (Clark, undated). Stevens (1992) recommends using Tukey's tests, which can be computed by hand, providing that the sphericity assumption has been met.

If there is no significant interaction but there are either one or two significant main effects then it is permissible to perform post-hoc tests, comparing levels of each effect to identify the location of the difference. This is a simple two-step procedure which is commonly used in research. First perform an ANOVA: if there is no significant F then stop; if there is a significant F, perform post-hoc tests.

If there is a significant interaction effect then interpretation of the main effects can lead to the wrong conclusions. Investigating the interaction can be a complex procedure and authors differ in their opinions on the best approach to this. Where most authors agree is on the need to produce a graph of the cell means so that the nature of the interaction can be identified (Huck, 2000; Keppel, 1973; Kirk, 1982; Oshima & McCarty, 2000). The interaction can then be investigated statistically by performing tests of simple main effects (Keppel, 1973) where each factor is examined at a fixed level of the other factor. So in the research design for this study, the frequency factor would be examined against each of the five levels of the environment factor. Conversely, environment would be examined against each of the three levels of frequency. The overall error rate from the three families (0.01 for each of A, B and AB) would be corrected to account for the number of tests conducted (0.03/8 = 0.0037) as suggested by Kirk (1982). Tests of simple main effects can help the researcher to narrow down the area of search for differences and to specify suitable pairs of cell means for post-hoc tests. So it can be seen that the procedure for investigating an interaction comprises four steps. Perform an ANOVA; after a significant interaction, plot the cell means; perform tests of simple main effects and finally perform pairwise comparisons on the pairs of cell means of interest.

It is now expected that researchers will provide more than just statistically significant results to support their findings. Schutz & Gessaroli (1993) noted that, at the time of their review that 'the majestical and omnipotent significance level continues to be worshipped' but recently there has been a move away from simply testing hypotheses and all of the limitations inherent in such an approach (the binary outcome, reject or fail to reject for example). Researchers are now encouraged to provide estimates of effect size to support their findings although the widespread adoption of this practice has been hampered by the lack of available formulae, especially for more complex ANOVA designs. The monograph by Cortina & Nouri (2000) for example provides calculations for most of the more basic designs but not for factorial, fully-within subjects designs. Olejnik & Algina (2003) have proposed an effect size statistic called generalized eta squared (Gen η^2) for many of the commonly used ANOVA designs. Gen η^2 has been extended for use in repeated measures designs by Bakeman (2005) and it is based on the formulae therein that the calculations of effect size in this thesis have been based. The formulae and calculations are detailed in appendix D. Bakeman (2005) recommends using the following guidelines to describe gen η^2 effect sizes: 0.02=small, 0.13=medium and 0.26=large.

For paired t-test designs where only two means are compared the effect size formula is thus (for equal n):

$$d = t_r [2(1 - r)n]^{0.5}$$

Where: t_r = t statistic from paired t-test
r = Pearson correlation coefficient between the two means

(Cortina & Nouri, 2000)

Cohen (1988) proposes that an effect size (d) of 0.8 is interpreted as large, 0.5 is moderate and 0.2 is small.

9.2 Face-Cooling Study

The statistical analyses in the face-cooling study differ only slightly from the first two studies. These small variations are detailed in the methods section of chapter 6 since no new concepts are introduced.

9.3 Non-Parametric Tests

The procedures previously described are known as parametric tests and they require that the data to be analysed fulfil certain criteria. Data should be on a ratio or interval scale, random, independent, normally distributed and exhibit homogeneity of variance (or sphericity in the case of repeated measures). As previously stated, violations of sphericity can be overcome by using a correction. Good research design should ensure that the data fulfil the assumptions of randomness and independence and the scale of measurement is usually decided *a priori*. Therefore the most common cause of violations of test assumptions are cases of non-normally distributed data. In each of the studies in this thesis normality was checked in SPSS using the Kolmogorov-Smirnov Goodness of Fit test. This test compares the collected data against an internal data set that is known to be normally distributed to determine whether the two differ significantly. A non-significant outcome indicates that the data are normal and that it is safe to proceed with parametric analysis. Parametric tests are known to be extremely robust to departures from normality and Keppel (1973) has described the relatively small inflation of α that can occur in such cases. In extreme cases however the data may be transformed using one of a number of techniques. Taking the reciprocal and $1/\surd$ are common methods for transforming data sets for example. When these transformations are unsuccessful the researcher must decide whether to proceed with parametric analysis or choose a nonparametric equivalent.

There are apparently no nonparametric equivalents to the two-way, fully within-subjects ANOVA. A limited solution is to analyse each main effect using a Friedman test for multiple repeated samples. For each main effect the data are collapsed for further analysis. The environmental data were collapsed by taking the grand mean for each environment (each was conducted at three different lift frequencies) and vice-versa for the frequency data. See table 4 for an illustration of this procedure. The environment data were then analysed in a one-way Friedman test with five repeated measures. The frequency data were similarly analysed but with three repeated measures.

15 test conditions	***Collapsed Means***	
Thermoneutral 1 lift.min^{-1}	Thermoneutral	Friedman analysis performed on these 5 means
Thermoneutral 4.3 lifts.min^{-1}		
Thermoneutral 6.7 lifts.min^{-1}		
Warm-Dry 1 lift.min^{-1}	Warm-Dry	
Warm-Dry 4.3 lifts.min^{-1}		
Warm-Dry 6.7 lifts.min^{-1}		
Warm-Humid 1 lift.min^{-1}	Warm-Humid	
Warm-Humid 4.3 lifts.min^{-1}		
Warm-Humid 6.7 lifts.min^{-1}		
Hot-Dry 1 lift.min^{-1}	Hot-Dry	
Hot-Dry 4.3 lifts.min^{-1}		
Hot-Dry 6.7 lifts.min^{-1}		
Hot-Humid 1 lift.min^{-1}	Hot-Humid	
Hot-Humid 4.3 lifts.min^{-1}		
Hot-Humid 6.7 lifts.min^{-1}		

Table 4. Example of Collapsing Data for the Environment Effect.

Unfortunately, nonparametric tests are generally regarded as having less power than their parametric equivalents but in some situations they may provide the only method for conducting analysis. It is also the case that the Friedman test only permits analysis of the main effects and not the interaction.

The nonparametric equivalent of the Tukey's test is the Wilcoxon Signed-Ranks Test for Matched Pairs (Huck,2000). This would be used as a follow-up to a significant result of a Friedman test.

10. Ethics

Ethical approval was applied for and granted by the Research Ethics Committee, Faculty of Health & Wellbeing, Sheffield Hallam University for all of the studies reported herein. Participants were treated in accordance with the Helsinki (World Medical Association, 1964) document regarding the use of human subjects in scientific research and the British Association of Sports and Exercise Sciences (BASES, 2000) code of conduct. They were given verbal and written descriptions of the procedures involved (see appendix A for the written description) and completed a medical questionnaire (see appendix A) before giving written informed consent to continue. Participants with any previous history of musculoskeletal disorders were excluded from the study, as were participants with illness, disorders or diseases known to affect the thermoregulatory system (e.g. thyroid conditions).

11. Range of Participants

All of the participants in the three studies included in this thesis were male. Females were specifically excluded because of the possible confounding influence of the menstrual cycle on core temperature which is reported to rise by around 0.5 °C during the luteal phase (Coyne *et al.*, 2000). In accordance with ethical requirements only males between the ages of 18 and 40 years were recruited. It was initially envisaged that our research collaborators would provide participants with industrial experience but this proved to be problematic so volunteers were recruited from both within the university and the local populace.

The research design required participants to attend at the same time each day for more than 20 working days; a schedule which naturally precluded the undergraduate student population. As such, the participants represented a broad range of ages, backgrounds and abilities which gave the studies better ecological validity. A number of the participants were in their thirties for instance (the mean age in the third study was 28.4 years) which conformed to what was observed during the site visits. Similarly, activity levels as self-reported in the pre-screening health questionnaires varied from sedentary to very active perhaps mirroring what one would expect to find in the general working population. The racial composition of the participants was predominantly white, northern European. Of these the majority were British nationals with the remainder consisting of eastern Europeans. Three Indians (all international students) and one native of southern Europe also participated.

12. Site Visits

Several visits to industrial sites were undertaken in 2003 prior to the laboratory-based phase of the project. The purposes of the visits were to take environmental measurements in hot and cold workplaces and to assess the nature of the manual handling tasks being performed.

At each location measures of air temperature, radiant temperature and humidity were recorded for periods of up to four hours. All of the locations were indoors so air velocity was assumed to be negligible. Where manual handling was taking place the nature of the task, weight of load, frequency, height and duration of lift were recorded.

Workplaces where the environment was warm or hot included a glassworks, a steel fabrication factory and three bakeries. Amongst the cold environments visited there were sections of bakeries (creameries, sandwich filling production) and a supermarket distribution warehouse. An example of the type of data collected during the visits is provided in appendix G.

4 The Effects of Warm and Hot Environments on Performance of an Intermittent Lifting Task

1. Summary

This chapter presents an original study into the effects of warm and hot environments on the performance of a floor to knuckle-height lifting task. It also examines the participants' responses to two dissimilar environments with an equivalent WBGT.

2. Introduction

Previous research in this area has established that work in warm and hot environments results in increased physiological strain and lesser loads lifted when compared to the same work in a moderate environment. The number of studies is small however, and their findings are open to criticism due to limitations in design and method. Kamon & Belding (1971) for example used only three participants and reported only descriptive results. None of the studies reviewed examined the effects of high humidity and none attempted to ascertain hydration status prior to testing. Acclimation status varied: Snook & Ciriello (1974) did not acclimate their participants, Hafez & Ayoub (1991) and Kamon & Belding (1971) did. All adopted different manual handling protocols, one with fixed weights of load, the others with psychophysically adjusted loads. All of these factors contribute to the difficulty in accurately assessing the effects of warm and hot environments on lifting performance and physiological strain.

The purpose of this experiment was to assess physiological strain and the amount of weight lifted when participants were exposed to a range of warm and hot environments and required to lift at different frequencies. The five environments chosen were a reflection of what had been investigated previously and what was measured in the field during the industrial site visits. This ensured that the study had good ecological validity. A 'thermoneutral' environment represented a baseline, providing an environment where a standing, normally-clothed man would experience no net heat gain nor net heat loss to his surroundings. The other four environments consisted of a warm 'dry' (low humidity), a warm 'humid' (high humidity), a hot-dry and a hot-humid condition. So that the assumption that different environments with equivalent WBGT values elicit the same physiological strain could be tested, the warm humid and hot dry conditions were designed to have the same WBGT (~27° C).

Three lifting frequencies were used which were again a reflection of those used previously and what was encountered on the site visits. The slowest frequency of 1 $lift.min^{-1}$ was analogous to a worker lifting boxes of pre-mixed seasonings in a food factory. These boxes were automatically filled with measured amounts of ingredients by a machine and the time taken for this to be completed was around one minute. The other two frequencies of 4.3 $lifts.min^{-1}$ (a lift every 14 seconds) and 6.7 $lifts.min^{-1}$ (every nine seconds) represented tasks such as pallet loading and box stacking. These three frequencies have been extensively studied, notably by Snook & Ciriello (1991) and are included in tables of acceptable loads based on percentiles of the population. These data provide a normative set of values with which to compare the results of this study.

3. Methods

3.1 Participants

Twelve male participants between the ages of 18 and 40 years were recruited to take part in the study. Anyone with a previous history of musculoskeletal disorders were excluded from the study, as were participants with illness, disorders or diseases known to affect the thermoregulatory system (e.g. thyroid conditions). All participants were white, northern Europeans except for two Indians who had been resident in the UK for at least two years. Participant details are presented in table 5 below.

n	*Age (years)*	*Stature (m)*	*Mass (kg)*	*Knuckle Height (m)*	*Body Mass Index*	*Body Surface Area (m^2)*
12	25.2 ± 5.7	1.7 ± 0.1	74.9 ± 11.9	0.8 ± 0.1	25 ± 3.9	1.9 ± 0.2

Table 5. Participant Details (mean ± 1 standard deviation). Body Surface Area from Mosteller (1987).

3.2 Procedures

The participants reported to the environmental chamber at the Centre for Sport and Exercise Science (CSES), Sheffield Hallam University. Stature (stadiometer, Holtain, Crymych, UK), mass (Balance Scales, Avery, Birmingham, UK) and knuckle height (distance from floor of second metacarpo-phalangeal joint when standing relaxed) were measured.

The participants were asked to provide a urine sample immediately upon arrival so that hydration status could be assessed prior to the start of the experiment. Urine osmolality was assessed by an osmometer (Advanced Micro Osmometer Model 3300, Advanced Instruments, Norwood, MA). Skin thermistors (Grant Instruments, Cambs. UK) were fixed to the body with Micropore tape (3M, USA) according to the Ramanathan (1964) four point measurement site for estimation of mean weighted skin temperature; at the chest (centre of pectoral region, midpoint between nipple and clavicle), arm (posterior aspect of the upper-arm, at the centre of the belly of the triceps), thigh (anterior aspect, over rectus femoris at midpoint of femur) and shin (anterior aspect of lower-leg, at midpoint of tibia). An aural bead thermistor (Grant Instruments, Cambs. UK) was fitted into the ear, fixed into position with cotton wool and tape and insulated with a pair of industrial ear defenders (figure 7b). The thermistor was modified by Grant Instruments by removing most of the plastic moulding that encapsulated the bead (see figure 7a). This improved the response of the bead thermistor to the surrounding environment. The thermistors were all supplied with 5 m leads so a wiring harness using a polythene spiral wrap was constructed to facilitate cable management and reduce any possible trip hazard (see figure 8). All thermistors were connected to a data logger (Squirrel 1021, Grant Instruments, Cambs. UK) so that measurements could be recorded throughout testing. The participant also put on a heart rate monitor (Polar S610, Polar, UK) prior to putting on the clothing ensemble.

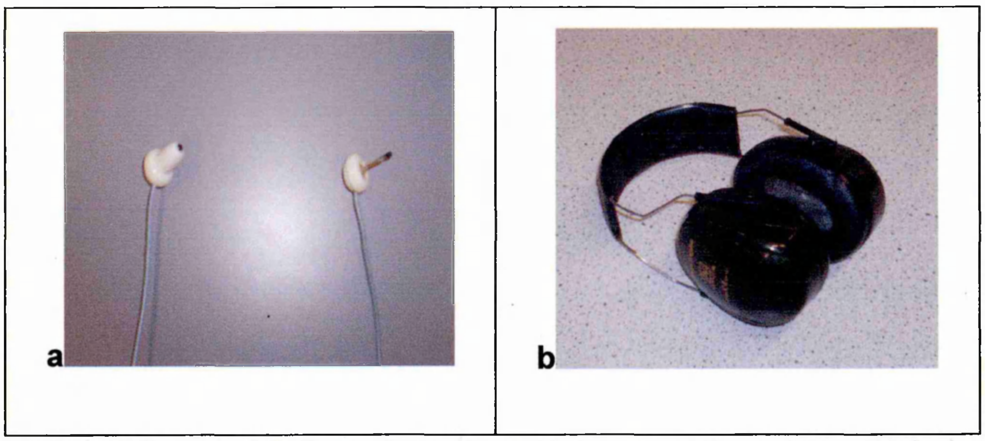

Figure 7. (a) Standard (left) and modified (right) aural thermistor. (b) Industrial ear defenders.

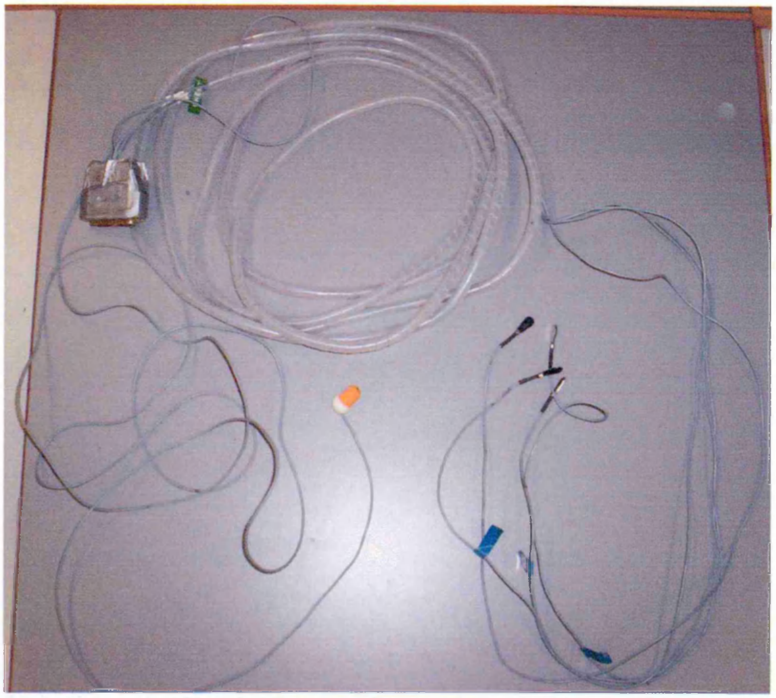

Figure 8. Wiring harness for skin and aural thermistors. Note the polythene spiral wrap providing cable management.

Each participant then dressed in a standard clothing ensemble (table 6). The ensemble was chosen to replicate as closely as possible the clothing observed to be worn during the site visits. No gloves were worn. The estimated Clo value was designed to ensure that the participant was comfortable whilst standing in the thermally neutral environment.

Clothing Item	***Clo***
Underwear (shorts, socks supplied by participant)	0.05
Working trousers (cotton/polyester) 9oz	0.25
Working jacket (cotton/polyester) 9oz	0.25
Safety boots	0.1
Estimated Clo of ensemble	**0.65**

Table 6. Standardised clothing ensemble and estimated Clo values.

3.2.1 Acclimation

The first week was used for acclimation and consisted of five one-hour sessions. Published literature has shown that this amount of exposure can provide in excess of 75% of an individual's total adaptation to a particular environment (Parsons, 2003) with the final ~25% adaptation occurring over a further five days. The environmental chamber was set at 38°C and 70% relative humidity (34 °C WBGT). This replicated the most hostile environment used in the experiment.

Each acclimation session was divided into rest, work and a final rest period and the participants were required to remain in the environmental chamber throughout the sixty minutes. Two twenty-minute rest periods were interspersed with a twenty-minute lifting task. Drinking water was available throughout and participants were encouraged to drink regularly.

3.2.2 MAWL Stabilisation

The participants were introduced to the psychophysical method of lift assessment in one session prior to commencement of testing proper. The purpose of this session was to habituate the participant to the proposed lifting protocol and to ensure that they were able to consistently select an acceptable box-weight (i.e. to demonstrate the repeatability of the protocol). It also provided an opportunity to practice using the RPE scale especially for those participants for whom the concept was unfamiliar. The protocol is described in detail in chapter 3.

3.2.3 Main Experimental Sessions

The main portion of the study commenced once acclimation and MAWL stabilization had been achieved. This comprised 15 test sessions made up of a combination of the five environments and three lifting frequencies. A within-subjects repeated measures design was used. Each participant took part in all of the fifteen test conditions and exposure to each condition was counter-balanced using an unbalanced Latin Square. Table 7 describes the environmental conditions chosen together with the actual mean values (and standard deviations) achieved across the entire experiment. Table 8 describes the frequency of lift undertaken in each environment.

Environment	***Air temperature (°C)***	***Relative humidity (%)***	***WBGT (°C)***
Thermoneutral	21 (21.9 ± 0.9)	45 (47.3 ± 5.5)	17
Warm dry	30 (29.9 ± 0.5)	25 (24.8 ± 1.2)	22
Warm humid	30 (30.5 ± 0.4)	65 (68.4 ± 2.1)	27
Hot dry	39 (38.7 ± 0.6)	25 (21.9 ± 1.1)	27
Hot humid	38 (37.4 ± 0.3)	70 (70.6 ± 2.5)	34

Table 7. Environmental Specification (actual mean values ± 1 standard deviation achieved).

Frequency	***Lifts.min^{-1}***
1 lift every 9 seconds	6.7
1 lift every 14 seconds	4.3
1 lift every 60 seconds	1

Table 8. Lifting frequencies.

The protocol was as detailed in Chapter 3 with the participants lifting for 20 minutes whilst adjusting the box weight and then for a further 15 minutes at the box weight selected. RPE was recorded every five minutes throughout the session and the participants were encouraged to convey this information discreetly so as not to influence other lifters present (two lifters were usually tested simultaneously). Heart rate readings were also taken manually every five minutes as a precaution against any failure of the recording equipment. To ensure the health and safety of the participants a second experimenter was always present in the chamber. Drinking water was available at all times and everyone was encouraged to drink *ad libitum*.

After 35 minutes the test was stopped and the participants were removed to the intermediate room where the instrumentation was removed. The final box weight was recorded as the maximum acceptable weight of lift (MAWL) for the session. Heart rate and temperature data from the monitors and data loggers were downloaded to a PC for analysis.

3.2.4 Withdrawal Criteria

The withdrawal criterion was set at an aural temperature of 38.5 °C at the specific request of the Health & Safety Laboratory. This withdrawal limit is also recommended in ISO 9886 (Annex C) as long as temperature is monitored continuously which was the case. Heart rate was monitored simultaneously and consideration given to removing the subject if this exceeded 85% of their age-predicted maximum (based on the other objective and subjective measurements).

3.3 Hypotheses

The null hypotheses to be tested were:

1. ($H_0$1) Frequency of lift does not significantly affect the dependent variables.
2. ($H_0$2) There is no difference in physiological strain when lifting in a hot environment compared to lifting in a thermoneutral environment.
3. ($H_0$3) There is no difference in MAWL when lifting in a hot environment compared to lifting in a thermoneutral environment.
4. ($H_0$4) There is no difference in physiological strain when lifting in a high humidity environment compared to lifting in a similar air temperature with low humidity.

5. (H_05) There is no difference in MAWL when lifting in a high humidity environment compared to lifting in a similar air temperature with low humidity.
6. (H_06) Lifting in two dissimilar environments (warm-humid and hot-dry) with an equivalent WBGT imposes the same physiological strain.

3.4 Statistical Analysis

The five dependent variables (heart rate, core temperature, mean skin temperature, ratings of perceived exertion and maximum acceptable weight of lift) were each planned to be individually analysed for significant differences using a two-factor ANOVA with repeated measures on both factors. α was initially set at 0.05 but subsequently adjusted using a Bonferroni correction to 0.01 (0.05/5) to account for the five ANOVA tests (Huck, 2000). Significant F ratios were followed-up by Tukey's post-hoc tests and generalized η^2 effect sizes were computed. The procedures are described in detail in chapter 3.

4. Results

4.1 Hydration Status

The mean urine osmolality for each participant prior to the test sessions is presented in figure 9.

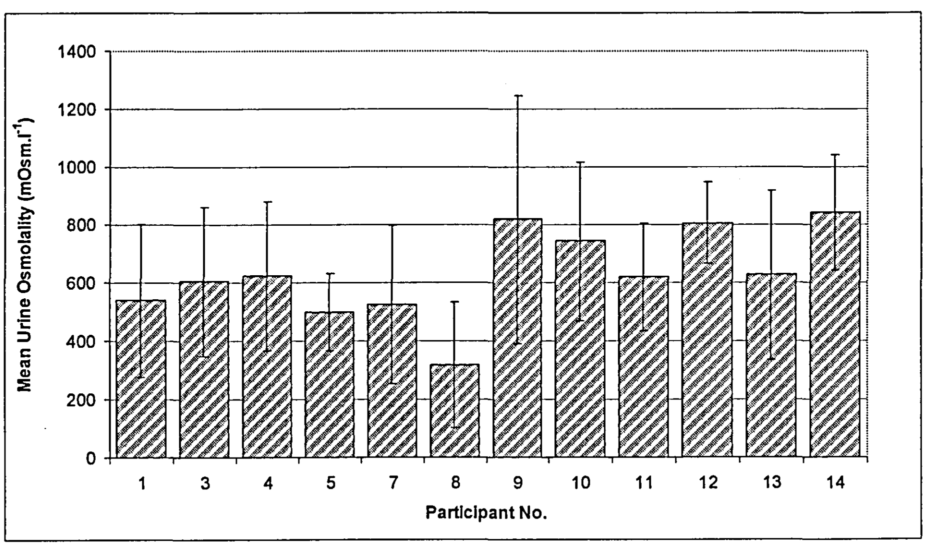

Figure 9. Mean urine osmolality (pre-session) for each participant. Columns represent means, error bars represent ± 1 standard deviation.

4.2 Heart Rate

The mean end heart rates (mean of the final two minutes) for each lifting frequency by environment are presented in figure 10 below.

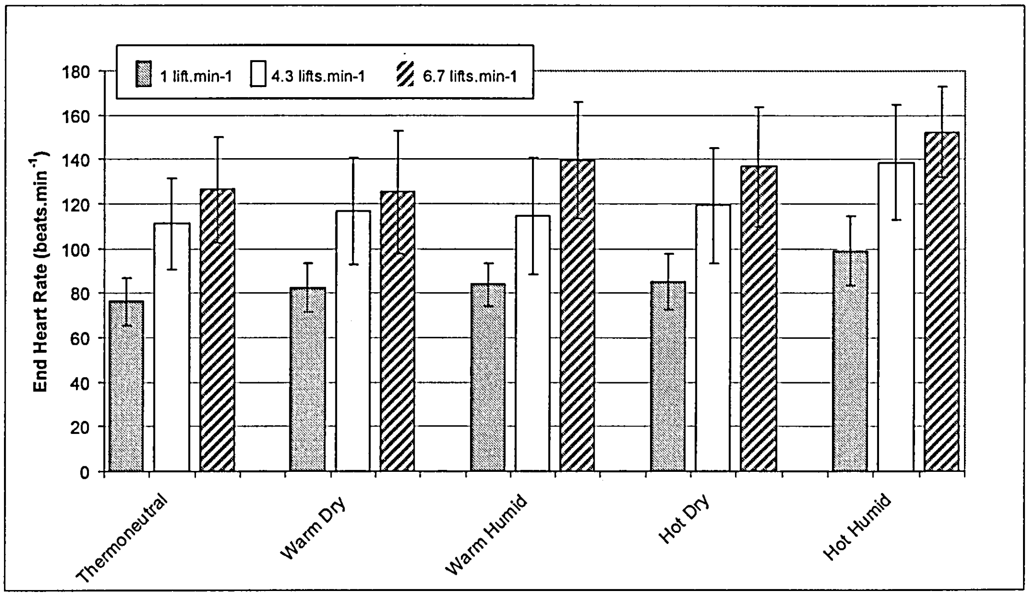

Figure 10. Mean end heart rate for each test condition (columns represent means, error bars represent ± 1 standard deviation).

Heart Rate – ANOVA

One data set out of the fifteen conditions was not normally distributed but this was considered to have a minimal effect on the subsequent analysis. Mauchly's test was non-significant for the main effects and the interaction effect so sphericity was assumed. There were significant main effects for environment [$F(4,44) = 47.5$] and frequency [$F(2,22) = 94.5$] (both $P<0.001$). The interaction effect was not significant.

Heart Rate – Post Hoc Tests

The significant main effects were investigated further using Tukey's HSD post-hoc tests. For the environment effect, the mean heart rate in the hot-humid condition was significantly higher ($P<0.01$) compared to all other conditions. No other conditions differed significantly. For frequency, heart rate was significantly higher ($P<0.01$) in both the 4.3 lifts.min^{-1} and 6.7 lifts.min^{-1} conditions when compared to 1 lift.min^{-1}. There was no significant difference between 4.3 lifts.min^{-1} and 6.7 lifts.min^{-1}.

Heart Rate – Effect Sizes

Generalised η^2 effect sizes were calculated for both of the main effects and the interaction and are presented in table 9.

Source	***Gen η^2***	***Effect***
Environment	0.22	Medium
Frequency	0.63	Large
Interaction	0.02	Small

Table 9. Generalised η^2 effect sizes for Heart Rate.

4.3 Core Temperature

The mean end core temperatures (mean of the final two minutes) for each lifting frequency by environment are presented in figure 11 below.

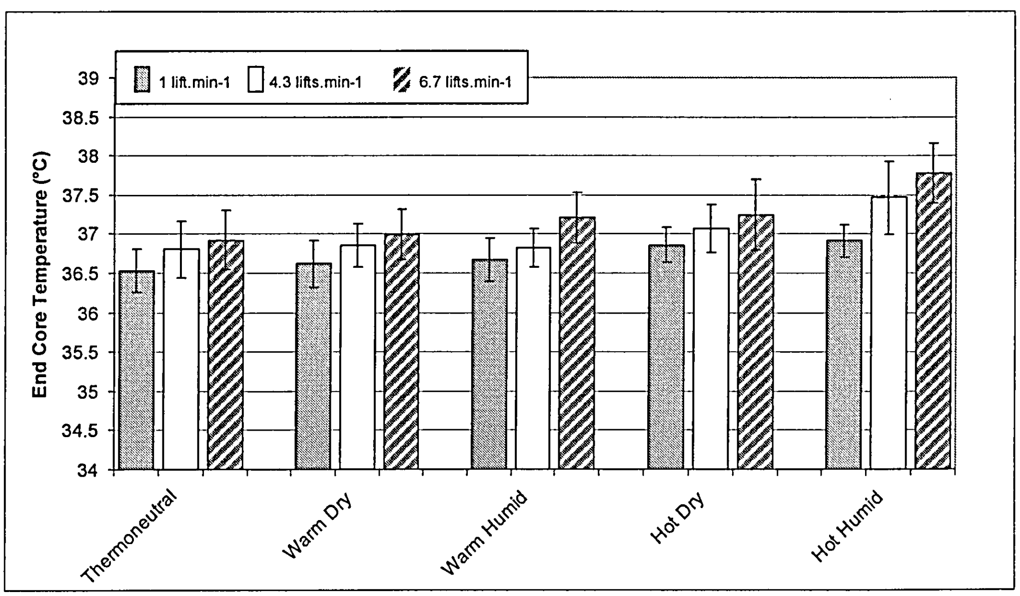

Figure 11. Mean end core temperature for each test condition (columns represent means, error bars represent ± 1 standard deviation).

Core Temperature – ANOVA

All of the data for core temperature were normally distributed. Mauchly's test was significant for the frequency effect so a Greenhouse-Geisser correction was applied. Sphericity was assumed for the environment and interaction effects. There was a significant interaction effect [$F(8,88) = 3.7$, $P=0.001$] and significant main effects for both environment [$F(4,44) = 72.1$] and frequency [$F(1.35,14.8) = 80.2$] both ($P<0.001$).

The significant interaction was investigated further using the steps detailed in chapter 3. Graphs of cell means depicting the interaction are displayed in figure 12 a & b.

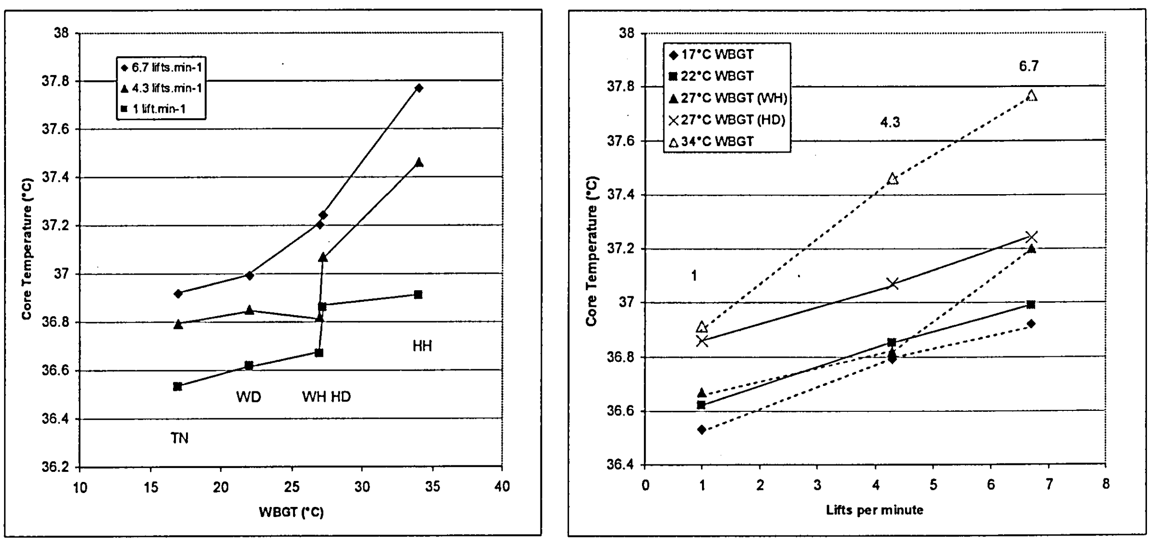

Figure 12. Interaction effects by (a) environment and (b) frequency. Data points represent means for each condition.

Core Temperature – Tests of Simple Main Effects

The significant interaction effect was examined in greater detail by tests of simple main effects as described in chapter 3. The results of the tests of simple main effects for core temperature are detailed in table 10.

Source	*MS*	*df*	*F*
A at b_1	0.32	4,44	12 *
A at b_2	0.93	4,44	19.4 *
A at b_3	1.35	4,44	31.1 *
B at a_1	0.48	2,22	7.7 §
B at a_2	0.41	2,22	12.7 §
B at a_3	0.9	2,22	32.7 §
B at a_4	0.4	2,22	10.2 §
B at a_5	2.27	2,22	41.1 §

Table 10. Tests of Simple Main Effects for Core Temperature.

* F 0.01; 4,44 = 3.83
§ F 0.01; 2,22 = 5.72

The tests of simple main effects were all significant at the critical value for F at 0.01.

Core Temperature – Pairwise Comparisons

The results of the tests of simple main effects were considered in conjunction with a visual examination of the interaction plots and a limited number of pairwise comparisons of interest were conducted. Although all tests of simple main effects were significant the largest F-ratios for factor A (environment) occurred at b_2 and b_3 (4.3 lifts.min^{-1} and 6.7 lifts.min^{-1}) and the largest F-ratios for factor B (frequency) were at a_3 and a_5 (warm-humid and hot-humid). The interaction plots depicted a similar pattern so the following pairwise comparisons were conducted (results in tables 11 and 12).

	4.3 lifts.min^{-1} – warm-dry	***4.3 lifts.min^{-1} – warm-humid***	***4.3 lifts.min^{-1} – hot-dry***	***4.3 lifts.min^{-1} – hot-humid***
4.3 lifts.min^{-1} – thermoneutral	ns	ns	ns	**
4.3 lifts.min^{-1} – warm-dry		ns	ns	**
4.3 lifts.min^{-1} – warm-humid			ns	**
4.3 lifts.min^{-1} – hot-dry				**
	6.7 lifts.min^{-1} – warm-dry	***6.7 lifts.min^{-1} – warm-humid***	***6.7 lifts.min^{-1} – hot-dry***	***6.7 lifts.min^{-1} – hot-humid***

6.7 lifts.min^{-1} – thermoneutral	ns	**	**	**
6.7 lifts.min^{-1} – warm-dry		ns	ns	**
6.7 lifts.min^{-1} – warm-humid			ns	**
6.7 lifts.min^{-1} – hot-dry				**

Table 11. Pairwise comparisons for b_2 (4.3 lifts.min^{-1}) and b_3 (6.7 lifts.min^{-1}). **significant at q;5,44 (0.01).

The core temperature at 4.3 lifts.min^{-1} was significantly higher in the hot-humid environment compared to all other environments. The same was true at 6.7 lifts.min^{-1} although here there were two additional significant pairwise comparisons. At 6.7 lifts.min^{-1} core temperature was significantly higher in the hot-dry and warm-humid environments compared to the thermoneutral environment.

	warm-humid 4.3 lifts.min^{-1}	***warm-humid - 6.7 lifts.min^{-1}***
warm-humid - 1 lift.min^{-1}	ns	**
warm-humid - 4.3 lifts.min^{-1}		**
	hot-humid 4.3 lifts.min^{-1}	***hot-humid - 6.7 lifts.min^{-1}***
hot-humid - 1 lift.min^{-1}	**	**
hot-humid - 4.3 lifts.min^{-1}		**

Table 12. Pairwise comparisons for a_3 (warm-humid) and a_5 (hot-humid) **significant at q;3,22 (0.01).

In the warm-humid environment core temperature was significantly higher when lifting at 6.7 lifts.min^{-1} compared to both other lifting frequencies. In the hot-humid environment core temperature was significantly different between all lifting frequencies.

Core Temperature – Effect Sizes

Generalised η^2 effect sizes were calculated for both of the main effects and the interaction and are presented in table 13.

Source	*Gen η^2*	*effect*
Environment	0.46	Large
Frequency	0.42	Large
Interaction	0.11	Small

Table 13. Generalised η^2 effect sizes for Core Temperature.

4.4 Maximum Acceptable Weight of Lift (MAWL)

The mean MAWL for each lifting frequency by environment is presented in figure 13 below.

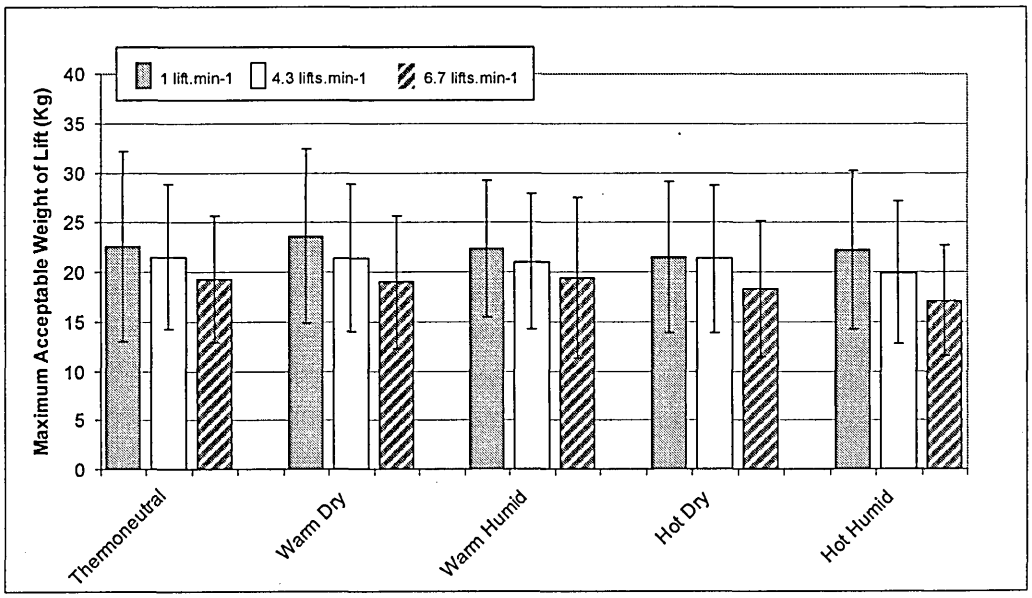

Figure 13. Mean maximum acceptable weight of lift for each test condition (columns represent means, error bars represent ± 1 standard deviation).

Maximum Acceptable Weight of Lift – ANOVA

All of the data for MAWL were normally distributed. Mauchly's test was significant in all three cases therefore sphericity was not assumed and Greenhouse-Geisser corrections were applied. There were significant main effects for environment [$F(2.6,28.5) = 4.7$, $P=0.01$] and frequency [$F(1.1,12.5) = 18.2$, $P=0.001$]. The interaction effect was not significant.

Maximum Acceptable Weight of Lift – Post Hoc Tests

The significant main effects were investigated further using Tukey's HSD post hoc tests. Tukey's tests did not identify any significant differences in either of the main effects. As reported in chapter 3, SPSS does not permit follow-up tests to repeated measures designs except for pairwise analyses of estimated marginal means. When these were performed with the Bonferroni correction there were no significant differences between any of the environments. For the frequency effect, MAWL was significantly lower (P<0.005) when lifting at 6.7 lifts.min^{-1} compared to both of the other lifting frequencies. The Bonferroni correction would have markedly reduced the power of the tests to detect any significant differences so another analysis was performed using no corrections (Least Significant Difference in SPSS). This analysis yielded significant differences between the hot-humid condition and both the thermoneutral and warm-dry conditions (both P<0.01). The hot-dry condition was also significantly different to the thermoneutral environment (P=0.01). The results for frequency were the same as for the Bonferroni analysis.

Maximum Acceptable Weight of Lift – Effect Sizes

Generalised η^2 effect sizes were calculated for both of the main effects and the interaction and are presented in table 14.

Source	***Gen η^2***	***effect***
Environment	0.01	None
Frequency	0.05	Small
Interaction	0	None

Table 14. Generalised η^2 effect sizes for Maximum Acceptable Weight of Lift.

4.5 Rating of Perceived Exertion (RPE)

The mean RPE (average of the three ratings taken during the final 15 minutes) for each lifting frequency by environment is presented in figure 14 below. Note that, although the RPE scale runs from 6 to 20, the y axis originates at 0 for sake of clarity.

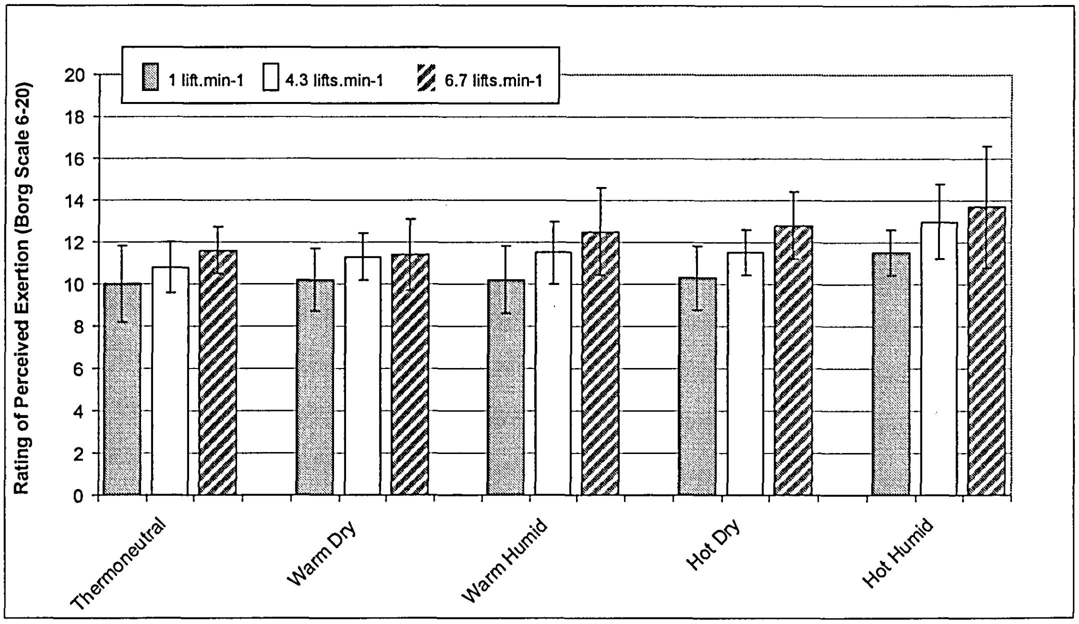

Figure 14. Mean ratings of perceived exertion for each test condition (columns represent means, error bars represent ± 1 standard deviation).

Rating of Perceived Exertion – ANOVA

Eleven of the 15 data sets were not normally distributed and transformations were unsuccessful. Transformations attempted included taking the natural logarithm and the reciprocal of the square root. A Friedman analysis was performed on each main effect (procedure detailed in chapter 3). The results of the Friedman tests are presented in table 15. The main effects were both significant according to the Friedman analysis.

Factor	*n*	*Chi-Square*	*df*	*Asymp. Sig*
Environment	12	28.3	4	<0.001
Frequency	12	23.5	2	<0.001

Table 15. Friedman tests of main effects for ratings of perceived exertion.

Analysis of Variance has been widely reported to be robust to violations of underlying assumptions (Keppel, 1973). Because of this, an ANOVA was also conducted on these data. There were significant main effects for environment [$F(4,44) = 15.8$] and frequency [$F(1.3,14.3) = 25.9$] both ($P<0.001$). The interaction effect was not significant.

Rating of Perceived Exertion – Post Hoc Tests

The significant main effects were investigated further using Wilcoxon Signed Ranks Tests for Matched Pairs. For the environment main effect, RPE in the hot-humid condition was significantly higher ($P<0.005$) than in all other conditions. RPE in the hot-dry condition was also significantly higher ($P<0.005$) than in the warm-dry condition. None of the other environments differed significantly. For frequency, all of the conditions differed significantly ($P<0.005$) from one another.

As with the omnibus F-test, the possibility that parametric analysis might be sufficiently robust to the violations of assumptions led to a follow-up investigation using Tukey's HSD post hoc tests. For the environment effect, the mean RPE in the hot-humid condition was significantly higher ($P<0.01$) than both the thermoneutral and warm-dry conditions. No other conditions differed significantly. There were no significant differences for the frequency main effect at the 0.01 level although 1 lift.min^{-1} and 6.7 lifts.min^{-1} did differ at the 0.05 level however.

Rating of Perceived Exertion – Parametric vs Nonparametric Results

		Parametric	*Nonparametric*
Main	**Environment**	sig	sig
	Frequency	sig	sig
	Interaction	ns	Not tested
Follow-Up	**Environment**	HH vs TN and WD (<0.01)	HH vs all other conditions (<0.005)
		ns	HD vs WD (<0.005)
	Frequency	1 vs 6.7 (<0.05)	All sig (<0.005)

Table 16. Summary of results for RPE from parametric and nonparametric analyses.

To aid comparison between the parametric and nonparametric analyses, a summary of the results for ratings of perceived exertion are presented in table 16.

Rating of Perceived Exertion – Effect Sizes

Generalised η^2 effect sizes were calculated for both of the main effects and the interaction and are presented in table 17.

Source	*Gen η^2*	*effect*
Environment	0.16	Medium
Frequency	0.21	Medium
Interaction	0.02	Small

Table 17. Generalised η^2 effect sizes for Ratings of Perceived Exertion.

4.6 Mean Skin Temperature (T_{msk})

Data for mean end T_{msk} (mean of final two minutes) were incomplete because the skin thermistors frequently became detached or broke during testing. There were a total of 100 sessions where skin data were complete out of a possible 180. The means and standard deviations for the complete data sets are presented in figure 15. Further statistical analysis was not possible due to the amount of lost data.

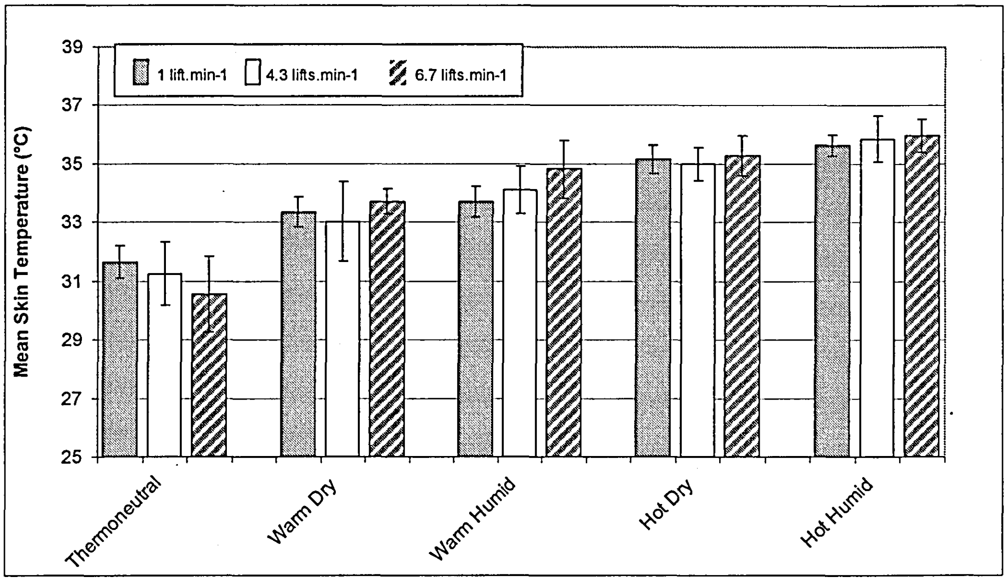

Figure 15. Mean end skin temperature for each test condition (columns represent means, error bars represent ± 1 standard deviation).

4.7 Synopsis

The six null hypotheses were tested using a combination of parametric and nonparametric omnibus and follow-up tests.

The first null hypothesis ($H_0 1$) stated that frequency of lift does not significantly affect the dependent variables. It can be seen from the results that, in all cases, there were significant main effects for lift frequency. The significant interaction effect seen for core temperature means that the main effects must be treated with caution but nevertheless it is proposed that the null hypothesis in this case is rejected.

The second null hypothesis ($H_0 2$) stated that there is no difference in physiological strain when lifting in a hot environment compared to lifting in a thermoneutral environment. There were significant main effects for environment for both heart rate and core temperature. Again, the interaction for core temperature should be borne in mind but it is proposed that the null hypothesis is rejected.

$H_0$3 stated that there is no difference in MAWL when lifting in a hot environment compared to lifting in a thermoneutral environment. The significant environmental main effect for MAWL means that the null hypothesis is rejected.

The fourth null hypothesis ($H_0$4) stated that there is no difference in physiological strain when lifting in a high humidity environment compared to lifting in a similar air temperature with low humidity. Tukey's tests comparing heart rate and core temperature reported significant differences when the hot-humid condition was compared to the hot-dry condition (both environments with an air temperature of 38-39 °C). There were no significant differences for warm-dry and warm-humid (both 30 °C) however. The null hypothesis is retained in this instance although there is clearly a difference at the higher temperature that merits further investigation.

$H_0$5 stated that there is no difference in MAWL when lifting in a high humidity environment compared to lifting in a similar air temperature with low humidity. There were no significant differences in MAWL between warm-dry/warm-humid and hot-dry/hot-humid therefore the null hypothesis is retained.

The final null hypothesis ($H_0$6) stated that lifting in two dissimilar environments (warm-humid and hot-dry) with an equivalent WBGT imposes the same physiological strain. There were no significant differences in heart rate and core temperature when the results in the hot-dry condition were compared to the warm-humid condition (both ~27 °C WBGT). The null hypothesis is retained.

5. Discussion

The purpose of this study was to investigate the physiological strain and the amount of weight lifted when participants were exposed to a range of warm and hot environments and required to lift at different frequencies. The results will be discussed with respect to previous findings in the literature. Any unexpected or anomalous findings will be identified and commented upon. The practical significance of the results will be assessed along with the limitations in the research design and suggestions for possible improvements will be made.

Findings with Respect to Previous Studies

Hydration Status

An attempt was made to control for hydration status in the present study since it appeared to have been overlooked in previous manual handling research in the heat. Urine osmolality was measured immediately upon the participant's arrival so that an excessively high reading (possibly indicating hypohydration) could be addressed by asking them to start drinking water during the period prior to commencement of testing. A cursory examination of the mean values of osmolality reported in the previous section demonstrate the extreme intra- and inter-individual variability that existed in this sample. Some participants routinely returned osmolality readings in excess of 1000 $mOsm.l^{-1}$; others rarely presented with anything higher than 200. Generally speaking, individuals with high activity levels (runners for example) were well hydrated; those who were sedentary and admitted to drinking a lot of caffeinated beverages were less well so. The urine samples did not vary enormously in colour so it is unlikely that using a colour chart such as that in Armstrong (2000) to assess hydration status would have been a better indicator. As such, the attempts to control for hydration status must be considered a best effort since it could not be stated with any certainty that all of the participants were completely euhydrated in every session.

Heart Rate

There were significant main effects for environment and frequency on heart rate. Post-hoc tests for environment identified heart rate in the hot-humid condition as being significantly higher (P<0.01) than in all other environments. No other environmental conditions differed significantly. Previous research has reported similar responses although exact comparisons are difficult due to variations in test design (choice of environments and frequencies) and, in some cases, less than comprehensive presentation of results. Snook & Ciriello (1974) reported significantly increased heart rates (P<0.01) when lifting at 4.3 lifts.min^{-1} in 27 °C WBGT compared to 17.2 °C WBGT. These environments roughly equate to the thermoneutral and warm-humid environments in the present study where no significant difference was found. The task differed slightly by being a floor to knuckle-height lift over a fixed distance of 20 inches (50.8 cm) as opposed to the present study where lift distance was based on the measured knuckle-height of each participant. The mean heart rate increase in Snook & Ciriello (1974) was 10 beats.min^{-1}, a comparable response to this study (↑ 8 beats.min^{-1}) although here the increase represents the mean across all lifting frequencies. Hafez & Ayoub (1991) reported significant (P not given) rises in heart rate at 27 °C WBGT and 32 °C WBGT compared to 22 °C WBGT. These roughly correspond to the warm-humid, hot-humid and warm-dry environments respectively in this study where only the hot-humid environment differed significantly. The mean increase in heart rate from warm-dry to hot-dry was the same (~3 – 4 beats.min^{-1}) in both studies but the increase from warm-dry to hot-humid was ~10 beats.min^{-1} in Hafez & Ayoub (1991) and ~22 beats.min^{-1} here. This difference is probably accounted for by the variation in environments between the two studies. The WBGT of 32 °C in Hafez & Ayoub (1991) was composed of a dry-bulb temperature of 38 °C and a relative humidity of 52% compared with a WBGT of 34 °C (dry-bulb 38 °C, relative humidity 70%) in the present study. The mean environmental heart rate data also represent a mean across all three lifting frequencies of 0.1, 3 and 6 lifts.min^{-1}, variables which again differed between studies. Knuckle-height was also fixed at 51 cm regardless of the stature of each participant. Kamon & Belding (1971) reported a similar increase (to this study) of ~20 beats.min^{-1} when comparing heart rates in an air temperature of 20 °C and 45 °C. Interestingly, although the WBGT of the 45 °C (air temperature) environment in Kamon & Belding (1971) was approximately 31 °C making it closer to the 32 °C WBGT in Hafez & Ayoub (1991), the heart rate response bore more resemblance to the present study. Variation in research design probably accounts for this anomaly as does the fact that Kamon & Belding (1971) only used three participants.

The heart rate was significantly lower ($P<0.01$) at 1 lift.min^{-1} compared to both of the other frequencies whereas Hafez & Ayoub (1991) reported significant differences (P not given) between all frequencies. Mean heart rates at the lowest lift frequency were the same in both studies (~84-85) suggesting that, although 1 lift.min^{-1} is ten times faster than 0.1 lifts.min^{-1}, it imposes a similarly light physiological load. A comparison of the mean heart rates at the two other frequencies shows that they were substantially lower in Hafez & Ayoub (1991). At 3 lifts.min^{-1} mean heart rate was 102 beats.min^{-1} and at 6 lifts.min^{-1}, 111 beats.min^{-1}. Again, the frequencies differ between studies but at 4.3 lifts.min^{-1} here the mean heart rate was 120 beats.min^{-1} and at 6.7 lifts.min^{-1}, 136 beats.min^{-1}. The small differences in lift frequency cannot fully explain this result and it is likely that the interaction with the different environments contributed to the dissimilar responses. It is also possible that the shorter lift distance of 51 cm (compared to a mean of 80 cm in the present study) contributed to the lower heart rates as this lift would have required less physical effort to perform. The mean age of their participants was also lower (22.1 vs. 25.2yrs); they were also taller (184.3 cm vs. 170 cm) and heavier (80.3 kg vs. 74.9 kg); factors which may have also contributed to the differences.

Core Temperature

There was a significant interaction between environment and frequency for core temperature. This presented a challenge for follow-up analysis since the interaction meant that one or more pairs of means were significantly different out of a possible 105 pairwise comparisons. The tests of simple main effects were all significant, yielding no additional information so pairs were nominated based on the size of the F ratios and also a visual examination of the interaction plot.

The finding that core temperature was significantly higher in the hot humid condition compared to all of the other environments (when lifting at both 4.3 lifts.min^{-1} and 6.7 lifts.min^{-1}) was in agreement with the findings of Hafez &

Ayoub (1991) although the mean increases were more pronounced in this study. It is likely that the variations in research design (faster lift frequencies and environments with higher WBGTs) and the choice of aural over rectal measurement contributed to this difference.

In both the warm-humid and hot-humid environments, core temperatures were significantly higher when lifting at 6.7 lifts.min^{-1} compared to 4.3 lifts.min^{-1}. Indeed, the core temperature at all lift frequencies differed significantly in the hot-humid environment. Hafez & Ayoub (1991) reported similar significant (*P* not given) main effects for the frequency variable.

Snook & Ciriello (1974) reported a significant increase ($P<0.01$) of 0.2 °C in core temperature when lifting at 4.3 lifts.min^{-1} in 27 °C WBGT compared to 17.2 °C WBGT but in the present study these conditions were not significantly different. Indeed, an examination of the mean core temperatures in these two environments at 4.3 lifts.min^{-1} in the present study show an increase of less than 0.03 °C. Possible reasons for the difference in response include the relative ages of the two sample populations (Snook & Ciriello's participants were, on average, ten years older and ranged up to 56 years), a slight variation in lifting duration (40 vs 35 minutes) and the fact that aural temperature was measured here as opposed to rectal temperature. The final point is interesting because, all things being equal, one would expect rectal temperature to be less sensitive to changes in activity level and to rise more slowly.

Maximum Acceptable Weight of Lift

The main effects for the Maximum Acceptable Weight of Lift (MAWL) were both significant. Unfortunately, Tukey's tests did not identify any significant differences and identifying their exact locations was hindered by the limited scope for follow-up analysis in SPSS. Pairwise comparisons using no corrections (Least Significant Difference) yielded significant differences between the hot-humid condition and both the thermoneutral and warm-dry conditions. The hot-dry condition was also significantly different to the thermoneutral environment. Hafez & Ayoub (1991) reported a significant interaction effect (P=0.01) for MAWL so examination of their main effects must be treated with caution. At 3 lifts.min^{-1}, MAWL decreased by 5.6% at 27 °C WBGT and by 18.3% at 32 °C WBGT when compared to 22 °C WBGT. The percentage reductions in comparable conditions in the present study were 1.5% and 7% respectively. At 6 lifts.min^{-1} in Hafez & Ayoub (1991), MAWL decreased by 7.7% at 27 °C WBGT and by 21.2% at 32 °C WBGT when compared to 22 °C WBGT. The percentage differences in comparable conditions in the present study were +1.8% and 10% respectively. That there should be an increase in MAWL in a supposedly more uncomfortable environment is surprising and possible reasons for this will be discussed in a later section. For frequency, Hafez & Ayoub (1991) reported reductions of ~20% between 3 and 6 lifts.min^{-1} in all environments. In similar conditions in the present study the percentage reductions varied between 8 and 14%.

Snook (1978) has suggested that tasks should only be performed with weights that are acceptable to 75% of the working population and has published tables based on data collected in many studies (Snook & Ciriello, 1991). According to the tables the weight acceptable to 75% of the working population lifting from floor to knuckle-height at 1 lift.min^{-1} is 22 kg. The mean MAWL in the present study at this frequency across environments slightly exceeded this value at 22.4 kg. The mean MAWLs at 4.3 and 6.7 lifts.min^{-1} also exceeded the published 75% values for these lifting frequencies (21 vs. 17 kg and 18.6 vs. 14 kg respectively).

If one considers the results of MAWL with respect to the modified NIOSH equation published by Hidalgo *et al.* (1997) it can again be seen that the reductions in amount of weight lifted in the warmer environments were modest. The heat stress multiplier is the same (1.0) for thermoneutral, warm-dry, warm-humid and hot-dry conditions since none of these conditions exceeded 27 °C WBGT. The hot-humid condition was 34 °C WBGT however and the multiplier at this temperature is 0.83. Since all of the other components of the equation were held constant then one would have expected to see decrements in MAWL between thermoneutral and hot-humid that approximated this multiplier but this was not the case. At 1 lift.min^{-1} for example the mean MAWL in the thermoneutral condition was 22.6 kg. Using the heat stress multiplier the modified equation yields a value of 18.8 kg (22.6*0.83) at 34 °C WBGT yet the actual mean MAWL in the hot-humid environment at the same lifting frequency was 22.2 kg. There were similar discrepancies at the higher lifting frequencies: 17.8 kg (modified NIOSH) vs. 19.9 kg (actual) at 4.3 lifts.min^{-1} and 16 kg vs. 17.1 kg at 6.7 lifts.min^{-1}. It is of course possible that the heat stress multiplier itself is inaccurate. Hidalgo *et al.* (1997) cite an unpublished PhD thesis (Hafez, 1984) as the multiplier's origin and it may be that it requires further validation. In particular, the precise point (WBGT value) at which the multiplier comes into effect is +27 °C. There were two environments in the present study that had a

WBGT of 27° C and the MAWL in one of these (hot-dry) differed significantly from the thermoneutral condition (17 °C WBGT). Unfortunately, the multiplier was not validated below 19 °C WBGT so its value at 17 °C is not known. Even so, this finding would seem to contradict the underlying assumption of the multiplier (i.e. that environments up to and including 27 °C WBGT impose the same physiological strain).

The mean box-weights lifted in this study all exceeded the guidelines published in the HSE MHOR guidance document (HSE, 1998). Using the diagram reproduced in chapter 2 the base weight limit for this type of lifting task would be 20 kg when lifting at 1 lift.min^{-1}. At 6.7 lifts.min^{-1} the guidance recommends a 50% reduction which would impose a limit of 10 kg. There is no specific guidance for 4.3 lifts.min^{-1} but it is suggested that a 40% reduction would be appropriate, imposing a limit of 12 kg. The participants exceeded these limits at each of the three lifting frequencies.

To summarize, the percentage reductions in MAWL were generally much smaller in the present study and possible reasons for this will be discussed shortly. The reductions in MAWL were also smaller than expected when baseline values in the thermoneutral condition were recalculated using the heat stress multiplier in the modified NIOSH equation.

Ratings of Perceived Exertion

There were significant main effects for environment and frequency in ratings of perceived exertion (RPE). Tukey's tests identified RPE in hot-humid as significantly higher (P<0.01) than in either thermoneutral and warm-dry. For frequency, RPE was significantly higher ($P<0.05$) when lifting at 6.7 lifts.min^{-1} compared to 1 lift.min^{-1}. The mean differences when expressed as RPE scores were small however (The greatest mean difference was 2 in both environment and frequency) and possible reasons for this will be discussed shortly. There do not appear to be any lifting studies in the heat that have recorded RPE but the results are in agreement with other non-thermally related research into manual handling. Wu & Chen (1997) and Asfour *et al.* (1983) for example have reported consistent rises in RPE as the frequency of lift increases in a thermoneutral environment. Furthermore, these rises are also relatively small (↑ ~1.7 between 1 and 6 lifts.min^{-1}) so they can be considered comparable despite slight variations in experimental design.

Unexpected Findings

A surprising outcome of this study was the consistency of MAWL values across all conditions. There were significant main effects for both environment and frequency admittedly but upon closer examination the mean weights lifted only varied by a maximum of 5.5 kg. Consider that at 4.3 lifts.min^{-1} the difference in mean MAWL between thermoneutral and hot-humid was ~1.6 kg and at 6.7 lifts.min^{-1}, just ~2.1kg. The percentage reductions in MAWL across both main effects were considerably less than in previously published research. The practical significance of these findings will be discussed in a forthcoming section but a comment on the phenomenon of stable MAWLs is merited here.

The participants were remarkably conservative in their box-weight adjustments, even after the training period and the emphasis placed on trying a wide range of weights. The maxim that 'you don't know if its too heavy until you have tried it' was stressed in both the script and in verbal instructions during the training period. A number of the participants were students without specific industrial backgrounds and many adopted a cautious approach to the lifting task because of a perceived injury risk (Some participants were particularly protective of their lower backs despite being screened for any prior injuries). This would be less likely to occur in industry where some form of 'natural selection' would be expected to take place. Individuals who find that they are unsuited to the demands of manual handling are likely to seek alternative employment unless there is an overriding financial imperative that forces them to persevere.

In a similar vein, mean ratings of perceived exertion varied by only a few points across all conditions. This despite the thorough grounding provided during the training phase. Some of the participants were sports science undergraduates or graduates for whom both the RPE scale and its correct use should have been second nature. All, including those from completely different backgrounds, received at least six exposures to the scale prior to commencement of the main testing phase. There is a possibility that some participants were conscious of the ratings given by the other participant in the session (most sessions were run with two participants lifting simultaneously) and that a competitive element was introduced. The effects of this should have been minimal however because participants were asked to convey their ratings discreetly to the tester and also because of the high noise levels in the chamber. It might also be the case that the RPE scale is inherently unsuitable for use during intermittent tasks. Participants were advised to give an overall feeling of exertion (i.e. not focusing on any particular body area or specific discomfort) and to consider this in terms of an average over the lifting cycle. This appeared to be easier to do at 4.3 and

6.7 lifts.min^{-1} where, although still intermittent, the frequencies could be considered high enough to be thought of as 'continuous'. Certainly, many participants found it difficult to rate their exertion during the sessions when they had to lift only once a minute. The lifting task took approximately 2.5 seconds to perform so in these sessions the participant was standing still for the best part of 57 seconds. In light of this it is not hard to imagine the difficulties experienced in accurately gauging exertion. Despite some significant differences in the analysis it would seem that the RPE scale is not a sensitive enough tool to regulate work in thermal environments particularly at very low lifting frequencies.

Recent research into the effects of dissimilar environments with equivalent wet bulb globe temperatures (WBGT) has shown that physiological strain is greater when humidity is higher (Kellett *et al.,* 2003). This finding runs contrary to the assumption underpinning the WBGT scale that any combination of environmental conditions will impose the same physiological strain providing the WBGT number is the same. The results of Kellett *et al.* (2003) have yet to be replicated so the fact that there were no significant differences in physiological strain between the hot-dry and warm-humid conditions (both ~27 °C WBGT) in the present study should perhaps not come as a complete surprise. It is possible that the variation in response, if indeed it is a true response, only manifests itself at higher WBGT levels (Kellett *et al,* 2003 tested their participants at 32 °C WBGT). A second possibility is that the response is only observed during a longer-term, continuous exercise protocol such as the 60-minute treadmill walking protocol adopted by Kellett *et al.* (2003).

Practical Significance of the Findings

In this study, generalized eta squared effect sizes were calculated to supplement the findings from the analyses of variance. These are discussed together with an examination of the descriptive statistics so that a clearer picture of the real-world effects can be gleaned.

The calculated effect sizes were larger for both heart rate and core temperature compared to MAWL and RPE. Part of the reason for the much smaller effects for the latter two variables is probably attributable to the previously mentioned conservatism of the participants. The large and medium effects for heart rate and core temperature show that, even when participants are allowed to regulate their own workload to suit the conditions, they don't compensate sufficiently leading to a concomitant increase in both variables.

The differences in mean core temperature between thermoneutral and hot-humid at the three lifting frequencies were 0.4, 0.65 and 0.9 °C respectively. These increases were apparent after just 35 minutes of intermittent activity and represent the temperature in the auditory canal, a dynamic and fast-responding thermal environment. One can only speculate at the rises that might occur during extended periods of lifting or of the temperature in the rectum which, although slower to respond, would continue to rise for a period after activity has ceased.

Statistical analysis of mean skin temperature was not possible because of the number of missing data sets. The descriptive data showed that there was a considerable rise in mean skin temperature between the thermoneutral (~31 °C) and both the hot-dry and hot-humid environments (~35 °C) however. The mean increase in core temperatures between these environments was between 0.3 and 0.7 °C meaning that the thermal gradient between core and skin was flattened somewhat. This would reduce the body's ability to dissipate heat effectively from the deep tissues and skeletal muscles.

Frequency of lift had a larger effect on heart rate than environment, partly due to the adoption of 1 lift.min^{-1} as the lowest lift frequency. Mean heart rates at this frequency were, particularly in the less arduous environments, only barely raised above resting levels. The much elevated heart rates in the more hostile environments suggest that the participants would have struggled to maintain their workload throughout a complete working day. This highlights a limitation of the psychophysical strategy and demonstrates the difficulty in selecting a realistic box-weight in a relatively short space of time. There was a huge amount of inter-individual variation in heart rate response with one participant routinely working at or around 200 beats.min^{-1} with no apparent discomfort or breathlessness. This suggests that heart rate should not be used in isolation when determining safe withdrawal criteria in hot environments.

The general trend for heart rate response at 6.7 lifts.min^{-1} was that there was a plateau after the end of the MAWL stabilisation period except in the hot-humid environment where heart rate continued to rise throughout the session. At 4.3 lifts.min^{-1}, heart rate reached a plateau in all environments suggesting that the upper limit for manual handling in hot-humid environments lies somewhere between 4.3 and 6.7 lifts.min^{-1}. Indeed, Snook & Ciriello (1991) have stated that tasks conducted at 4.3 lifts.min^{-1} generally result in individuals remaining within physiological guidelines and that 94% of industrial tasks are performed at this frequency or slower.

There was a small frequency effect for MAWL and no meaningful effect for environment. This reflects the aforementioned conservatism of the participants when selecting box-weights. The mean MAWL at 1 lift.min^{-1} was 22.4 kg compared to 21 kg and 18.6 kg at the two higher frequencies. It is unlikely that the participants would have benefited from a longer adjustment period as most seemed to finalise the box-weights within the first ten minutes. Although a 40-minute adjustment period was used in the early work by Snook & Ciriello (1974), more recent studies (Chen, 2003; Mital, 1987; Wu & Chen, 1997) have reported that between 20-25 minutes is an adequate length of time to establish MAWL.

Upon comparison with the tables published by Snook & Ciriello (1991) the participants in the present study exceeded the weight acceptable to 75% of the working population. This means that they would be at greater risk of suffering a lower back injury according to the data collected by Snook (1978). It should be remembered that this conclusion is based on data from customer claims to insurance companies. As yet there are no long-term, epidemiological studies that have specifically implicated manual handling tasks in the development of lower back disorders (Dempsey, 1998). Also, at 6.7 lifts.min^{-1} the mean MAWL of 18.6 kg approached the value of 19 kg which was highlighted as exceeding the physiological limit of 33% $\dot{V}O_{2max}$. Coupled to this, the finding that MAWL values remained relatively consistent across conditions indicates that the psychophysical strategy (if used in isolation) may be a poor method of protecting workers from heat injury.

There were medium effects for both frequency and environment for ratings of perceived exertion. The ramifications of the findings for RPE have been largely covered. Mean ratings ranged from 10 in thermoneutral at 1 lift.min^{-1} to 13.7 in hot-humid at 6.7 lifts.min^{-1}, the latter value recorded despite mean heart rates in this condition exceeding 152 beats.min^{-1}. There is a need for a ratings tool sensitive enough to be used during intermittent activity although whether one could be developed for tasks as infrequent as 1 lift.min^{-1} and below is questionable.

Overall, frequency of lift provided marginally larger effects than environment suggesting that this is the more important factor to control when considering reductions in heat stress. The environment effect was only greater than that for frequency for core temperature and even then the difference was minimal.

Limitations of the Design

Repeated measures designs are generally accepted as having greater power than designs where independent groups are used (Huck, 2000) because each participant acts as his own control. The increase in power permits smaller sample sizes to be used, making these designs more efficient. However, the characteristics that make repeated measures so attractive can also lead to problems. If the participant is asked to attend repeated test sessions over a period of time, fatigue and boredom can set in. There may also be a carry-over or learning effect from one session to the next which distorts the results. The participants in this study were required to attend 15 test sessions in addition to acclimation and MAWL stabilisation so these were very real concerns.

The issue of fatigue can probably be discounted as the activity levels could not be considered excessive. Any delayed onset muscle soreness and general fatigue experienced at the beginning due to undertaking a novel form of exercise were eliminated during the acclimation phase. Boredom was a distinct possibility as the protocol was especially dull (try listening to one of the audio tapes with the intermittent beeping sound for any length of time!) To try to minimise this the participants were reminded at the start of each session what exactly was expected of them. They were allowed to talk to each other, to the lowerers and data-collecters during the sessions with the proviso that they didn't discuss the experiment or how they were feeling at any particular time.

Carry-over effects were minimised by using an unbalanced Latin square, ensuring that the order of test conditions was almost completely counter-balanced across participants. Unfortunately a balanced Latin square could not be used because of the odd numbers of both independent variables. A simplified design with fewer, even numbers of independent variables would have meant that a balanced Latin square could have been used, thus ensuring complete counter-balancing. This solution would have had the additional benefit of reducing boredom and fatigue because of the reduced number of repeated measures.

The method of attaching thermistors to the skin was inadequate resulting in many missing data sets. The thermistors became detached due to a combination of continuous movement by the participants, friction of clothing and perspiration which weakened the bond between the fixing tape and the skin.

The loss of data meant that statistical analysis of mean skin temperature was not possible.

Although an attempt was made to control hydration status it could not be stated with complete confidence that each participant was euhydrated for every session. It is unlikely that the use of a colour chart to assess hydration would have yielded any more useful information. Perhaps this aspect could be better controlled by providing a measured quantity of water to be consumed in the hours prior to testing. This would still have the limitation of the water consumption being self-reported however.

Regarding the generalizability of the findings, a number of factors should be borne in mind. Only males under the age of 40 years (most of whom had no industrial experience) were studied so care should be taken when interpreting the results with respect to other populations. Snook & Irvine (1967) recommended that for studies of this type, older participants who are experienced industrial workers and better conditioned to the lifting task should be recruited. During the preliminary stages of the study it was anticipated that our research collaborators would supply volunteers with these attributes but unfortunately this did not transpire.

The results are also only applicable to the floor to knuckle-height lifting task. They should not be generalized to any other type of lift (floor to shoulder-height or knuckle to shoulder-height for example) or other manual handling task.

The environmental chamber was only able to manipulate air temperature and humidity and there was no radiant heat source present. This meant that we were unable to replicate the working conditions experienced where ovens or kilns were nearby.

6. Conclusions

The environment had a significant effect on both physiological strain and the amount of weight lifted. Heart rate and core temperature were significantly higher and MAWL significantly lower in the hot-humid environment compared to all of the other environments. At 6.7 lifts.min^{-1} core temperature was also significantly higher in the hot-dry and warm-humid conditions compared to thermoneutral. Ratings of perceived exertion were significantly higher in the hot-humid condition compared to both warm-dry and thermoneutral. These findings demonstrate that, although participants adjust their workloads downwards in hotter conditions, they do not compensate adequately and experience increases in physiological strain.

Frequency of lift also had a significant effect on all of the dependent variables. Across the board, lifting at 6.7 lifts.min^{-1} produced significant differences in physiological strain and weight lifted compared to all other frequencies. The only differences between 4.3 lifts.min^{-1} and 1 lift.min^{-1} were for ratings of perceived exertion and core temperature in the hot-humid condition.

Effect sizes were largest for heart rate and core temperature, ranging from 0.22 to 0.63 for the main effects. In general, effect sizes for both MAWL and ratings of perceived exertion were much smaller and it is suggested that this is partly due to the conservatism of the participants in their weight selections and judgements of exertion.

There were no significant differences in physiological response between two different environments with an equivalent WBGT (27 °C). This finding is contrary to other recent research for treadmill walking but it is possible that any differences only manifest themselves at higher WBGT values for the manual handling tasks used in the present study.

5 The Effects of Cold Environments on Performance of an Intermittent Lifting Task

1. Summary

This chapter presents an original study into the effects of cold environments on the performance of a floor to knuckle-height lifting task. It also examines the participants' responses while lifting in a 0 °C environment when wearing two different clothing ensembles.

2. Introduction

The review of literature highlighted the fact that there was little or no research into the effects of performing intermittent lifting tasks in the cold. This was something of a surprise since there are so many people employed in workplaces that are maintained at cool or cold temperatures.

The increased consumption of ready meals, pre-packed sandwiches, prepared vegetables and packaged salads for example has meant that the chilled food industry has expanded dramatically in recent years. The chilled meals sector in the UK has grown from an estimated £173 million in 1988 to over £1,750 million in 2005 (Chilled Food Association, 2006). In 2004 the industry employed over 56,000 people although not all of these work in cold environments and exact figures for these are unavailable. Chilled foods have to be stored at refrigeration temperatures below 8 °C and optimally at 5 °C. During preparation, food safety is principally ensured by temperature so employees in this sector would typically be exposed to conditions at or below 8° C for extended periods.

Other workplaces that operate at similar temperatures include slaughterhouses (5 – 12 °C) and warehouses (< 15 °C). This study deliberately excludes any examination of the frozen food industry or indeed any working environment that operates below 0 °C. Typically, cold stores in the frozen food industry are maintained at around -25 °C and it was not possible to replicate this environment in our chamber. Outdoor environments with the additional factors of wind-chill and precipitation in all its forms were similarly impossible to replicate and were also excluded.

The problems for people working in the cold are more numerous than for those working in the heat. The human body is better designed to cope with heat and the most effective forms of preventing heat loss in cold environments are behavioural. This usually means avoidance of the cold if at all possible and wearing clothing with better insulative properties. The musculoskeletal system is at risk in the cold probably due to persistent low muscle and joint temperature. A review by Griefahn *et al.* (1997) found that the onset of musculoskeletal disorders appeared to be accelerated by working in the cold. The peripheries of the body, notably the hands and the feet, can suffer particular problems because of the phenomenon of physiological amputation where a decline in core temperature results in vasoconstriction at the extremities in order to conserve heat (Havenith *et al.,* 1995). Vasoconstriction moves progressively from the extremities through the lower limbs as temperature continues to decline (Raman & Roberts, 1989). In this situation the concomitant loss of manual dexterity and grip strength can make many tasks very difficult to perform.

In cold air, as opposed to water immersion, both physical activity and clothing ensembles are factors which are known to help maintain a safe core temperature. Physical activity increases metabolic rate and produces heat whilst clothing creates layers of warm air which insulate the body from the environment (Noakes, 2000). The optimal combination of the two will depend on the rate of physical activity and the level of clothing insulation and it is fair to say that the ideal situation is rarely achieved. Most people can identify with the scenario where they have 'wrapped-up warm' prior to going out on a hill walk only to find themselves hot and sweaty halfway along the ascent. Industrial workers can experience this problem because they will often move between dissimilar thermal environments and their activity levels may vary throughout the course of a day. In a south Yorkshire supermarket distribution warehouse which was visited for this study for example, workers performed picking operations in two adjacent rooms; one maintained at around 0 °C, the other at around 12 °C. The ideal ensemble for the cooler environment was too warm to wear for any length of time in the warmer environment and vice-versa. Extra clothing can produce a hobbling effect, limiting free movement and gloves worn to keep the hands warm can interfere with tasks requiring a fine degree of manual dexterity.

The purpose of this experiment was to assess physiological strain and the amount of weight lifted when participants were exposed to a range of cold environments and required to lift at different frequencies. The five environments were chosen to reflect the conditions reported to exist in the chilled food industry and warehouse environments and those measured during the site visits. There was a 'thermoneutral' environment representing a baseline where a standing man wearing a clothing ensemble of approximately 1.06 Clo would be expected to experience no net heat gain nor net heat loss to his surroundings. The other four environments were 10 °C, 5 °C and two at 0 °C where two different clothing ensembles were tested. The relative humidity varied between 40 and 60% across all conditions.

Three lifting frequencies were used which were again a reflection of those used previously and what was encountered on the site visits. They were the same as for the hot study: 1 lift.min^{-1} ,4.3 lifts.min^{-1} (a lift every 14 seconds) and 6.7 lifts.min^{-1} (every nine seconds). This choice of frequencies again permitted easy comparison of the results with the published tables of Snook & Ciriello (1991).

3. Methods

3.1 Participants

Twelve male participants between the ages of 18 and 40 years were recruited to take part in the study. Anyone with a previous history of musculoskeletal disorders were excluded from the study, as were participants with illness, disorders or diseases known to affect the thermoregulatory system (e.g. thyroid conditions). All participants were white, northern Europeans except for one Indian who had been resident in the UK for at least two years. Participant details are presented in table 18 below.

n	*Age (years)*	*Stature (m)*	*Mass (kg)*	*Knuckle Height (m)*	*Body Mass Index*	*Body Surface Area (m^2)*
12	26 ± 5.6	1.77 ± 0.1	75.1 ± 9.2	0.8 ± 0.04	24.1 ± 2.7	1.9 ± 0.1

Table 18. Participant Details (mean ± 1 standard deviation). Body Surface Area from Mosteller (1987).

3.2 Procedures

Skin thermistors (Grant Instruments, Cambs. UK) were fixed to the body with Micropore tape (3M, USA) according to the Ramanathan (1964) four point measurement site for estimation of mean weighted skin temperature; at the chest (centre of pectoral region, midpoint between nipple and clavicle), arm (posterior aspect of the upper-arm, at the centre of the belly of the triceps), thigh (anterior aspect, over rectus femoris at midpoint of femur) and shin (anterior aspect of lower-leg, at midpoint of tibia). An additional skin thermistor was attached to the dorsal surface of the second finger on the proximal phalanx. An aural bead thermistor (Grant Instruments, Cambs. UK) was fitted into the ear, fixed into position with cotton wool and tape and insulated with a pair of industrial ear defenders. The aural thermistor used was the modified version as described in the previous chapter. All thermistors were connected to a data logger (Squirrel 1021, Grant Instruments, Cambs. UK) so that measurements could be recorded throughout testing. The participant also put on a heart rate monitor (Polar S610, Polar, UK) prior to donning the clothing ensemble.

The participants then dressed in either of the two designated clothing ensembles depending on the session that they were attending. The details for the standard and enhanced clothing ensembles are presented in tables 19 and 20 below.

Clothing Item	***Clo***
Underwear (shorts as supplied by participant)	0.06
Working trousers (cotton) 9 oz	0.25
T-shirt, thermal	0.15
Fleece jacket	0.4
Socks, long, thick	0.1
Safety boots	0.1
Estimated Clo of ensemble	**1.06**

Table 19. Standard clothing ensemble and estimated Clo value.

Clothing Item	***Clo***
Underwear (shorts as supplied by participant)	0.06
Underpants, Long, Thermal	0.1
T-shirt, thermal	0.15
Working trousers (cotton) 9 oz	0.25
Fleece jacket	0.4
Woolly hat	0.1
Socks, long, thick	0.1
Safety boots	0.1
Estimated Clo of ensemble	**1.26**

Table 20. Enhanced clothing ensemble and estimated Clo value.

The ensembles were chosen to mimic as closely as possible the type of clothing worn by workers in the cold environments we visited. The estimated Clo was designed to ensure that the participant was comfortable while standing still in the thermoneutral environment.

3.2.1 Orientation

The first two days were dedicated to orienting the participants to both the climatic environment and the lifting protocol. Orientation took the form of two one-hour sessions per day in the environmental chamber at an air temperature of 10 °C.

3.2.2 MAWL Stabilisation

The participants were introduced to the psychophysical method of lift assessment in one session prior to commencement of testing proper. The purpose of this session was to habituate the participant to the proposed lifting protocol and to ensure that they were able to consistently select an acceptable box-weight (i.e. to demonstrate the repeatability of the protocol). It also provided an opportunity to practice using the RPE scale especially for those participants for whom the concept was unfamiliar. The protocol is described in detail in chapter 3.

3.2.3 Main Experimental Sessions

The main portion of the study commenced once orientation and MAWL stabilization had been completed. This comprised 15 test sessions made up of a combination of five environments and three lifting frequencies. A within-subjects repeated measures design was used. Each participant took part in all of the fifteen test conditions and exposure to each condition was randomised using an unbalanced Latin Square. Table 21 describes the environmental conditions chosen and also the actual mean values (and standard deviations) achieved across the entire experiment. The thermoneutral environment differed from the hot study because of the extra clothing insulation required here. The participants in the present study would have probably experienced a net heat gain while at rest in the thermoneutral environment specified for the hot study. Table 22 describes the frequency of lift undertaken at each condition.

Environment	*Air temperature (°C)*	*Relative humidity (%)*
Thermoneutral	16 (15.9±0.7)	65 (67.3±6.5)
10° C	10 (9.9±0.8)	55 (56.2±7.6)
5° C	5 (5±1)	45 (44.3 ± 4.4)
0° C (standard ensemble)	0 (0.5±0.7)	55 (60±3.6)
0° C (enhanced ensemble)	0 (0.4±0.8)	55 (54.8±3)

Table 21. Environmental Specifications (actual means ± 1 standard deviation achieved).

Frequency	*Lifts.min^{-1}*
1 every 9 seconds	6.7
1 every 14 seconds	4.3
1 every 60 seconds	1

Table 22. Lifting frequencies.

Fifteen sessions were conducted at the same time each day on Monday to Friday. The participants were clothed and equipped as in the orientation sessions and then rested for 20 minutes in an intermediate room prior to commencement. This period allowed their aural environment to stabilise once the bead thermistor had been fitted and insulated. During this period the shelf heights were set and box starting weights were randomised. The participant was told the lift frequency for the session but was not aware of the environmental conditions nor the starting box weight. Where two participants were tested simultaneously (as was usually the case) they were informed that their starting box weights were different thus removing any competitive element from the session. They then completed a grip strength test (Grip Strength Dynamometer, TKK 5401, Grip D, Takei Scientific Instruments, Japan) in the intermediate room. The dynamometer was held in the dominant hand in a relaxed fashion at the participant's side and then gripped as tightly as possible, isometrically contracting the muscles of the fingers and lower arm. Participants were allowed up to three trials and the highest reading was taken. The participants entered the chamber and all recording equipment was started. The protocol was as detailed in Chapter 3 with the participants lifting for 20 minutes whilst adjusting the box weight and then for a further 15 minutes at the box weight selected. RPE was recorded every five minutes throughout the session and the participants were encouraged to convey this information discreetly so as not to influence the other lifter (this proved relatively easy due to the level of ambient noise in the chamber). Heart rate readings were also taken every five minutes as a back-up procedure. To comply with ethics a second experimenter was always present should an emergency arise and drinking water was available at all times. The intermediate room was maintained at a warm temperature and blankets were available for re-warming should the need to remove anyone have arisen.

After 35 minutes the test was stopped, the grip strength test was repeated immediately and then the participants were removed to the intermediate room to de-kit. The final box weight was recorded as the maximum acceptable weight of lift (MAWL). Heart rate and temperature data from the monitors and data loggers were downloaded to a PC for analysis.

3.2.4 Withdrawal Criteria

The withdrawal criterion was set at an aural temperature of 35.5 °C providing a safety margin which protected the participant from the onset of hypothermia. Because of the considerable inter-individual response to the cold the researchers also relied on their observations of each participant to assist them in their decision to withdraw.

3.3 Hypotheses

The null hypotheses to be tested were:

1. ($H_0$1) Frequency of lift does not significantly affect the dependent variables (grip strength excluded).
2. ($H_0$2) There is no difference in physiological strain when lifting in a cold environment compared to lifting in a thermoneutral environment.
3. ($H_0$3) There is no difference in MAWL when lifting in a cold environment compared to lifting in a thermoneutral environment.
4. ($H_0$4) There is no difference in grip strength after lifting in cold environments compared to lifting in a thermoneutral environment.

5. (H_05) There is no difference in core temperature and heart rate when lifting in 0° C in a standard clothing ensemble compared to lifting in 0° C in an enhanced clothing ensemble.
6. (H_06) There is no difference in finger surface temperature when lifting in a cold environment compared to lifting in a thermoneutral environment.

3.4 Statistical Analysis

Six of the dependent variables (heart rate, core temperature, mean skin temperature, ratings of perceived exertion, maximum acceptable weight of lift and mean finger surface temperature) were each planned to be individually analysed for significant differences using a two-factor ANOVA with repeated measures on both factors. Change in grip strength was analysed using a three-way ANOVA with repeated measures on all factors (time*environment*frequency). α was initially set at 0.05 but subsequently adjusted using a Bonferroni correction to 0.007 (0.05/7) to account for the seven planned ANOVA tests (Huck, 2000). Significant F ratios were followed-up by Tukey's post-hoc tests and generalized η^2 effect sizes were computed. The procedures are described in detail in chapter 3.

4. Results

4.1 Heart Rate

The mean end heart rate for each lifting frequency by environment is presented in figure 16 below.

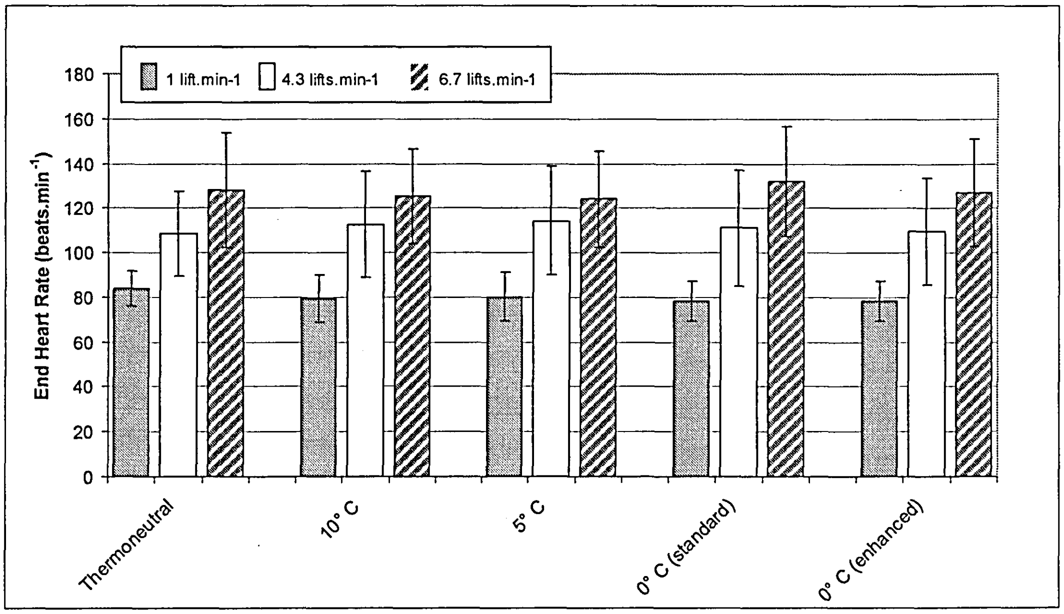

Figure 16. Mean end heart rate in each condition (columns represent means, error bars represent ± 1 standard deviation).

Heart Rate – ANOVA

All of the data for HR were normally distributed. The Mauchly's statistic for frequency was significant so the Greenhouse-Geisser correction was used for this main effect as sphericity could not be assumed. There was a significant main effect for frequency [$F(1.07,11.7) = 65.6$, $P<0.001$]. The main effect for environment and the interaction effect were not significant.

Heart Rate – Post Hoc Tests

The significant main effect for frequency was investigated further using Tukey's HSD post hoc tests. Heart rate at 1 lift.min^{-1} was significantly lower ($P<0.01$) than heart rate at 6.7 lifts.min^{-1}. No other comparisons were statistically significant.

Heart Rate – Effect Sizes

Generalised η^2 effect sizes were calculated for both the main effects and the interaction and are presented in table 23.

Source	Gen η^2	effect
Environment	0	None
Frequency	0.51	Large
Interaction	0.01	None

Table 23. Generalised η^2 effect sizes for Heart Rate.

4.2 Core Temperature

The mean end core temperature for each lifting frequency by environment is presented in figure 17 below.

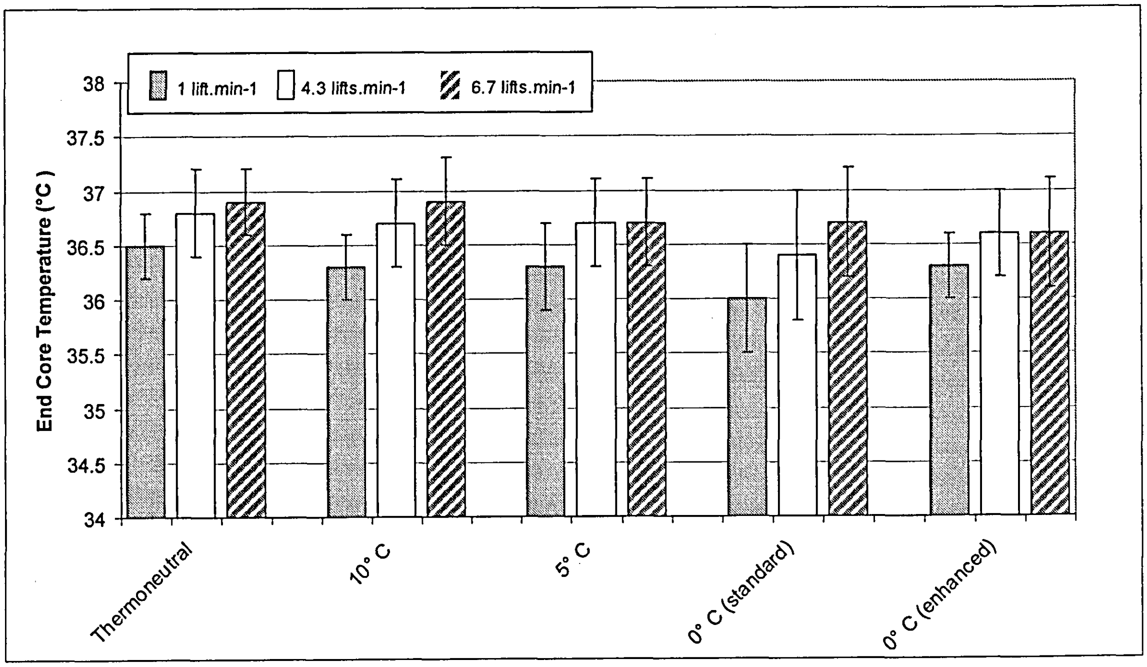

Figure 17. Mean end core temperature in each condition (columns represent means, error bars represent ± 1 standard deviation).

Core Temperature – ANOVA

All of the data for core temperature were normally distributed. Mauchly's test was not significant for any of the factors so sphericity was assumed in the main analysis. There were significant main effects for environment [$F(4,44) = 15.7$] and frequency [$F(2,22) = 50.8$] both $P<0.001$. The interaction effect was not significant.

Core Temperature – Post Hoc Tests

The significant main effects for environment and frequency were investigated further using Tukey's HSD post hoc tests. Core temperature in the thermoneutral environment was significantly higher ($P<0.05$) than core temperature in 0° C while wearing the standard clothing ensemble. There were no other statistically significant differences for the environment effect. For the frequency effect, core temperature was significantly lower ($P<0.05$) when lifting at 1 lift.min^{-1} compared to lifting at the other two frequencies. There was no significant difference in core temperature between 4.3 and 6.7 lifts.min^{-1}.

Core Temperature – Effect Sizes

Generalised η^2 effect sizes were calculated for both the main effects and the interaction and are presented in table 24.

Source	***Gen η^2***	***effect***
Environment	0.1	Small
Frequency	0.22	Medium
Interaction	0.02	Small

Table 24. Generalised η^2 effect sizes for Core Temperature.

4.3 Maximum Acceptable Weight of Lift (MAWL)

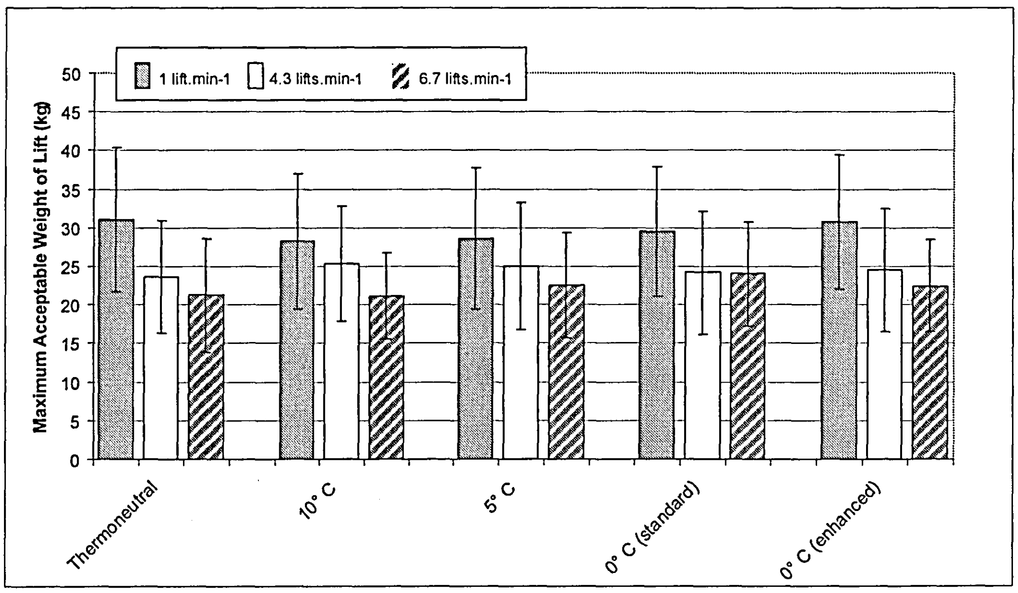

Figure 18. Mean maximum acceptable weight of lift in each condition (columns represent means, error bars represent ± 1 standard deviation).

The mean MAWL for each lifting frequency by environment is presented in figure 18.

Maximum Acceptable Weight of Lift – ANOVA

All of the data for MAWL were normally distributed. Mauchly's test was significant for frequency and the interaction so a Greenhouse-Geisser correction was applied to these effects as sphericity could not be assumed. There was a significant main effect for frequency [$F(1.4,14.8) = 34.4$, $P<0.001$]. The main effect for environment and the interaction effect were not significant.

Maximum Acceptable Weight of Lift – Post Hoc Tests

The significant main effect for frequency was investigated further using Tukey's HSD post hoc tests. The MAWL was significantly higher ($P<0.05$) when lifting at 1 lift.min^{-1} compared to 6.7 lifts.min^{-1}. There were no other significant differences.

Maximum Acceptable Weight of Lift – Effect Sizes

Generalised η^2 effect sizes were calculated for both the main effects and the interaction and are presented in table 25.

Source	*Gen η^2*	*effect*
Environment	0	None
Frequency	0.15	Medium
Interaction	0.01	None

Table 25. Generalised η^2 effect sizes for Maximum Acceptable Weight of Lift.

4.4 Rating of Perceived Exertion (RPE)

The mean RPE (average of the three ratings taken during the final 15 minutes) for each lifting frequency by environment is presented in figure 19 below. Note that, although the RPE scale runs from 6 to 20, the y axis originates at 0 for sake of clarity.

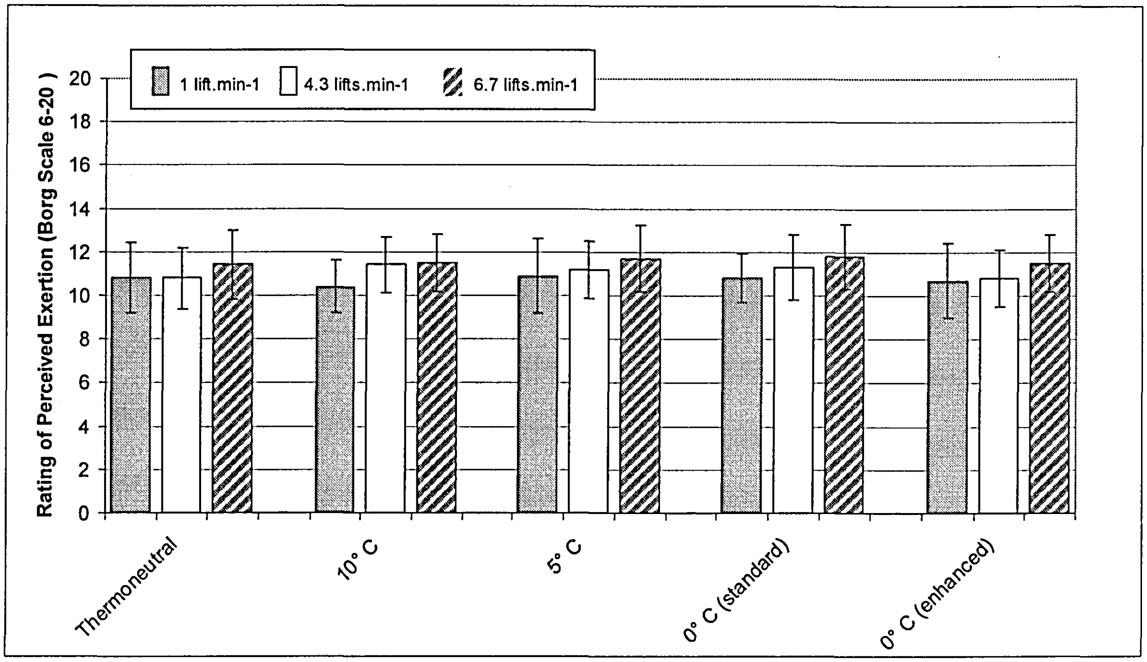

Figure 19. Mean rating of perceived exertion in each condition (columns represent means, error bars represent ± 1 standard deviation).

Rating of Perceived Exertion – ANOVA

Six of the 15 data sets were not normally distributed and transformations were unsuccessful. Transformations attempted included taking the natural logarithm and the reciprocal of the square root. As with the hot study, Friedman tests for multiple repeated samples were performed as a limited alternative. The results of the Friedman tests are presented in table 26.

Factor	*n*	*Chi-Square*	*Df*	*Asymp. Sig*
Environment	12	7.4	4	ns
Frequency	12	16.7	2	<0.001

Table 26. Friedman tests of main effects for ratings of perceived exertion.

The main effect for frequency was significant according to the Friedman analysis.

Analysis of Variance has been widely reported to be robust to violations of underlying assumptions (Keppel, 1973) so an ANOVA was also conducted on these data. Mauchly's test was significant for the frequency main effect so the Greenhouse-Geisser correction was applied. There was a significant main effect for frequency [$F(1.25, 13.7) = 10.4$, $P<0.005$]. The main effect for environment and the interaction effect were not significant.

Rating of Perceived Exertion – Post Hoc Tests

The significant main effect for frequency was investigated further using nonparametric Wilcoxon Signed Ranks tests for Matched Pairs. The RPE was significantly higher at 6.7 lifts.min^{-1} ($P<0.01$) compared to the other two frequencies. The difference between 1 lift.min^{-1} and 4.3 lifts.min^{-1} was not significant.

As with the omnibus F-test, the possibility that parametric analysis might be sufficiently robust to the violations of assumptions led to a follow-up investigation using Tukey's HSD post hoc tests. Despite the significant omnibus F, Tukey's tests were unable to identify any significant pairwise differences. It was possible to perform post hoc analysis using the work around in SPSS detailed in chapter 3 and also used in the hot study. Pairwise comparisons using the Bonferroni correction showed that RPE was significantly higher at 6.7 lifts.min^{-1} ($P<0.01$) compared to the other two frequencies. The difference between 1 lift.min^{-1} and 4.3 lifts.min^{-1} was not significant. The results of the parametric and nonparametric analysis for RPE were the same for both the omnibus and post hoc tests.

Ratings of Perceived Exertion – Effect Sizes

Generalised η^2 effect sizes were calculated for both the main effects and the interaction and are presented in table 27.

Source	***Gen*** η^2	***Effect***
Environment	0.01	None
Frequency	0.06	Small
Interaction	0.01	None

Table 27. Generalised η^2 effect sizes for Ratings of Perceived Exertion.

4.5 Grip Strength Change

The mean change in grip strength from pre- to post-session is presented in figure 20 below.

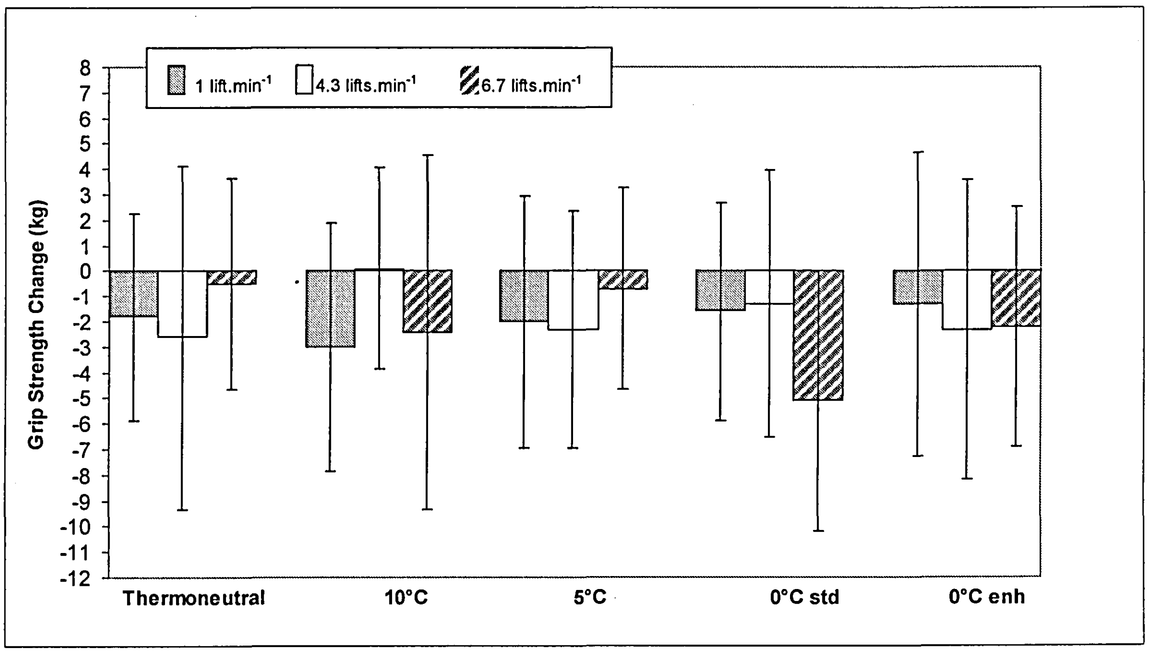

Figure 20. Mean change in grip strength in each condition (columns represent means, error bars represent ± 1 standard deviation).

Grip Strength Change – ANOVA

Two of the thirty data sets were not normally distributed but this was considered to have a minimal effect on the subsequent analysis. Mauchly's test was significant for the interaction between environment and frequency and the Greenhouse-Geisser correction was therefore applied to this effect. There were no significant main effects nor any significant interaction effects for mean grip strength change.

Grip Strength Change – Effect Sizes

Generalised η^2 effect sizes were calculated for all of the main effects and interactions. There was a small effect for time (Gen $\eta^2 = 0.02$) only.

4.6 Mean Skin Temperature

Data for mean end skin temperature (mean of final two minutes) were incomplete because the skin thermistors frequently became detached or broke during testing. There were a total of 81 sessions where skin data were complete out of a possible 180. The means and standard deviations for the complete data sets are presented in figure 21. No further statistical analysis was possible because of the lost data.

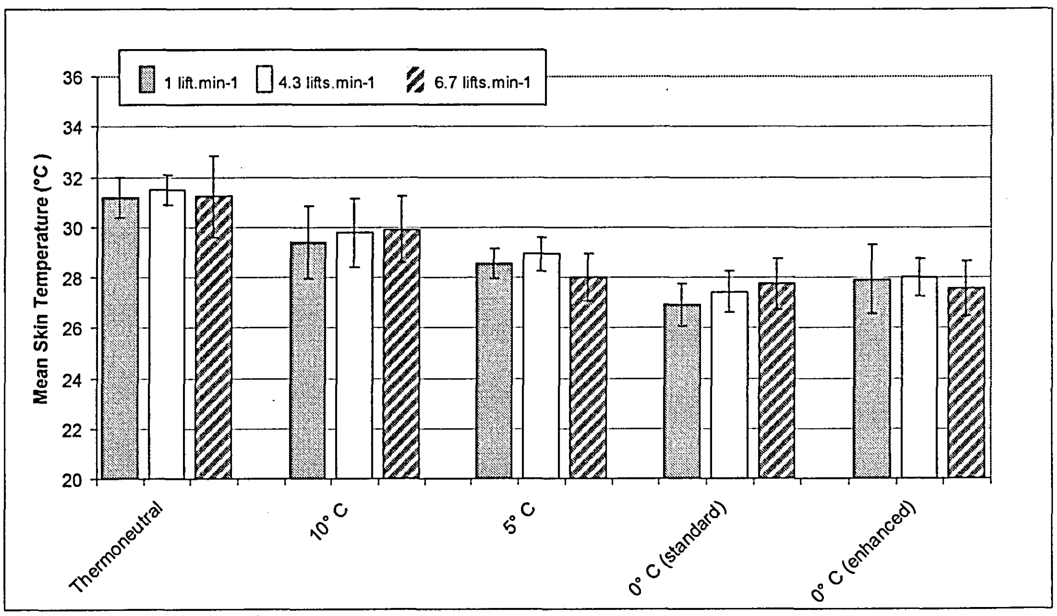

Figure 21. Mean skin temperature in each condition (columns represent means, error bars represent ± 1 standard deviation).

4.7 Finger Surface Temperature

The mean finger surface temperature (mean of final two minutes) in each condition is presented in figure 22 below.

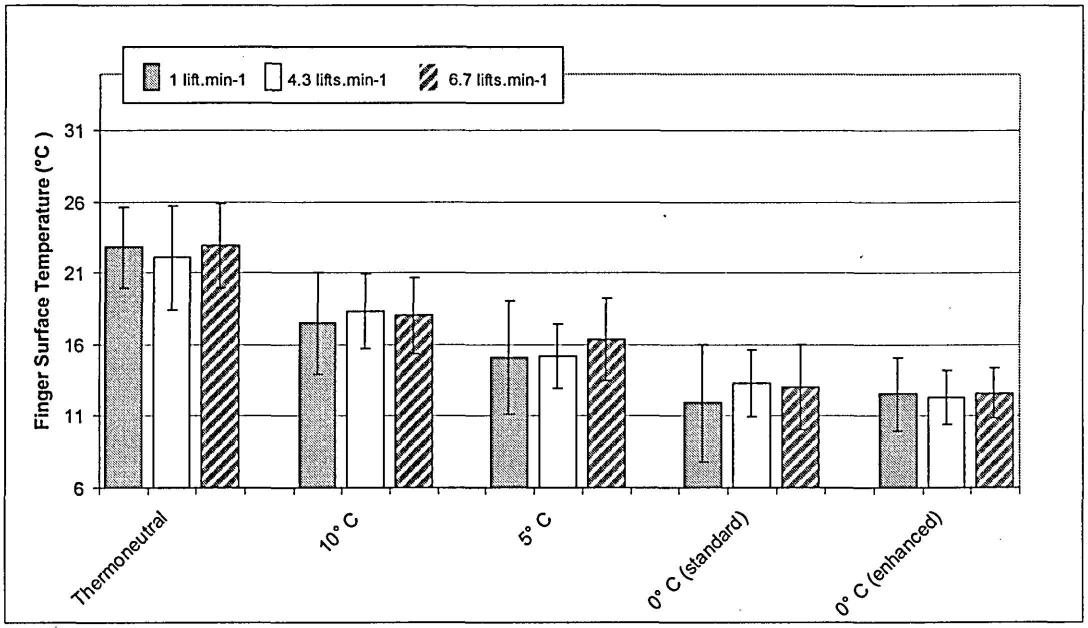

Figure 22. Mean finger surface temperature in each condition (columns represent means, error bars represent ± 1 standard deviation).

Finger Surface Temperature – ANOVA

The data for mean finger surface temperature were all normally distributed. Mauchly's tests were significant for environment and the interaction so Greenhouse Geisser corrections were applied to these effects. There was a significant main effect for environment [$F(1.3,6.5) = 56.1$, $P<0.001$]. The main effect for frequency and the interaction were not significant.

Finger Surface Temperature – Post Hoc Tests

The significant main effect for environment was investigated further using Tukey's HSD post hoc tests. Tukey's tests did not identify any significant differences between environments so a follow-up in SPSS was conducted using the Bonferroni correction for multiple pairwise comparisons. Mean finger temperature was significantly higher in the thermoneutral condition compared to all of the other conditions ($P<0.05$). It was also significantly higher in 10° C compared to both 0° C (standard) and 0° C (enhanced) (P<0.05). Mean finger temperature was also significantly higher in 5° C compared to both conditions at 0° C (P<0.05).

Finger Surface Temperature – Effect Sizes

Generalised η^2 effect sizes were calculated for both the main effects and the interaction and are presented in table 28.

Source	***Gen η^2***	***effect***
Environment	0.72	Large
Frequency	0.01	None
Interaction	0.03	Small

Table 28. Generalised η^2 effect sizes for Mean Finger Surface Temperature.

4.8 Synopsis

The six null hypotheses were tested using a combination of parametric and nonparametric omnibus and follow-up tests.

The first null hypothesis (H_01) stated that frequency of lift does not significantly affect the dependent variables (grip strength excluded). The frequency main effects for heart rate, core temperature, ratings of perceived exertion and maximum acceptable weight of lift were all significant (all P <0.001). This null hypothesis is therefore rejected.

The second null hypothesis (H_02) stated that there is no difference in physiological strain when lifting in a cold environment compared to lifting in a thermoneutral environment. There was a significant environmental main effect for core temperature and post-hoc tests identified the difference between the thermoneutral and 0 °C (standard ensemble) as significant (P <0.01). The null hypothesis is rejected.

The third null hypothesis (H_03) stated that there is no difference in MAWL when lifting in a cold environment compared to lifting in a thermoneutral environment. There was no significant main environmental effect for MAWL therefore the null hypothesis is retained.

The fourth null hypothesis (H_04) stated that there is no difference in grip strength after lifting in cold environments compared to lifting in a thermoneutral environment. There was no significant main environmental effect for grip strength change therefore the null hypothesis is retained.

The fifth null hypothesis (H_05) stated that there is no difference in core temperature and heart rate when lifting in 0 °C in a standard clothing ensemble compared to lifting in 0 °C in an enhanced clothing ensemble. There were no significant differences in these two variables in the two environmental conditions specified. The null hypothesis is therefore retained.

The final null hypothesis (H_06) stated that there is no difference in finger surface temperature when lifting in a cold environment compared to lifting in a thermoneutral environment. There was a significant environmental main effect for mean finger surface temperature therefore the null hypothesis is rejected.

5. Discussion

The purpose of this study was to investigate the physiological strain and the amount of weight lifted when participants were exposed to a range of cold environments and required to lift at different frequencies. The results will be discussed with respect to previous findings in the literature. Any unexpected or anomalous findings will be identified and commented upon. The practical significance of the results will be assessed along with the limitations in the research design and suggestions for possible improvements will be made.

Findings with Respect to Previous Studies

Most investigations conducted on the responses of workers in the cold have taken the form of self-reporting questionnaires rather than experimental research. It is therefore difficult to draw direct comparisons with these findings.

Heart Rate

There was no environmental main effect for heart rate which was not expected since heart rate usually decreases in the cold to compensate for vasoconstriction and to prevent hypertension. In fact mean heart rates remained remarkably stable across environments, only varying between approximately 104 and 107 beats.min^{-1}. It is possible that the normally observed bradycardia in the cold was offset by the increased metabolic rate associated with lifting. The mean heart rate in the thermoneutral condition in the hot study (chapter 4) was 104.6 beats.min^{-1}, a difference of only 2 beats.min^{-1} compared to the present study. There was an upward trend in mean heart rate in the hot study across environments demonstrating that the cardiovascular response to working in the cold is different. Considering the decrease in core temperature across environments here (to be discussed), this would suggest that heart rate is an inappropriate measure of cold stress when working in indoor environments between 16 °C and 0 °C.

The significant main effect for frequency was in agreement with previous findings. In contrast with the hot study however where the mean heart rates at both 4.3 and 6.7 $lifts.min^{-1}$ were significantly higher than 1 $lift.min^{-1}$, only 6.7 $lifts.min^{-1}$ was significantly higher than 1 $lift.min^{-1}$. The mean heart rates at 4.3 and 6.7 $lifts.min^{-1}$ were 120.2 and 136 $beats.min^{-1}$ respectively in the hot study. This compares with mean values of 111.2 and 127.1 $beats.min^{-1}$ in the present study, providing further evidence of a blunted cardiovascular response to working in the cold.

Core Temperature

Environment and frequency significantly affected core temperature as they did in the hot study although in the previous case the interaction between the two was significant.

The only environment where core temperature was significantly lower than in thermoneutral was 0 °C (standard ensemble). The core temperature at 0 °C (enhanced ensemble) was not significantly lower than thermoneutral suggesting that the additional clothing in this ensemble, consisting of woolly hat and long thermal leggings, provided some measure of protection against heat loss.

Core temperature was significantly higher when lifting at both 4.3 and 6.7 $lifts.min^{-1}$ compared to 1 $lift.min^{-1}$. The mean core temperatures at all three frequencies were all approximately 0.5 °C lower in the present study compared to the hot study. Although there was no significant interaction, the core temperatures at 1 $lift.min^{-1}$ in 10 °C, 5 °C and both 0 °C conditions were all between 36.0 and 36.2 °C. This is concerning because the core temperature would probably be expected to fall further during a longer exposure. It would appear that the lowest lifting frequency in these lower air temperatures does not raise the metabolic rate sufficiently to prevent this decline.

Maximum Acceptable Weight of Lift

The environment did not have a significant effect on MAWL. This is contrary to the findings of the hot study where there was a downward trend in amount of weight lifted across environments. One point of interest is that, overall, mean weights were between 4 and 6 kg higher in the present study. It is possible that the participants deliberately increased their workloads in order to further raise their metabolic rates in an attempt to maintain thermal homeostasis.

As expected, frequency of lift had a significant effect on MAWL. The maximum acceptable weight at 6.7 lifts.min^{-1} was significantly lower than at 1 lift.min^{-1}. In the hot study 6.7 lifts.min^{-1} was also significantly lower than 4.3 lifts.min^{-1} but that was not the case in the present study. Again, when examining the mean values across frequencies, they were all much higher than in the hot study. The mean MAWL at thermoneutral in the present study was 29.6 kg compared to 22.4 kg previously. Indeed, at 1 lift.min^{-1}, some of the participants were lifting around 40 kg. This value is recorded in the tables of Snook & Ciriello (1991) as being acceptable to only 10% of the male working population. This suggests that if heavier weights are selected as a way of keeping warm, some workers might be putting themselves at increased risk of injury to the musculoskeletal system.

With respect to the published tables of Snook & Ciriello (1991), the participants exceeded the weight acceptable to 75% of the working population at 1 $lift.min^{-1}$. At 4.3 $lifts.min^{-1}$ the mean weight lifted exceeded the 50% limit and at 6.7 $lifts.min^{-1}$ the 25% limit was exceeded. The mean weight lifted at 6.7 $lifts.min^{-1}$ also exceeded the reported physiological limit of 33% $\dot{V}O_{2max}$.

As with the hot study, the mean box-weights lifted in this study all exceeded the guidelines published in the HSE MHOR guidance document (HSE, 1998). The participants exceeded the recommended limits at each of the three lifting frequencies.

Ratings of Perceived Exertion

There was no environmental effect for ratings of perceived exertion. This was perhaps to be expected as the findings in the literature are equivocal on this point. The stability of RPE across environments mirrors the relative stability of both heart rate and MAWL also found in this study.

According to the results of the nonparametric Wilcoxon signed-ranks tests, ratings of perceived exertion were significantly higher when lifting at 6.7 $lifts.min^{-1}$ compared to both other frequencies. The results of a similar analysis in the hot study showed that there was a significant difference in RPE between all frequencies. As reported in the hot study, Wu & Chen (1997) and Asfour *et al.* (1983) have all reported consistent rises in RPE as the frequency of lift increases in a thermoneutral environment.

Grip Strength Change

Mean grip strength was not significantly affected by time, environment nor frequency. It is probable that the fall in core temperature during the sessions, though stimulating vasoconstriction to a certain degree, was not sufficient to reduce force production in the hands. The lifting task also required an isometric contraction of the fingers and upper-limbs in general probably promoting blood flow to the working muscles in these areas. The thermal properties of the box material would have also been a factor since plastic exhibits low thermal conductivity. This would mean that heat loss from the hands via conduction to the box would have been very small.

Mean Skin Temperature (T_{msk})

Only descriptive data are available for mean T_{msk} however, upon examination, a definite trend emerges. Mean T_{msk} declined in a linear fashion from thermoneutral through to 0 °C (standard ensemble). In the latter environment the mean T_{msk} across lifting frequencies was approximately 4 °C lower compared to the former. There was a departure from this linear trend at 0 °C (enhanced ensemble) where mean T_{msk} was ~0.5 °C higher than at 0 °C (standard ensemble). It seems that the increased insulative qualities of the enhanced ensemble did offset some of the effects of the cold environment.

Finger Surface Temperature

As with mean T_{msk}, mean finger surface temperature declined in a linear fashion across conditions although in this case the enhanced clothing ensemble worn at 0 °C did not appear to confer any benefit. Mean finger temperature was significantly higher in the thermoneutral environment compared to all other environments. This decline is consistent with the findings in published literature

(Havenith *et al.,* 1995; Heus *et al.*, 1995) and can be explained by the phenomenon of physiological amputation whereby blood vessels in the peripheries are gradually constricted to reduce heat-loss. The extent of physiological amputation is unknown since temperature measurements at sites on the hand and lower arm were not taken.

Unexpected Findings

That there was no significant environmental effect on mean heart rate was perhaps a surprise when viewed in isolation. However, the lack of any significant findings with respect to grip strength suggest that vasoconstriction, certainly in the upper extremities, did not occur to any great extent. The absence of any hypertensive stimulus would mean that heart rate would not be expected to decline. It should be remembered that hand temperature was not measured so the absence of vasoconstriction is speculation based on the consistency of grip strength measurements only. Mean maximum acceptable weights of lift were also extremely consistent across environments meaning that the participants were always working at similar intensities.

The higher maximum acceptable weights of lift recorded here compared to the hot study were unexpected. Certainly the cold was unpopular with most of the participants, a fact communicated to the investigators on more than one occasion! A strategy to keep warm alluded to by a number of the participants was to stimulate heat production by lifting more weight. This agrees with the investigator's own experiences in the army where physical tasks were often readily undertaken when out in the field as a way of keeping warm.

Practical Significance of the Findings

The difference in mean heart rate between 1 lift.min^{-1} and 6.7 lifts.min^{-1} was approximately 47 beats.min^{-1}. The calculated generalized η^2 effect size was large at 0.51. This compares to 0.63 in the hot study, demonstrating that the mean heart rate responses in the selected cold environments of the present study were smaller. The lack of environmental effect for heart rate suggests that it is a poor predictor of cold stress in working environments between 16 °C and 0 °C since core temperature was seen to decline during the sessions. The safety margin for downward departures from normal core temperature is smaller than that for upward movements. Hypothermia is diagnosed as a core temperature of 35 °C and below, only a 2 °C fall from the generally considered norm of 37 °C. Conversely, a 2 °C increase to 39 °C might signal the onset of heat exhaustion but many published studies routinely report higher core temperatures than these in participants exercised to voluntary exhaustion.

In the present study the lowest mean aural temperature was 36.0 °C in the 1 lift.min^{-1} condition at 0 °C (standard ensemble). There was considerable inter-individual variation however and some participants were measured at very close to the withdrawal criterion of 35.5 °C. Clearly this particular combination of environment, lift frequency and clothing ensemble provided little protection against heat loss and a longer exposure would have probably resulted in the onset of hypothermia. Even at 10 °C, 5 °C and 0 °C (enhanced ensemble), the mean core temperature at 1 lift.min^{-1} was only around 36.2 °C. How long it would have taken for hypothermia to occur is not known but it is clear that individuals performing very low frequency or sedentary work in the cold should pay special attention to the length of exposure to the conditions and to the insulative properties of their clothing. The relative effect sizes for environment (0.1, small) and frequency (0.22, medium) again indicate, as with heart rate, that the frequency of lift is of particular importance when considering the physiological strain experienced by workers in the cold.

Mean maximum acceptable weight of lift varied by only ~ 1 kg across all environments. Across frequencies the effect size of 0.15 was medium however. According to tables of Snook & Ciriello (1991) the mean MAWL at 1 lift.min^{-1} across environments of 29.6 kg would be acceptable to only 50% of the male working population. One would assume from this that the sample consisted of young, strong, athletic men but this was far from the case. Most were in their twenties admittedly but many classed their activity levels as low and a few were completely sedentary. For comparison, consider that the mean MAWL at 1 lift.min^{-1} across environments in the hot study was about 7 kg lower, a weight acceptable to 75% of the male working population (Snook & Ciriello, 1991). Furthermore, the mean MAWL across frequencies in thermoneutral was 25.3 kg in the present study compared to 21.1 kg in the hot study. The thermoneutral conditions in the two studies were dissimilar but the clothing ensembles also differed and the relative Clo values should have ensured thermal comfort in both studies. The differences in MAWL values between the two studies are most likely due to the participants selecting heavier weights so as to increase their activity levels and therefore maintain thermal comfort. The mean values reported at the three lifting frequencies all exceeded the 75% limit stipulated by Snook (1978) suggesting that the participants were at increased risk of suffering a lower back injury. The reader's attention is again drawn to the comments made by Dempsey (1998) regarding the lack of epidemiological evidence to support a causal relationship between manual handling tasks and the onset of lower back disorders.

As with the hot study there were considerable problems analysing the ratings of perceived exertion data because of the numerous departures from a normal distribution. The generalised η^2 effect size for frequency was just 0.06 which is classed as small. The mean ratings barely varied; a range of less than 0.3 across environments and only slightly more (~0.4) across frequencies. The lowest mean RPE was 10.4 at 1 lift.min^{-1} in 10 °C and the highest, 11.7 at 6.7 lifts.min^{-1} in 0 °C (standard ensemble). One could again put forward the suggestion that the participants were being extremely conservative in their assessments but the ratings reported are in agreement with the remarkably stable heart rates also recorded.

There was a small generalised η^2 effect between pre- and post-session grip strength of 0.02 despite the lack of significant result from the analysis of variance. The mean difference of ~2 kg was more likely to be the result of general fatigue as opposed to any cold effect. The protocol for using the grip dynamometer was standardised but it is possible to produce large variations in recorded forces by making subtle adjustments to the way it is held. For this reason the grip strength data and any conclusions drawn from them should be treated with great caution.

Mean T_{msk} declined linearly across environments except in 0 °C whilst wearing the enhanced ensemble. This suggests that further investigation is necessary to discover the optimal clothing ensemble for use during manual handling tasks in the cold. Special attention would need to be paid to the hobbling effect of clothing and how this might affect the execution of said tasks.

The decline in finger surface temperature is especially interesting. The finding itself is not surprising but the implications for anyone involved in manual handling should not be ignored. Mean finger surface temperature in the 0 °C environments were 10 °C lower compared to the thermoneutral environment. All mean finger surface temperatures in the 10 °C environment and below were less than 20 °C, dropping to ~13 °C at 0 °C (both ensembles). Studies have reported slight decreases in manual dexterity at finger surface temperatures below 20 °C (Schieffer *et al.*, 1984) and Heus (1993) recommended a safe minimum local skin temperature of about 15 °C. The decreases in manual dexterity reported are usually for complex motor tasks and it is probable that this is less critical for gross motor tasks such as lifting. It is also the case that gloves could usually be worn during the performance of this type of task. If, for any reason, gloves cannot be worn then care should be taken to avoid finger temperatures falling to a point where there may be a loss of sensibility or mobility. In addition to the inter-individual differences encountered in this study, Enander (1984) has also highlighted the fact that there may be considerable differences in hand and finger temperature responses between the sexes and different ethnic groups. Given the fact that the workforces employed in cold environments are likely to be composed of both sexes and of numerous ethnic groups then it would suggest that further investigation is merited into these groups' particular responses to the cold.

Limitations of the Design

Many of the limitations inherent in the design of the hot study are also present here. The first of these is the choice of repeated measures which, although generally accepted to have greater power than designs where independent groups are used (Huck, 2000), has some potentially undesirable effects. Fatigue and boredom can set in and there may also be a carry-over or learning effect from one session to the next which distorts the results. The participants in this study were again required to attend 15 test sessions in addition to orientation and MAWL stabilisation so these were very real concerns.

As with the previous study, many of the skin thermistors became detached during testing. It had been thought that excessive sweating was the main cause but as this did not occur in the present study it is likely that friction from clothing may have been the major culprit. This is supported by the fact that not a single finger thermistor fell off during any of the sessions.

As in the hot study, only males under the age of 40 years (most of whom had no industrial experience) were studied so care should be taken when interpreting the results with respect to other populations. The results are also only applicable to the floor to knuckle-height lifting task. They should not be generalised to any other type of lift (floor to shoulder-height or knuckle to shoulder-height for example) or other manual handling task.

6. Conclusions

The lift frequency had a significant effect on both physiological strain and the amount of weight lifted. Mean heart rate was significantly higher when lifting at 6.7 lifts.min^{-1} compared to 1 lift.min^{-1}. Mean core temperature was significantly lower at 1 $lift.min^{-1}$ compared to both of the other frequencies.. There was also an environmental effect on mean core temperature. Mean maximum acceptable weight of lift was significantly lower at 6.7 $lifts.min^{-1}$ compared to 1 $lift.min^{-1}$ and overall, mean weights lifted were higher than in the hot study. Mean ratings of perceived exertion were significantly higher at 6.7 $lifts.min^{-1}$ compared to both of the other frequencies. Grip strength change was unaffected by environment or frequency but there was a small generalised η^2 effect between pre- and post-session readings.

Overall, mean heart rates and ratings of perceived exertion exhibited little variation across all conditions and MAWL varied little across environments. In all environments below thermoneutral the mean end core temperature was 36.2 °C or below when lifting at 1 $lift.min^{-1}$. This suggests that workers performing low frequency or sedentary tasks might be at risk of hypothermia during prolonged exposure to cold conditions if sufficient attention is not paid to wearing a suitable clothing ensemble. The finding that mean maximum acceptable weights of lift were higher than in the hot study suggest that participants increased their activity levels as a method of maintaining thermal comfort. A comparison with published tables showed that some participants were lifting a load that would be acceptable to only 10% of the male working population. It is possible that this strategy might place a worker at greater risk of chronic or acute musculoskeletal injury.

6 The Effects of Face-Cooling on Physiological Strain During an Intermittent Lifting Task in a Warm-Humid Environment

1. Summary

This chapter presents an original study into the effects of a face-cooling strategy on markers of physiological strain during an intermittent lifting task in a warm-humid environment.

2. Introduction

The findings from the hot study demonstrated that working in warm and hot conditions significantly affected some physiological responses. In the warm-humid environment (30 °C, 65% RH, 27 °C WBGT) core temperature was significantly higher when lifting at 6.7 lifts.min^{-1} compared to the thermoneutral environment. Mean skin temperature was also ~3 °C higher in the warm-humid environment compared to thermoneutral. These results were obtained after just 35 minutes of lifting and it is reasonable to assume that the physiological strain would have been greater had the session been prolonged. A typical working shift totalling nine hours is usually divided into four segments which are separated by a half-hour lunch break and a 15-minute break either side. Each segment lasts two hours so a worker would likely be exposed to an uncomfortable thermal environment for this period of time without respite. It is probable then that workers in these environments would experience symptoms of heat stress during their working day. Any strategies that could alleviate these symptoms would be of considerable benefit.

Food preparation facilities like bakeries and heavy industries such as steel and coal-mining are examples of workplaces that may present a thermal hazard to employees. In many instances the working conditions also necessitate the wearing of protective clothing which imposes further strain by reducing heat loss from the body. These problems mean that practical strategies designed to reduce heat strain in the workplace are of particular interest both to employees and employers. Face-cooling is one such strategy that has been recently studied but to understand its possible role in the mediation of heat strain a little background information is required.

There is some acceptance now for the theory of centrally mediated fatigue (Davis, 1995) where changes in the central nervous system are responsible for increased perceptions of exertion (Nielsen & Nybo, 2003) and reduced work output. It is also believed that increases in core temperature may be one of the factors responsible for the onset of central fatigue (Pitsiladis *et al.,* 2002). Though the mechanisms are complex and poorly understood it seems that changes in serotoninergic and dopaminergic activity within parts of the brain play a role in this phenomenon. Because direct measurement of these neurotransmitters is difficult, concentrations of the hormone prolactin in peripheral circulation are often studied instead. Prolactin is secreted from the anterior pituitary gland under hypothalamic control by two neurotransmitters, prolactin releasing hormone (PRH) and prolactin inhibiting hormone (PIH). The latter has been identified as dopamine; the former is believed to be serotonin (Marieb, 1998) therefore changes in prolactin concentration are used as indirect markers of the serotoninergic and dopaminergic activity in the brain.

Studies have reported significantly elevated levels of prolactin during exercise in the heat compared to cold and normal conditions (Pitsiladis *et al.,* 2002; Low *et al.*, 2005). Low *et al.* (2005) reported that serum prolactin measured post-exercise was significantly positively correlated (all P<0.001) to core, skin and mean body temperature and also to end heart rate. These relationships were only significant for the participants whose core temperature exceeded 38 °C however. This supports a previously proposed theory that there may be an exercise-induced threshold temperature of 38 °C above which prolactin starts to rise exponentially (Radomski *et al.,* 1998). Armand-Da-Silva *et al.* (2004) warmed 10 male participants in a sauna until their core temperatures reached 38.5 °C then asked them to perform 14 minutes of cycling at approximately 63% of maximum power output ($\dot{V}O_{2max}$) in a 35 °C environment. Plasma prolactin was significantly elevated (P<0.05) post-exercise compared to the control condition where no pre-warming occurred (1598 $mU.l^{-1}$ vs. 225 $mU.l^{-1}$). Although blood was not collected immediately post-sauna it is reasonable to assume that, at 38.5° C, plasma prolactin would already have started to rise markedly. This suggests that it is the rise in core temperature (not necessarily exercise-induced) that is responsible for increased prolactin secretion or hyperprolactinaemia. Recent studies (Armand-Da-Silva *et al.*, 2004; Mundel *et al* ., 2004) have examined the effects of face-cooling on participants performing a continuous cycle-ergometer exercise protocol. Mundel *et al.* (2004) reported significantly lower (P<0.05) plasma prolactin levels in face-cooled subjects undertaking a 40-min cycle ergometer task at 65% $\dot{V}O_{2max}$. Heart rate was also ~5 $beats.min^{-1}$ lower (significance not reported) during face-cooling but there was no difference in ratings of perceived exertion. Armand-Da-Silva *et al.* (2004) reported that in a shorter 14 minute cycling task both plasma prolactin

($P<0.05$) and ratings of perceived exertion (*ns*) were lower when face-cooling was provided.

It has been suggested that face-cooling, rather than directly cooling the brain as previously thought, affects thermal comfort by cooling local skin afferents (Frank *et al.,* 1999). The signals from these afferents are received by the pre-optic area of the hypothalamus together with temperature information from other internal and external sensors providing an integrated indication of thermal strain (Jessen, 1985). The studies by Armand-Da-Silva *et al.* (2004) and Mundel *et al.* (2004) both reported reductions in local skin temperature and plasma prolactin during face-cooling whilst core temperatures remained unchanged suggesting that face-cooling can modulate the integrated response to thermal strain. Furthermore, these components of thermal strain could be integrated into the overall perception of exertion during a lifting task thus providing subjective assessments of the efficacy of the face-cooling intervention. The Borg RPE scale (1970), used in the previous two studies, would seem to be an appropriate tool in this respect.

The purpose of this investigation was to assess the effects of face-cooling on individuals performing an intermittent, whole-body lifting task in a warm-humid environment. It was hoped that the results would give an insight into whether or not periodic face-cooling with a cold water spray was a practical and effective method of reducing physiological strain and perceived exertion in an occupational setting. The findings could have benefits for workers employed in uncomfortable hot environments.

3. Methods

3.1 Participants

Ten male participants between the ages of 18 and 40 years were recruited to take part in the study. Anyone with a previous history of musculoskeletal disorders were excluded from the study, as were participants with illness, disorders or diseases known to affect the thermoregulatory system (e.g. thyroid conditions). All participants were white, northern Europeans except one who was from southern Europe. Participant details are presented in table 29 below.

n	*Age (years)*	*Stature (m)*	*Mass (kg)*	*Knuckle Height (m)*	*Body Mass Index*	*Body Surface Area (m^2)*
10	28.4 ± 5.1	1.82 ± 0.1	79.5 ± 13.1	0.81 ± 0.05	24 ± 1.8	2 ± 0.1

Table 29. Participant Details (mean ± 1 standard deviation). Body Surface Area from Mosteller (1987).

3.2 Procedures

The participants reported to the environmental chamber at the Centre for Sport and Exercise Science (CSES), Sheffield Hallam University. Stature (stadiometer, Holtain, Crymych, UK), mass (Balance Scales, Avery, Birmingham, UK) and knuckle height (distance from floor of second metacarpo-phalangeal joint when standing relaxed) were measured.

Immediately upon arrival the participant provided a urine sample so that hydration status could be assessed. Urine osmolality was assessed by an osmometer (Advanced Micro Osmometer Model 3300, Advanced Instruments, Norwood, MA). A sample of venous blood was then taken from the participant's ante-cubital vein. The participant was recumbent on a treatment bench during the procedure and a tourniquet was not used. Some studies have reported changes in concentrations of certain blood components with the use and nonuse of tourniquets (Rosenson *et al.*, 1998). Whether prolactin is affected is not known but it was decided to err on the side of caution and avoid the use of a tourniquet in this case. A 9 ml sample was collected in an SST (Silica Clot Activator, Polymer Gel, Silicone-Coated Interior) BD Vacutainer (Becton, Dickinson: Franklin, NJ) flask which was then inverted five times and stored upright while the blood clotted. A full description of the treatment of the blood samples post-collection is provided in a later paragraph.

After blood collection a skin thermistor (Grant Instruments, Cambs. UK) was fixed to the middle of the forehead with Micropore tape (3M, USA) and adhesive gauze (Fixomull stretch, Beiersdorf AG, Hamburg, Germany). An aural bead thermistor (Grant Instruments, Cambs. UK) was fitted into the ear, fixed into position with cotton wool and tape and insulated with a pair of industrial ear defenders. As in the previous two studies the aural thermistor used was the modified version. Both thermistors were connected to a data logger (Squirrel 1021, Grant Instruments, Cambs. UK) so that measurements could be recorded throughout testing. The participant also put on a heart rate monitor (Polar S610, Polar, UK) prior to putting on the clothing ensemble.

Each participant then dressed in a standard clothing ensemble (table 30). The clothing ensemble was chosen to replicate as closely as possible the clothing observed to be worn during the site visits. No gloves were worn. The estimated Clo value was designed to ensure that the participant was comfortable whilst standing in the thermally neutral environment.

Clothing Item	*Clo*
Underwear (shorts, socks supplied by participant)	0.05
Working trousers (cotton/polyester) 9oz	0.25
Working jacket (cotton/polyester) 9oz	0.25
Safety boots	0.1
Estimated Clo of ensemble	**0.65**

Table 30. Standardised clothing ensemble and estimated Clo values.

3.2.1 MAWL Stabilisation

The participants were introduced to the psychophysical method of lift assessment in one session prior to the commencement of testing proper. The purpose of this session was to habituate the participant to the proposed lifting protocol and to ensure that they were able to consistently select an acceptable box-weight (i.e. to demonstrate the repeatability of the protocol). It also provided an opportunity to practice using the Borg RPE scale especially for those participants for whom the concept was unfamiliar. The protocol is described in detail in chapter 3.

3.2.2 Main Experimental Sessions

There were two experimental sessions, one with a face-cooling intervention and the other without. The participants completed both sessions in a within-subjects design and the order of presentation was counter-balanced to minimise any carry-over effects. Both sessions were conducted in 27 °C WBGT (30 °C air temperature, 65% relative humidity) and the lift frequency was the same on both occasions (6.7 lifts.min^{-1}).

The protocol was similar to the previous two studies (detailed in Chapter 3) with the participants lifting for 20 minutes whilst adjusting the box weight and then for a further 15 minutes at the box weight selected. A tone from an audio tape was the cue to commence each lift and upon completion an assistant returned the box to its starting position. The starting box weight was randomised prior to each session by secreting bags of ball-bearings in the compartment created by the false bottom. Unlike the previous studies it was only possible to test one participant at a time on this occasion.

The participants were instructed to stop lifting after every five minutes for a period of 30 seconds. During this period the face and neck were towelled-down and, in the face-cooling session, a mist of very cold water from an atomiser was sprayed onto the face and neck for 10 seconds by the experimenter. The water was kept at a cold temperature (<5 °C) by keeping the atomiser in a bath of cold water surrounded by ice-bricks. In the control session the participants had their face and neck towelled-down but received no face-cooling. As stated, these conditions were presented in a balanced design so that half of the participants received face-cooling first and half did not. Drinking water was available *ad libitum*.

Heart rate, core and local skin temperatures were recorded throughout the session and ratings of perceived exertion (Borg 6-20 RPE scale) were taken every five minutes, immediately prior to the 30-second rest period. At the end of the session the final box weight was recorded as the maximum acceptable weight of lift (MAWL). The participant moved to the intermediate room and all recording equipment was removed. A post-session blood sample was then taken, following the same protocol as at the beginning.

Heart rate and temperature data were downloaded to a PC for analysis. The blood samples were then centrifuged (Heraeus Labofuge 400R) at 1800 RCF (4 °C) for 10 minutes. An aliquot of the separated serum for each sample was pipetted into an Eppendorf micro-tube and stored at -80 °C prior to radio-immunoassay analysis at the Clinical Chemistry Department, The Royal Hallamshire Hospital, Sheffield. The serum was batch-analysed for concentrations of prolactin and the results were notified by e-mail.

3.2.4 Withdrawal Criteria

The withdrawal criterion was set at an aural temperature of 38.5 °C to conform with ISO 9886. Heart rate was monitored simultaneously and consideration given to removing the participant if this exceeded 85% of their age-predicted maximum (based on the other objective and subjective measurements).

3.3 Hypotheses

The null hypotheses to be tested were:

1. ($H_0$1) There is no difference in serum prolactin after face-cooling (compared to no face-cooling) during a bout of intermittent box-lifting in a warm-humid environment.
2. ($H_0$2) There is no difference in ratings of perceived exertion with face-cooling (compared to no face-cooling) during a bout of intermittent box-lifting in a warm-humid environment.
3. ($H_0$3) There is no difference in local skin temperature (forehead) when receiving face-cooling during a bout of intermittent box-lifting in a warm-humid environment.

4. (H_04) There is no difference in heart rate when receiving face-cooling during a bout of intermittent box-lifting in a warm-humid environment.

3.4 Statistical Analysis

Heart rate, core temperature, local skin temperature and serum prolactin were analysed for significant differences using a two-way ANOVA with repeated measures on both factors. The factors were time (two levels) and treatment (two levels). Sphericity was assumed because of there were only two levels of the repeated measures. Maximum acceptable weight of lift and ratings of perceived exertion were both analysed using paired t-tests.

4. Results

4.1 Urine Osmolality

The urine osmolality measured for each participant prior to each session is presented in figure 23.

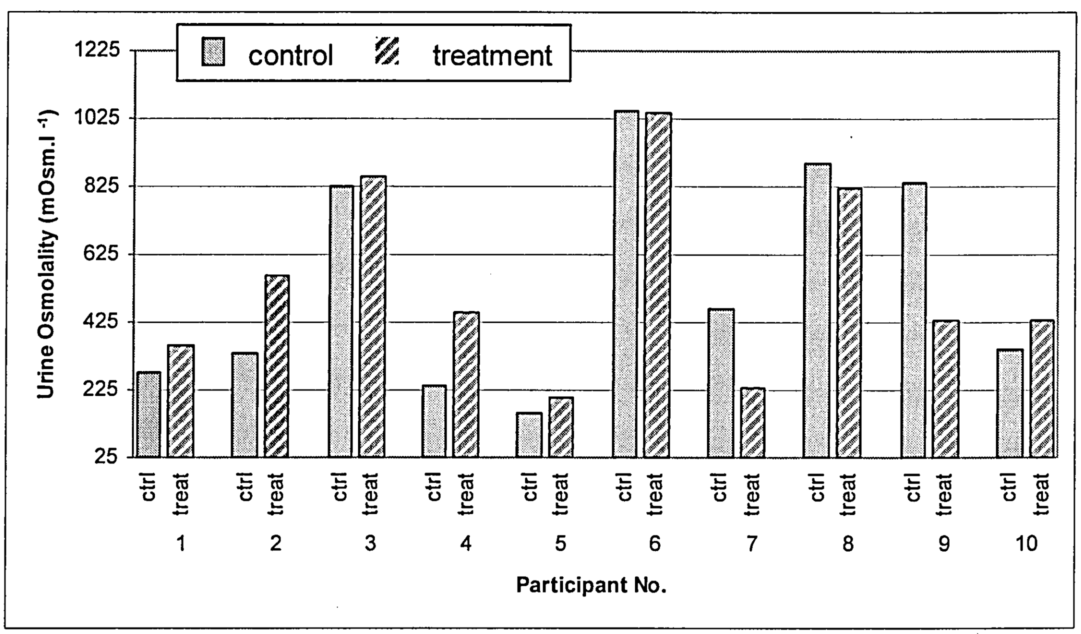

Figure 23. Urine osmolality for each participant in each session. Columns represent raw values.

4.2 Heart Rate

The mean pre- and post-heart rates for both the control and treatment conditions are presented in figure 24.

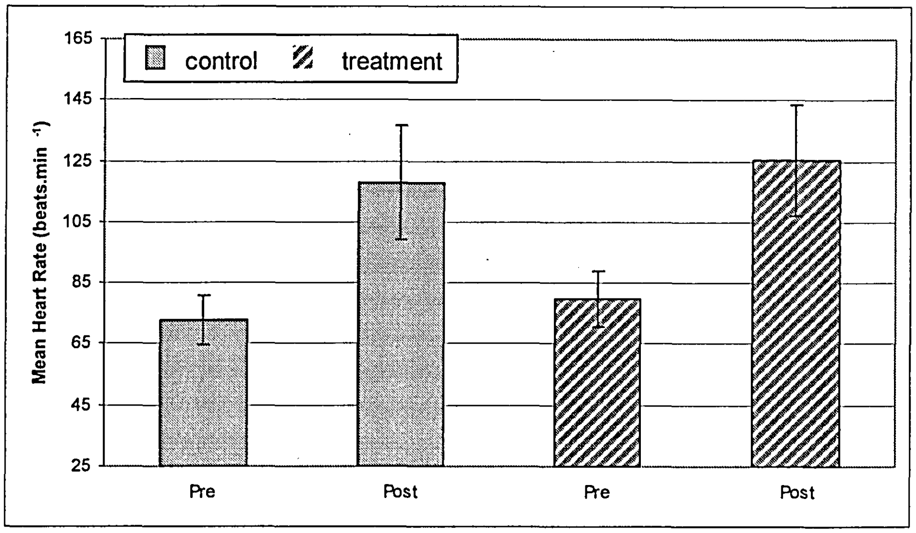

Figure 24. Mean heart rates (pre and post) in both conditions. Columns represent means; Error bars represent ± 1 standard deviation.

Heart Rate – ANOVA

Heart rate data were all normally distributed and sphericity was assumed. There were significant main effects for time [$F(1,9) = 109.8$, $P<0.001$] and treatment [$F(1,9) = 18.9$, $P=0.002$]. The interaction effect was not significant.

Heart Rate – Effect Sizes

Generalised η^2 effect sizes were calculated for both of the main effects and the interaction and are presented in table 31.

Source	*Gen η^2*	*effect*
Time	0.73	Large
Treatment	0.07	Small
Interaction	0	None

Table 31. Generalised η^2 effect sizes for Heart Rate.

4.3 Core Temperature

The mean pre- and post-core temperatures for both the control and treatment conditions are presented in figure 25.

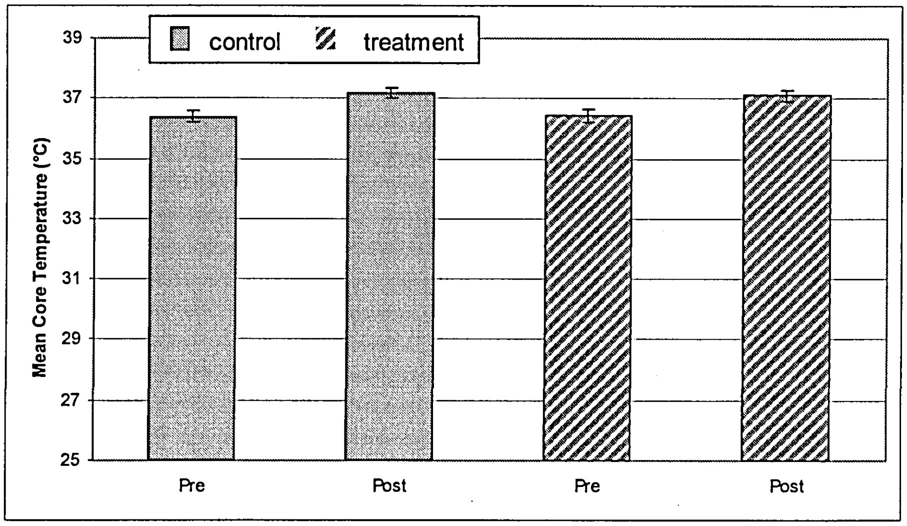

Figure 25. Mean core temperatures (pre and post) in both conditions. Columns represent means; Error bars represent ± 1 standard deviation.

Core Temperature – ANOVA

Core temperature data were all normally distributed and sphericity was assumed. There was a significant main effect for time [$F(1,9) = 110.9$, $P<0.001$]. The main effect for treatment and the interaction effect were not significant.

Core Temperature – Effect Sizes

Generalised η^2 effect sizes were calculated for both of the main effects and the interaction and are presented in table 32.

Source	***Gen η^2***	***effect***
Time	0.82	Large
Treatment	0	None
Interaction	0.02	Small

Table 32. Generalised η^2 effect sizes for Core Temperature.

4.4 Local Skin Temperature

The mean pre- and post-local skin temperatures for both the control and treatment conditions are presented in figure 26.

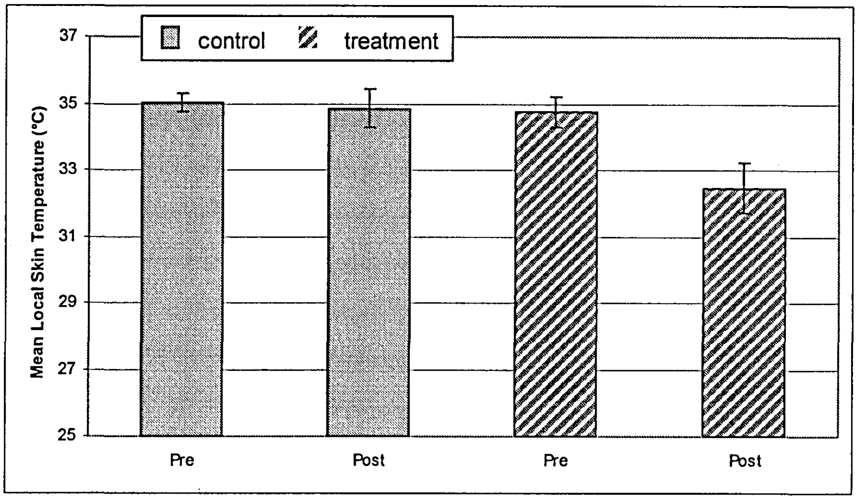

Figure 26. Mean local skin temperatures (pre and post) in both conditions. Columns represent means; Error bars represent ± 1 standard deviation.

Local Skin Temperature – ANOVA

Local skin temperature data were all normally distributed and sphericity was assumed. There were significant main effects for time [$F(1,9) = 30.1$, $P<0.001$] and treatment [$F(1,9) = 155.9$, $P<0.001$] and the interaction effect was also significant [$F(1,9) = 106.1$, $P<0.001$].

Local Skin Temperature – Effect Sizes

Generalised η^2 effect sizes were calculated for both of the main effects and the interaction and are presented in table 33.

Source	***Gen η^2***	***effect***
Time	0.58	Large
Treatment	0.64	Large
Interaction	0.53	Large

Table 33. Generalised η^2 effect sizes for Local Skin Temperature.

4.5 Serum Prolactin

The mean pre- and post-serum prolactin concentrations for both the control and treatment conditions are presented in figure 27.

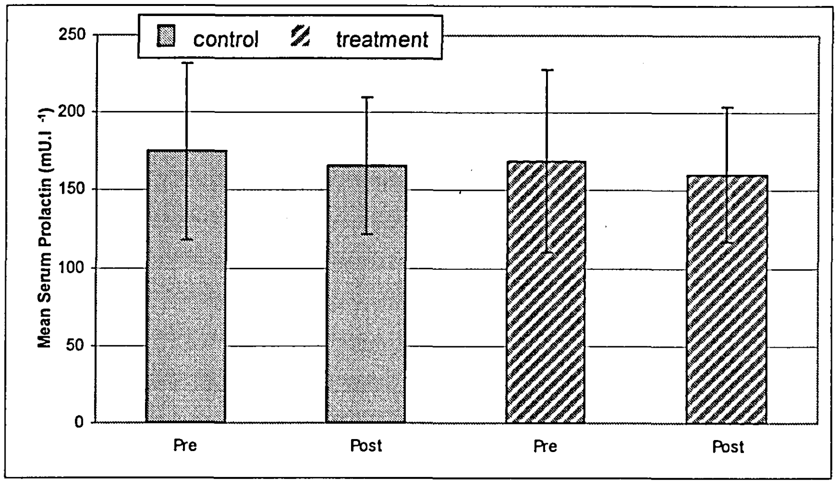

Figure 27. Mean serum prolactin concentrations (pre and post) in both conditions. Columns represent means; Error bars represent ± 1 standard deviation.

Serum Prolactin – ANOVA

Serum prolactin data were all normally distributed and sphericity was assumed. Neither the main effects nor the interaction effect were significant.

Serum Prolactin – Effect Sizes

Generalised η^2 effect sizes were calculated for both of the main effects and the interaction and are presented in table 34.

Source	*Gen η^2*	*effect*
Time	0.01	None
Treatment	0	None
Interaction	0	None

Table 34. Generalised η^2 effect sizes for Serum Prolactin.

4.6 Maximum Acceptable Weight of Lift

The mean maximum acceptable weights of lift for both conditions are presented in figure 28.

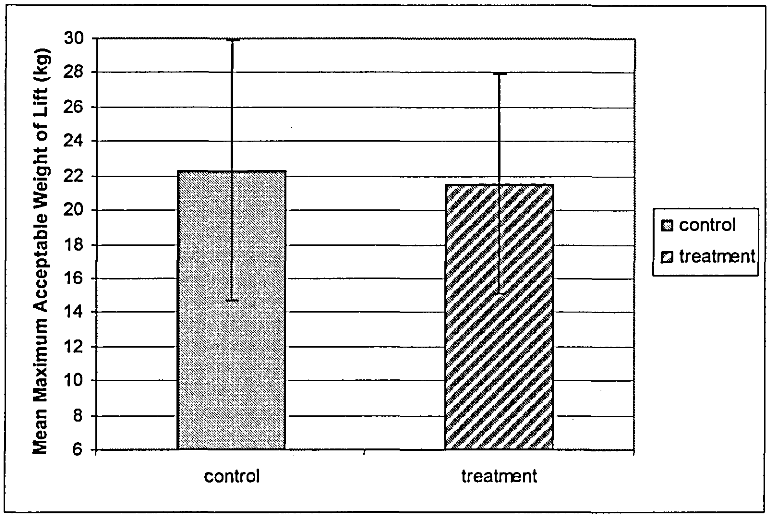

Figure 28. Mean maximum acceptable weight of lift. Columns represent means; Error bars represent ± 1 standard deviation.

Maximum Acceptable Weight of Lift – Wilcoxon Signed-Ranks Test

The MAWL data for the control condition were not normally distributed and transformations were unsuccessful. A Wilcoxon signed-ranks test was therefore conducted to test for a significant difference between the control and treatment condition. There was no significant difference between conditions.

Maximum Acceptable Weight of Lift – Paired t-test

A parametric analysis was also performed because of the reported robustness of these tests to departures from normality. The paired t-test reported no significant difference in maximum acceptable weight of lift between the two conditions.

There was no difference between the findings from the parametric and non-parametric analyses for maximum acceptable weight of lift.

Maximum Acceptable Weight of Lift – Effect Size

An effect size (*d*) was calculated for MAWL and is presented in table 35.

Source	d	Effect
Control-treatment	0.09	None

Table 35. Effect size for MAWL.

4.7 Ratings of Perceived Exertion

The mean ratings of perceived exertion for both conditions are presented in figure 29.

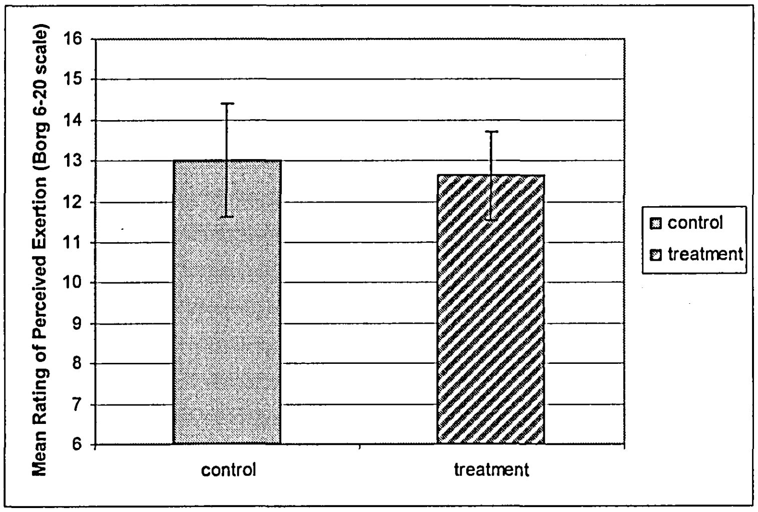

Figure 29. Mean ratings of perceived exertion. Columns represent means; Error bars represent ± 1 standard deviation.

Ratings of Perceived Exertion – Wilcoxon Signed-Ranks Test

The RPE data for the control condition were not normally distributed and transformations were unsuccessful. A Wilcoxon signed-ranks test was therefore conducted to test for a significant difference between the control and treatment condition. There was no significant difference between conditions.

Ratings of Perceived Exertion – Paired t-test

The paired t-test reported no significant difference in ratings of perceived exertion between the two conditions.

There was no difference between the findings from the parametric and non-parametric analyses for ratings of perceived exertion.

Ratings of Perceived Exertion – Effect Size

An effect size (*d*) was calculated for RPE and is presented in table 36.

Source	***d***	***effect***
Control-treatment	0.19	none

Table 36. Effect size for RPE.

4.8 Synopsis

The four null hypotheses were tested using repeated measures analyses of variance and paired t-tests or their non-parametric equivalents.

The first null hypothesis ($H_0$1) stated that there is no difference in serum prolactin after face-cooling (compared to no face-cooling) during a bout of intermittent box-lifting in a warm-humid environment. The non-significant results of the ANOVA for serum prolactin confirm this and the null hypothesis is retained.

The second null hypothesis ($H_0$2) stated that there is no difference in ratings of perceived exertion with face-cooling (compared to no face-cooling) during a bout of intermittent box-lifting in a warm-humid environment. Again, although there was a difference in RPE between conditions it was not significant and the null hypothesis is retained.

The third null hypothesis ($H_0$3) stated that there is no difference in local skin temperature (forehead) when receiving face-cooling during a bout of intermittent box-lifting in a warm-humid environment. The ANOVA for local skin temperature yielded a significant interaction effect and significant main effects. The significant interaction was likely caused by the delay in administration of the first application of face-cooling so one can be reasonably confident that the main effect for face-cooling was a 'real' effect. In this case the null hypothesis is rejected.

The fourth and final null hypothesis (H_04) stated that there is no difference in heart rate when receiving face-cooling during a bout of intermittent box-lifting in a warm-humid environment. There was a significant main treatment effect for heart rate therefore the null should be rejected. However, considerable care should be exercised when interpreting this finding due to the aforementioned anomalies in the pre-session heart rates.

5. Discussion

The purpose of this study was to investigate the effects of face-cooling on physiological strain, perceived exertion and the amount of weight lifted when participants were exposed to a warm, humid environment. The results will be discussed with respect to previous findings in the literature. The practical significance of the results will be assessed along with the limitations in the research design and suggestions for possible improvements will be made.

Findings with Respect to Previous Studies

Hydration Status

As with the findings in chapter 4, the results of the urinalysis again demonstrated the considerable intra- and inter-individual variation in urine osmolality. Participants with higher readings were again asked to consume plenty of water in the 20-30 minutes prior to the commencement of the test. In practice, nearly everyone habitually drank water in the period before testing. As previously, urine colour was not an accurate predictor of the osmolality of the sample. The attempt to control hydration status must again be considered a 'best effort'.

Serum Prolactin

Serum prolactin decreased slightly in both conditions in contrast to previously reported results however the main effects for time and treatment were not statistically significant. A rise in serum prolactin in the control condition and a reduction in the face-cooling condition were expected but it is likely that the participants in this study did not reach the threshold core (rectal) temperature of 38 °C at which prolactin has been shown to increase exponentially (Low *et al.*, 2005). The mean end aural temperature was ~37.2 °C which would mean that the rectal temperature would have been roughly 37.8 °C based on the work published by Muir *et al.* (2001). Rectal temperatures are typically 1 °C higher than aural at rest but these values start to converge during exercise, with a difference of around 0.6 °C at 35 minutes. In essence, the participants weren't warmed up sufficiently to elicit a prolactin response so it was impossible to assess the efficacy of the face-cooling strategy.

The results from this study at least support one half of the threshold temperature theory; i.e. that there is little or no prolactin response when the core temperature is below 38 °C. Further work would have to be undertaken, either in a warmer environment or with a faster lifting frequency to elicit a core temperature of 38 °C and higher in order to more fully understand the prolactin response to thermal strain.

Ratings of Perceived Exertion

Ratings of perceived exertion (RPE) were lower in the face-cooling condition although this was not statistically significant. Findings in previous studies are similar; Armand-Da-Silva *et al.* (2004) also reported non-significant reductions in RPE whereas Mundel *et al.* (2004) reported no differences. Interestingly, an examination of the graph for RPE in the former study suggests that the mean difference in RPE between conditions was consistently approximately two points on the Borg scale. This contrasts with the present study where the mean difference in RPE was ~0.4 perhaps providing another example of the conservatism of the participants in their ratings of perceived exertion. Indeed, the ratings of perceived exertion in the present study are very similar to those in the equivalent session in the hot study (see chapter four).

Local Skin Temperature

There was a significant interaction between time and treatment for local skin temperature. The thermistor on the middle of the forehead measured significantly lower ($P<0.001$) temperatures in the face-cooling condition. At the final time-point the temperature of the forehead was nearly 2.5 °C lower in the face-cooling condition compared to the control. An inspection of the graphed temperatures recorded by the Squirrel data logger showed that the reduction in temperature occurred after the first application of face-cooling at five minutes and remained consistently lower for the rest of the session. This is in agreement with Mundel *et al.* (2004) although they managed a consistent reduction of

~6 °C throughout their sessions. Unfortunately, they did not describe how they cooled the face and it is possible that they managed to find a more efficacious method, possibly using a combination of iced water and directed cool-air although this remains speculation.

Maximum Acceptable Weight of Lift

There were no significant differences in maximum acceptable weight of lift between the face-cooling and control conditions and there are no direct comparisons in the literature. The mean maximum acceptable weights of lift are 2-3 kg higher compared with the means for the equivalent session in the hot study detailed in chapter four. There are two possible explanations for this outcome. Firstly, although the presentation of conditions was counter-balanced in the hot study it is still possible that fatigue and boredom over the fifteen sessions affected the amount of weight lifted. In the present study, with only two conditions, these factors are less likely to have had an effect. Secondly, there was a 30-second break every five minutes in both conditions in the present study. This means that the initial twenty-minute weight adjustment period consisted of only 18.5 minutes of lifting. It is conceivable that the short breaks during the adjustment period altered the participants' perceptions of what they thought was an acceptable weight to lift throughout a working day.

Heart Rate

Heart rates were significantly lower ($P<0.002$) in the face-cooling condition. Mundel *et al.* (2004) reported a similar bradycardia between conditions although in the present study the findings are confounded by the fact that starting heart rates were also significantly lower. The reasons for this are unknown since their was no face-cooling intervention for the first five minutes so to all intents and purposes the conditions at the beginning should have been identical.

The Practical Significance of the Findings

The clearest outcome from the study was the reduction in mean local skin temperature during the face-cooling condition. The mean reduction of ~2.5 °C, a large effect according to the generalised η^2 calculation, was measured by a thermistor placed in the centre of the forehead. As such, no claims about the surface temperature of the rest of the face can be made. Interestingly, the reduction in local skin temperature would seem to be a double-edged sword when one considers its effects on thermoregulation. On the one hand, the thermal gradient from the core (the head including the brain in this case) to the surface is steeper suggesting that heat loss to the body's periphery would be increased. On the other hand, the thermal and vapour pressure gradient between the skin and the surrounding air would be reduced, affecting heat transfer away from the body. The difference in local skin temperature of 2.5 °C would reduce the vapour pressure gradient between the skin and air by approximately 0.7 kPa. This would have the effect of reducing evaporative heat transfer by around 23%.

There was only a mean difference of 0.06 °C in core temperature between conditions supporting the previous findings that face-cooling does not affect this variable. The mean increase in core temperature was ~0.7 °C in both conditions and it is reasonable to assume that it would have continued to rise if the sessions had been longer. This highlights an important safety consideration; face-cooling only seems to mediate the *perception* of thermal strain as reported by RPE. It most definitely does not protect the individual from potential heat injury, indeed it might have the opposite effect. Because the perceptions of exertion (encompassing thermal strain) are attenuated (and that was not conclusive in this study), individuals might be motivated to continue working while their core temperatures rise to potentially injurious levels. This would suggest that face-cooling might only be useful as a method of improving thermal comfort over short periods of time.

Heart rate was significantly lower but the problems associated with this outcome have already been discussed. Nevertheless, the observed bradycardia supports what has been previously reported by Mundel *et al.* (2004). Further investigation is warranted in this area because any safe intervention which could reduce mean heart rate by ~8 beats.min^{-1} over the course of a working day would be desirable.

The similarity of maximum acceptable weights of lift and ratings of perceived exertion across conditions were not a complete surprise. Unlike the hot study, only one participant was tested at any time so at least in the present study any potential competitive element was absent. The similarity in subjective judgements is probably linked to the fact that core temperature did not reach the threshold value of 38 °C. The conditions did not differ sufficiently to firstly elicit a measurable change in physiological strain and secondly to alter participant's perceptions. It is probable, though still speculative, to suggest that a more uncomfortable environment and/or a greater work rate would have resulted in differences in the perception of exertion and the amount of weight lifted.

As with the previous two studies, the mean MAWL in both conditions exceeded Snook & Ciriello's (1991) 75% limit. The published limit of 19 kg acceptable to 50% of the working population was also exceeded as was the 33% $\dot{V}O_{2max}$ physiological limit.

Limitations of the Design

As stated earlier, the measurement of local skin temperature was limited to a very small area of the forehead. For a fuller picture of the skin's response to the face-cooling intervention a number of thermistors would have to be fixed to other areas of the face. The method of fixing the thermistors would have to be resistant to perspiration, application of the water-spray and towelling down. As it transpired the forehead thermistor proved remarkably stable and maintained contact with the skin throughout the sessions, probably because of the underlying solid skeletal structure and lack of friction from moving clothes (contrast this with the experiences in the previous studies). A thermistor fixed to a soft, moveable area of skin such as the cheek would likely have worked loose during the session.

The method of fixing the thermistor to the forehead might have created an artificial micro-climate. The thermistor was fastened by a combination of small patches of self-adhesive gauze and Micropore tape. Moisture accumulated in the material during the sessions which might have affected the temperature at the measurement site. It is also possible that unevaporated perspiration and water from the spray could have collected in any space between the skin and the thermistor surface. It is difficult to suggest any improvements to the method used and it might be that any implementation of the skin thermistor solution is inherently flawed. Perhaps in any future study some sort of thermal imaging would provide a non-invasive and valid method of measuring the temperature of the facial skin.

The combination of environment and lifting frequency did not provide sufficient thermal strain so the results of the face-cooling, apart from the reduction in local skin temperature, were inconclusive. Increasing the lifting frequency is impractical; 6.7 lifts.min^{-1} already requires considerable coordination between the participant and the lowerer. A very early test trial prior to the hot study conducted at 12 lifts.min^{-1} (every five seconds) was abandoned as even drinking water between lifts was impossible. Changing the environment is therefore the better solution. It is suggested that the experiment could be repeated at a WBGT of 32 °C (as opposed to 27 °C used here).

The attempt to control hydration status was limited but the results of the osmolality tests demonstrated the wide variability that exists within and between subjects. One could not state with complete confidence that each participant was euhydrated in every session. It can only be said that the issue of hydration was recognized and remedial action (drinking water prior to testing) was taken where participants presented with very high osmolality readings.

6. Conclusions

Face-cooling had a significant effect on local skin temperature and heart rate although the latter finding should be treated with caution. There were no significant differences for maximum acceptable weight of lift and ratings of perceived exertion. Similarly, serum prolactin and core temperature were unaffected by the face-cooling intervention. The participants were unlikely to have reached the threshold core temperature of 38 °C at which prolactin has been proposed to rise exponentially. This relative lack of thermal strain meant that the effect of face-cooling was limited to a reduction in mean local skin temperature. It is recommended that further research is conducted at higher wet bulb globe temperatures.

The effects of face-cooling appear to be limited to mediating the perceptions of heat strain as reported by RPE, independent of the core temperature which might continue to rise. Altering the perception of heat strain could have the effect of exposing the individual to a potential heat injury because the environmental dangers are underestimated. For this reason it is suggested that face-cooling is only used to improve thermal comfort over short periods. The length of these periods would be dictated by the interaction between environment and work rate.

The effects of face-cooling during the performance of a manual handling task are unclear at the temperature and humidity tested (27 °C WBGT). As industrial workers are likely to encounter wet bulb globe temperatures that exceed this value then further investigation is warranted in these more uncomfortable environments.

7 Final Conclusions & Recommendations for Further Study

1. Summary

This chapter reviews the main findings of the thesis and proposes areas for further research.

2. Main Findings

The purpose of this thesis was to investigate the physiological and subjective responses of individuals performing manual handling tasks in a range of uncomfortably hot, warm and cold environments. It also set out to investigate the effects of different levels of relative humidity on performance in the heat and the effects of two different clothing ensembles in the cold. Finally, the effects of a face-cooling intervention were examined to see if it could alleviate some components of thermal strain.

In the heat, environment had a significant effect on both physiological strain and maximum acceptable weight of lift. Although the participants selected less weight in the hotter environments the adjustments were not sufficient to prevent significant rises in heart rate and core temperature. Perceived exertion was significantly affected by environment and lifting frequency but absolute differences were small. It is suggested that the RPE scale may be inappropriate for rating exertion during the performance of an intermittent lifting task. There were no significant differences in physiological strain between two dissimilar environments with an equivalent WBGT. Physiological strain was greater in a high-humidity environment compared to a low-humidity environment at the same air temperature (~39 °C) but there were no differences at 30 °C.

In the cold, core temperature was significantly lower when lifting in the 0 °C environment wearing the standard clothing ensemble compared to the thermoneutral environment. Mean skin temperature was approximately 4 °C lower between the same two environments. Finger surface temperature was significantly lower in all environments compared to thermoneutral. Mean maximum acceptable weight of lift varied by only around 1 kg across all environments and, overall, the weights lifted in the cold study were markedly higher than in the hot study. The main finding from the cold study was that frequency of lift had a greater effect on the dependent variables than environment.

Face-cooling had a significant effect on local skin temperature at the forehead which was approximately 2.5 °C lower compared to the control condition. Core temperature and serum prolactin were unaffected by the intervention. Ratings of perceived exertion and maximum acceptable weights of lift were similarly unaffected. It is likely that the lack of effects were due to the combination of environment and lifting frequency chosen for the study. Core temperature did not rise sufficiently to elicit an increase in circulating prolactin.

The participants exceeded published limits for acceptable weights of lift in every study. This was especially true in the cold where some participants lifted loads that exceeded the weight regarded as being acceptable to only 10% of the working population. At higher lifting frequencies the participants often lifted loads that suggested that they were working at a rate likely to exceed 33% of their $\dot{V}O_{2max}$.

3. Final Conclusions

Performing a floor to knuckle-height lifting task in uncomfortable thermal environments can impose an undue physiological strain on workers. Allowing individuals to regulate their own workload does not confer sufficient protection against rises in core temperature and heart rate. Relative humidity appears to be a significant factor but only at higher temperatures.

Workers in the cold appear to lift heavier loads as a strategy for keeping warm, putting them at greater risk of injury to the musculoskeletal system. Individuals performing very low frequency lifts or those in sedentary occupations in cold conditions might be at greater risk of hypothermia if they remain in the cold for extended periods. It is important to ensure that the clothing ensembles worn by these workers possess insulative properties that are appropriate for the environment.

Face-cooling might have a place as a method of mediating the perception of heat strain but the findings herein were inconclusive. Core temperatures continued to rise and it may be the case that altering the perception of heat strain could lead to an underestimation of the environmental dangers. This would have the effect of exposing the individual to a potential heat injury.

The findings published herein provide information that could be used to supplement and improve the current guidance to industry published in the

Manual Handling Operations Regulations (MHOR, 1992). The current guidance is limited to a few general recommendations of the type detailed in chapter 2 but based on the results published here the following recommendations can be made. In the heat, humidity does not appear to impose any additional physiological strain at least in air temperatures up to 30 °C. At ~39 °C care must be exercised when relative humidity exceeds 25%. Workers should not be allowed to regulate their own workloads in the heat. Rather, reductions in workload should be specified by employers using a lifting equation with a heat stress multiplier such as the modified NIOSH equation (Hidalgo, 1997). In environments with an air temperature below 16 °C, care must be taken to ensure workers do not lift excessive loads as a strategy for keeping warm. This can be partly achieved by ensuring that clothing ensembles for work in the cold provide adequate insulation from the environment. This is especially pertinent for workers performing largely sedentary or low frequency tasks. Finally, face-cooling should not be considered as a protective mechanism against heat stress as core body temperature is likely to continue to rise during physical activity.

4. Further Study

The findings from the three studies highlighted areas that merit further investigation. Some of these potential areas of investigation are discussed below.

In the hot study, physiological responses were the same between a high-humidity and a low-humidity environment at an air temperature of 30 °C but significantly different at 38 °C. The effects of relative humidity should be investigated further so that the air temperature at which responses start to diverge can be identified. The physiological and subjective responses in dissimilar environments with an equivalent WBGT should be investigated at 32 °C. Dissimilar environments at this WBGT have been reported to elicit different responses in participants performing a continuous treadmill protocol. An investigation into the effects of radiant heat sources on individuals' physiological and subjective responses would provide information on working environments where employees lift in close proximity to ovens and kilns.

In the cold, exposure periods longer than 35 minutes should be investigated to assess how long workers can safely perform low-frequency or sedentary tasks without risk of hypothermia. Further examination of different clothing ensembles for these workers would also be merited. An investigation into lifting objects composed of different materials would give an insight into the effects of these materials on finger and hand temperature.

It is suggested that the face-cooling experiment is repeated at a WBGT of 32 °C. It is expected that the increased thermal strain will elicit a prolactin response that would allow the effects of face-cooling to be more readily understood.

The experiments conducted herein only provide information on a small subset of the working population (healthy males, 40 years of age and under). These experiments should be repeated with other sub-groups such as females and males over the age of 40 since they are likely to make up a large part of the UK working population.

The experiments should also be repeated using different manual handling tasks. It is likely that physiological and subjective responses are different for other lifting tasks and for lowering, pushing, pulling and carrying.

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Appendices

Contents

Sheffield Hallam University

School of Sport and Leisure Management

Research Ethics Committee

INFORMED CONSENT FORM

TITLE OF PROJECT:
The Effects of Thermal Environments on Manual Handling Tasks.

The participant should complete the whole of this sheet himself/herself

Have you read the Participant Information Sheet?	YES/NO
Have you had an opportunity to ask questions and discuss this study?	YES/NO
Have you received satisfactory answers to all of your questions?	YES/NO
Have you received enough information about the study?	YES/NO
To whom have you spoken? .... Do you understand that you are free to withdraw from the study: • at any time • without having to give a reason for withdrawing • and without affecting your future medical care	YES/NO
Have you had sufficient time to consider the nature of this project?	YES/NO
Do you agree to take part in this study?	YES/NO

Signed .... Date ....

(NAME IN BLOCK LETTERS)...

Signature of Parent / Guardian in the case of a minor

....

Sheffield Hallam University

School of Sport and Leisure Management

Research Ethics Committee

Pre-Test Medical Questionnaire

Name: ....

Date of Birth: .... Age: ....Sex: ....

Please answer the following questions by putting a circle round the appropriate response or filling in the blank.

1. How would you describe your present level of activity?
   Sedentary / Moderately active / Active / Highly active

2. How would you describe you present level of fitness?
   Unfit / Moderately fit / Trained / Highly trained

3. How would you consider your present body weight?
   Underweight / Ideal / Slightly over / Very overweight

4. Smoking Habits Are you currently a smoker? Yes / No
   How many do you smoke .... per day
   Are you a previous smoker? Yes / No
   How long is it since you stopped? .... years
   Were you an occasional smoker? Yes / No
   .... per day
   Were you a regular smoker? Yes / No
   .... per day

5. Do you drink alcohol? Yes / No
   If you answered **Yes**, do you have?
   An occasional drink / a drink every day / more than one drink a day?

6. Have you had to consult your doctor within the last six months? Yes / No
   If you answered **Yes**, please give details..
   ....
   ....

7. Are you presently taking any form of medication? Yes / No
   If you answered **Yes**, please give details..
   ....
   ....

8. As far as you are aware, do you suffer or have you ever suffered from:

a Diabetes? Yes / No **b** Asthma? Yes / No
c Epilepsy? Yes / No **d** Bronchitis? Yes / No
e *Any form of heart complaint? Yes / No **f** Raynaud's Disease? Yes / No
g *Marfan's Syndrome? Yes / No **h** *Aneurysm/embolism? Yes / No
I Anaemia Yes / No

9. *Is there a history of heart disease in your family? Yes / No

10. *Do you currently have any form of muscle or joint injury? Yes / No
If you answered **Yes**, please give details......................................
....
....

11. Have you had to suspend you normal training in the last two weeks? Yes / No
If the answer is **Yes** please give details...
....
....

12. * Please read the following questions:
a) Are you suffering from any known serious infection? Yes / No
b) Have you had jaundice within the previous year? Yes / No
c) Have you ever had any form of hepatitis? Yes / No
d) Are you HIV antibody positive Yes / No
e) Have you had unprotected sexual intercourse with any person from an HIV high-risk population? Yes / No
f) Have you ever been involved in intravenous drug use? Yes / No
g) Are you hemophiliac? Yes / No

13. As far as you are aware, is there anything that might prevent you from successfully completing the tests that have been outlined to you? Yes / No

---

IF THE ANSWER TO ANY OF THE ABOVE IS YES THEN:
a) Discuss with the Centre for Sport and Exercise Science the nature of the problem.
b) Questions indicated by (*) Allow your Doctor to fill out the 'Doctors Consent Form provided.

Signature: ....

Signature of Parent or Guardian if the subject is under 18:

....

Date: ....../....../......

Sheffield Hallam University

School of Sport and Leisure Management

Research Ethics Committee

Participant Information Sheet

Project Title	The Effects of Thermal Environments on Manual Handling Tasks.

Name of Participant	

Supervisor/Director of Studies	Dr. John Saxton

Principal Investigator	Andy Davies

Purpose of Study and Brief Description of Procedures
(Not a legal explanation but a simple statement)

The purpose of the study is to examine the effects of hot and cold working environments on manual handling tasks. The results of this study will give us valuable information that will be used to produce guidelines for industry hopefully resulting in a safer working environment.

You will be asked to lift a box onto a shelf at different lifting speeds. At the end of each lift another person will return the box to the starting position prior to the start of the next lift. The researcher will specify the speed at which they wish you to lift (e.g. 6 lifts per minute) and will give guidance accordingly. You should ensure that you lift in accordance with the health and safety training that you have received within your organisation.
It will be necessary for you to wear some testing equipment during the session. This will be as lightweight and unobtrusive as possible. A heart rate monitor chest band will be worn next to the skin. Additionally, small temperature sensors will be fixed to the skin with surgical tape and worn in the ears using ear plugs.

In the Environment Chamber:
You will receive acclimatization or orientation training on 5 consecutive days in the chamber. After this you will be required to attend 15 further sessions on consecutive working days. During these sessions both the frequency of lift and temperature will be varied. These sessions should last no longer than 2 hours each.

Your assistance in this study is entirely voluntary and you are free to withdraw at any time without giving any reason.

It has been made clear to me that, should I feel that these Regulations are being infringed or that my interests are otherwise being ignored, neglected or denied, I should inform Professor Edward Winter, Chair of the School of Sport and Leisure Management Research Ethics Committee (Tel: 0114 225 4333) who will undertake to investigate my complaint.

Sheffield Hallam University

Faculty of Health and Wellbeing
Sport and Exercise Research Ethics Committee

Participant Information Sheet

Project Title	The Effects of Face-Cooling on Thermal Stress During Manual Handling Tasks
Supervisor/Director of Studies	Dr. John Saxton
Principal Investigator	Andrew Davies
Principal Investigator telephone/mobile number	0114 225 5590

Purpose of Study and Brief Description of Procedures
(Not a legal explanation but a simple statement)

The purpose of this study is to investigate the effects of face-cooling on some of the factors associated with heat strain.

You will be required to attend the laboratory on three separate occasions for about one hour each time. We will provide overalls; you will need to bring your own footwear and underwear and you may wish to bring a shower kit for afterwards.

You will be asked to lift a box every nine seconds onto a shelf set at your own knuckle height for 35 minutes. Your core temperature (just inside your ear) and heart rate will be monitored continuously and you will be asked to rate your perceived exertion every five minutes (full training will be provided in lifting technique and the use of the RPE scale). The RPE scale is a rating scale from 6-20 which allows you to tell us how hard you think you are working. Depending on which session you are participating in, you may also have your face and neck cooled by a fine mist of cold water periodically.

It will be necessary to take a blood sample both before and after each session. This sample will be taken from a vein in your arm by a trained phlebetomist and may result in very slight discomfort. A phlebotomist is someone trained to take blood samples from veins. You will also have skin thermistors taped to your forehead and neck area so that we can monitor local skin temperature.

Remember, you are a volunteer and are free to withdraw at any time without giving any reasons. Your information will be kept confidential. In subsequent analysis your data will be referred to by a code number not by name.

If necessary continue overleaf

It has been made clear to me that, should I feel that these Regulations are being infringed or that my interests are otherwise being ignored, neglected or denied, I should inform Professor Edward Winter, Chair of the Faculty of Health and Wellbeing Sport and Exercise Research Ethics Committee (Tel: 0114 225 4333) who will undertake to investigate my complaint.

Appendix B – Participant Data Sheet (Sample)

Subject Name:

Subject No:

Filenames	sub07sessionxx
Squirrel	

Shelf setting: Hole 15 + 19mm+9mm spacers

Age	22 years	9 months
Stature	1.81 m	
Mass	75 kg	
Knuckle Heigh	0.79 m	
Clothing	overalls, safety boots, u/wear	

	Baseline							Trial 1													Trial 2											
								Freq	Start Box kg	Start Time	5 Mins		10 Mins		15 Mins		20 Mins			Stop Time	Start Box kg	Start Time	5 Mins		10 Mins		15 Mins		20 Mins			Stop Time
	Date	*Osmol*					*HR*				RPE	HR	RPE	HR	RPE	HR	RPE	HR	MAWL				RPE	HR	RPE	HR	RPE	HR	RPE	HR	MAWL	
Zero 1																																
Zero 2																																
Zero 3																																

						Baseline						Time Start	5 Mins		10 Mins		15 Mins		20 Mins		25 Mins		30 Mins		35 Mins			Time Stop
	Date	Osmol	Environ	Freq	Box kg	Core	Chest	Arm	Thigh	Shin	HR		RPE	HR	RPE	HR	RPE	HR	RPE	HR	RPE	HR	RPE	HR	RPE	HR	MAWL	
Acc 1																												
Acc 2																												
Acc 3																												
Acc 4																												
Acc 5																												
6	26-Jan	820	TN	1	11.7	36.6	33.6	31.7	32.1	32.7	85	1335	8	100	8	100	9	102	9	102	9	81	10	97	10	85	32.7	1410
7	27-Jan	932	HH	14	8.7	36	35.1	33	34.2	34.6	85	1334	8	104	10	132	11	137	11	147	12	149	12	150	12	153	27.7	1409
8	28-Jan	883	HD	9	7.7	36.6	35.7	33.4	31	34.5	92	1333	8	129	9	137	9	150	10	153	10	152	10	147	10	150	25.7	1408
9	29-Jan	419	WH	1	10.7	36.9	35.1	33.4	33	34.8	85	1338	7	107	8	102	8	100	8	88	9	93	9	93	9	94	29.7	1413
10	30-Jan	688	WD	14	12.7	36.7	34.5	33.1	33.1	33.1	75	1336	8	108	8	118	9	126	9	128	9	125	9	125	9	118	31.7	1411
11	02-Feb	530	TN	9	7.7	36.9	34.1	31.6	30.9	32.4	80	1336	8	125	9	146	9	139	10	146	10	140	9	127	10	138	26.7	1411
12	03-Feb	498	HH	1	10.7	36.7	35.2	33.4	32.5	33.7	84	1331	8	100	8	82	9	97	9	104	10	103	9	92	10	110	31.7	1406
13	04-Feb	665	HD	14	12.7	36.9	34.6	33.4	32.5	33.3	87	1335	8	109	8	121	9	121	9	123	9	127	9	120	10	121	28.7	1410
14	05-Feb	358	WH	9	9.7	37	34.9	34.1	33.2	34.8	90	1335	8	132	9	143	9	145	10	150	10	140	10	143	10	148	24.7	1410
15	06-Feb	842	WD	1	14.7	36.7	33.8	30.8	31.9	33.3	86	1334	8	85	8	96	9	84	8	78	8	74	8	79	8	74	32.7	1409
16	09-Feb	107	TN	14	7.7	36.7	34.3	32.2	32.2	33.3	75	1303	8	109	8	104	9	114	9	111	9	121	9	115	9	114	28.7	1338
17	10-Feb	217	HH	9	6.7	36.6	35.4	32.6	32.7	34.1	94	1333	8	110	9	138	9	137	10	143	10	148	10	151	11	157	22.7	1408
18	11-Feb	468	HD	1	10.7	36.5	35.5	33.1	32.9	34.1	89	1333	8	103	8	101	8	101	8	100	8	82	8	85	8	97	29.7	1408
19	12-Feb	279	WH	14	9.7	36.4	34.6	31.9	32.6	33.6	90	1332	8	102	8	99	9	109	9	102	9	107	9	107	9	111	25.7	1407
20	13-Feb	169	WD	9	6.7	36.6	34.8	32.7	32.1	33	78	1334	8	106	9	123	9	120	9	126	9	124	9	129	9	128	25.7	1409

Appendix C – SPSS Output

Chapter 4 – The Effects of Warm & Hot Environments on Performance of an Intermittent Lifting Task

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
thermoneutral 1/min max heart rate (bpm)	.184	12	.200*	.925	12	.330
thermoneutral 1/min rating of perceived exertion (Borg 6-20)	.250	12	.037	.853	12	.040
thermoneutral 1/min max core temperature (C)	.097	12	.200*	.968	12	.885
thermoneutral 1/min maximum acceptable weight of lift (kg)	.202	12	.188	.867	12	.059
thermoneutral 14secs (4.3lifts.min-1) max heart rate (bpm)	.188	12	.200*	.920	12	.289
thermoneutral 14secs (4.3lifts.min-1) rating of perceived exertion (Borg 6-20)	.248	12	.040	.825	12	.018
thermoneutral 14secs (4.3lifts.min-1) maximum acceptable weight of lift (kg)	.108	12	.200*	.965	12	.857
thermoneutral 14secs (4.3lifts.min-1)max core temperature (C)	.196	12	.200*	.898	12	.147
thermoneutral 9 secs (6.7lifts.min-1) max heart rate (bpm)	.144	12	.200*	.947	12	.589
thermoneutral 9 secs (6.7lifts.min-1) max core temperature (degrees C)	.218	12	.119	.861	12	.050
thermoneutral 9secs (6.7lifts.min-1) maximum acceptable weight of lift (kg)	.174	12	.200*	.920	12	.290
wd1hra	.142	12	.200*	.939	12	.482
warm-dry	.291	12	.006	.837	12	.025
wd1tca	.165	12	.200*	.951	12	.658
warm-dry	.130	12	.200*	.927	12	.347
wd4.3hra	.180	12	.200*	.824	12	.018
warm-dry	.345	12	.000	.748	12	.003
wd4.3tca	.152	12	.200*	.973	12	.937
warm-dry	.155	12	.200*	.924	12	.320
wd6.7hra	.208	12	.160	.906	12	.190
warm-dry	.299	12	.004	.861	12	.050
wd6.7tca	.125	12	.200*	.931	12	.387
warm-dry	.182	12	.200*	.908	12	.200
wh1hra	.118	12	.200*	.971	12	.923
warm-humid	.200	12	.198	.893	12	.130
wh1tca	.154	12	.200*	.958	12	.748
warm-humid	.190	12	.200*	.920	12	.282
wh4.3hra	.213	12	.138	.863	12	.053
warm-humid	.302	12	.003	.835	12	.024
wh4.3tca	.130	12	.200*	.952	12	.662
warm-humid	.206	12	.169	.892	12	.125
wh6.7hra	.143	12	.200*	.971	12	.917
warm-humid	.179	12	.200*	.929	12	.372
wh6.7tca	.217	12	.126	.904	12	.180
warm-humid	.135	12	.200*	.919	12	.278
hd1hra	.190	12	.200*	.957	12	.734
hot-dry	.270	12	.016	.851	12	.038
hd1tca	.146	12	.200*	.937	12	.464
hot-dry	.199	12	.200*	.858	12	.046
hd4.3hra	.200	12	.200*	.916	12	.252
hd6.7hra	.156	12	.200*	.965	12	.849
hot-dry	.209	12	.157	.936	12	.448
hd6.7tca	.136	12	.200*	.941	12	.508
hot-dry	.199	12	.200*	.879	12	.085
hh1hra	.280	12	.010	.863	12	.053
hot-humid	.261	12	.024	.869	12	.063
hh1tca	.158	12	.200*	.957	12	.736
hot-humid	.169	12	.200*	.912	12	.229
hh4.3hra	.164	12	.200*	.949	12	.620
hot-humid	.250	12	.037	.931	12	.394
hh4.3tca	.230	12	.079	.874	12	.074
hot-humid	.202	12	.192	.851	12	.038
hh6.7hra	.184	12	.200*	.936	12	.445
hot-humid	.175	12	.200*	.940	12	.496
hh6.7tca	.142	12	.200*	.945	12	.564
hot-humid	.167	12	.200*	.933	12	.416

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Heart Rate

Within-Subjects Factors

Measure: MEASURE_1

env	freq	Dependent Variable
1	1	tn1hra
	2	tn4.3hra
	3	tn6.7hra
2	1	wd1hra
	2	wd4.3hra
	3	wd6.7hra
3	1	wh1hra
	2	wh4.3hra
	3	wh6.7hra
4	1	hd1hra
	2	hd4.3hra
	3	hd6.7hra
5	1	hh1hra
	2	hh4.3hra
	3	hh6.7hra

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
env	.339	10.195	9	.342	.759	1.000	.250
freq	.664	4.094	2	.129	.749	.840	.500
env * freq	.013	35.355	35	.543	.575	1.000	.125

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept

Within Subjects Design: env+freq+env*freq

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
env	Sphericity Assumed	13741.189	4	3435.297	47.528	.000
	Greenhouse-Geisser	13741.189	3.036	4526.137	47.528	.000
	Huynh-Feldt	13741.189	4.000	3435.297	47.528	.000
	Lower-bound	13741.189	1.000	13741.189	47.528	.000
Error(env)	Sphericity Assumed	3180.278	44	72.279		
	Greenhouse-Geisser	3180.278	33.396	95.230		
	Huynh-Feldt	3180.278	44.000	72.279		
	Lower-bound	3180.278	11.000	289.116		
freq	Sphericity Assumed	81003.911	2	40501.956	94.497	.000
	Greenhouse-Geisser	81003.911	1.497	54109.047	94.497	.000
	Huynh-Feldt	81003.911	1.680	48217.718	94.497	.000
	Lower-bound	81003.911	1.000	81003.911	94.497	.000
Error(freq)	Sphericity Assumed	9429.289	22	428.604		
	Greenhouse-Geisser	9429.289	16.468	572.598		
	Huynh-Feldt	9429.289	18.480	510.255		
	Lower-bound	9429.289	11.000	857.208		
env * freq	Sphericity Assumed	1156.978	8	144.622	1.682	.114
	Greenhouse-Geisser	1156.978	4.601	251.478	1.682	.161
	Huynh-Feldt	1156.978	8.000	144.622	1.682	.114
	Lower-bound	1156.978	1.000	1156.978	1.682	.221
Error(env*freq)	Sphericity Assumed	7565.156	88	85.968		
	Greenhouse-Geisser	7565.156	50.608	149.486		
	Huynh-Feldt	7565.156	88.000	85.968		
	Lower-bound	7565.156	11.000	687.741		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	2332672.672	1	2332672.672	460.692	.000
Error	55697.528	11	5063.412		

4. env * freq

Measure: MEASURE_1

env	freq	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
1	1	76.250	3.063	69.509	82.991
	2	111.167	5.899	98.183	124.151
	3	126.333	6.797	111.373	141.294
2	1	82.333	3.144	75.414	89.253
	2	116.833	6.868	101.718	131.949
	3	125.167	7.992	107.576	142.758
3	1	83.833	2.763	77.752	89.915
	2	114.750	7.568	98.093	131.407
	3	139.750	7.554	123.124	156.376
4	1	85.083	3.692	76.958	93.209
	2	119.167	7.509	102.639	135.695
	3	136.833	7.807	119.650	154.017
5	1	98.917	4.434	89.158	108.675
	2	138.833	7.497	122.332	155.335
	3	152.333	5.888	139.373	165.293

Core Temperature

Within-Subjects Factors

Measure: MEASURE_1

env	freq	Dependent Variable
1	1	tn1tca
	2	tn4.3tca
	3	tn6.7tca
2	1	wd1tca
	2	wd4.3tca
	3	wd6.7tca
3	1	wh1tca
	2	wh4.3tca
	3	wh6.7tca
4	1	hd1tca
	2	hd4.3tca
	3	hd6.7tca
5	1	hh1tca
	2	hh4.3tca
	3	hh6.7tca

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
env	.446	7.601	9	.581	.758	1.000	.250
freq	.519	6.553	2	.038	.675	.736	.500
env * freq	.010	37.692	35	.437	.504	.831	.125

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: env+freq+env*freq

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
env	Sphericity Assumed	9.095	4	2.274	72.084	.000
	Greenhouse-Geisser	9.095	3.033	2.999	72.084	.000
	Huynh-Feldt	9.095	4.000	2.274	72.084	.000
	Lower-bound	9.095	1.000	9.095	72.084	.000
Error(env)	Sphericity Assumed	1.388	44	.032		
	Greenhouse-Geisser	1.388	33.362	.042		
	Huynh-Feldt	1.388	44.000	.032		
	Lower-bound	1.388	11.000	.126		
freq	Sphericity Assumed	7.747	2	3.873	80.228	.000
	Greenhouse-Geisser	7.747	1.351	5.735	80.228	.000
	Huynh-Feldt	7.747	1.473	5.261	80.228	.000
	Lower-bound	7.747	1.000	7.747	80.228	.000
Error(freq)	Sphericity Assumed	1.062	22	.048		
	Greenhouse-Geisser	1.062	14.858	.071		
	Huynh-Feldt	1.062	16.198	.066		
	Lower-bound	1.062	11.000	.097		
env * freq	Sphericity Assumed	1.294	8	.162	3.749	.001
	Greenhouse-Geisser	1.294	4.029	.321	3.749	.010
	Huynh-Feldt	1.294	6.648	.195	3.749	.002
	Lower-bound	1.294	1.000	1.294	3.749	.079
Error(env*freq)	Sphericity Assumed	3.798	88	.043		
	Greenhouse-Geisser	3.798	44.317	.086		
	Huynh-Feldt	3.798	73.130	.052		
	Lower-bound	3.798	11.000	.345		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	246154.412	1	246154.412	237556.5	.000
Error	11.398	11	1.036		

4. env * freq

Measure: MEASURE_1

env	freq	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
1	1	36.526	.079	36.353	36.699
	2	36.797	.105	36.566	37.027
	3	36.918	.109	36.679	37.156
2	1	36.620	.086	36.430	36.810
	2	36.850	.081	36.671	37.029
	3	36.987	.091	36.786	37.187
3	1	36.668	.086	36.479	36.858
	2	36.824	.068	36.674	36.974
	3	37.205	.091	37.005	37.405
4	1	36.859	.065	36.717	37.001
	2	37.068	.090	36.871	37.266
	3	37.239	.130	36.954	37.524
5	1	36.910	.061	36.775	37.045
	2	37.460	.132	37.170	37.750
	3	37.770	.109	37.530	38.010

MAWL

Within-Subjects Factors

Measure: MEASURE_1

env	freq	Dependent Variable
1	1	tn1mawl
	2	tn4.3maw
	3	tn6.7maw
2	1	wd1mawl
	2	wd4.3maw
	3	wd6.7maw
3	1	wh1mawl
	2	wh4.3maw
	3	wh6.7maw
4	1	hd1mawl
	2	hd4.3maw
	3	hd6.7maw
5	1	hh1mawl
	2	hh4.3maw
	3	hh6.7maw

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
env	.077	24.189	9	.005	.647	.864	.250
freq	.242	14.205	2	.001	.569	.591	.500
env * freq	.002	52.644	35	.049	.474	.753	.125

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept
Within Subjects Design: env+freq+env*freq

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
env	Sphericity Assumed	61.867	4	15.467	4.717	.003
	Greenhouse-Geisser	61.867	2.588	23.905	4.717	.011
	Huynh-Feldt	61.867	3.454	17.910	4.717	.005
	Lower-bound	61.867	1.000	61.867	4.717	.053
Error(env)	Sphericity Assumed	144.267	44	3.279		
	Greenhouse-Geisser	144.267	28.469	5.068		
	Huynh-Feldt	144.267	37.997	3.797		
	Lower-bound	144.267	11.000	13.115		
freq	Sphericity Assumed	446.678	2	223.339	18.181	.000
	Greenhouse-Geisser	446.678	1.137	392.723	18.181	.001
	Huynh-Feldt	446.678	1.181	378.191	18.181	.001
	Lower-bound	446.678	1.000	446.678	18.181	.001
Error(freq)	Sphericity Assumed	270.256	22	12.284		
	Greenhouse-Geisser	270.256	12.511	21.601		
	Huynh-Feldt	270.256	12.992	20.802		
	Lower-bound	270.256	11.000	24.569		
env * freq	Sphericity Assumed	31.767	8	3.971	.754	.644
	Greenhouse-Geisser	31.767	3.788	8.386	.754	.554
	Huynh-Feldt	31.767	6.026	5.272	.754	.609
	Lower-bound	31.767	1.000	31.767	.754	.404
Error(env*freq)	Sphericity Assumed	463.300	88	5.265		
	Greenhouse-Geisser	463.300	41.669	11.119		
	Huynh-Feldt	463.300	66.283	6.990		
	Lower-bound	463.300	11.000	42.118		

Pairwise Comparisons

Measure: MEASURE_1

(I) env	(J) env	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	-.194	.248	.449	-.740	.351
	3	.250	.442	.583	-.723	1.223
	4	.806*	.261	.010	.231	1.380
	5	1.417*	.427	.007	.478	2.356
2	1	.194	.248	.449	-.351	.740
	3	.444	.579	.459	-.831	1.719
	4	1.000	.468	.056	-.030	2.030
	5	1.611*	.482	.007	.551	2.671
3	1	-.250	.442	.583	-1.223	.723
	2	-.444	.579	.459	-1.719	.831
	4	.556	.379	.171	-.279	1.390
	5	1.167*	.492	.037	.085	2.248
4	1	-.806*	.261	.010	-1.380	-.231
	2	-1.000	.468	.056	-2.030	.030
	3	-.556	.379	.171	-1.390	.279
	5	.611	.378	.134	-.221	1.443
5	1	-1.417*	.427	.007	-2.356	-.478
	2	-1.611*	.482	.007	-2.671	-.551
	3	-1.167*	.492	.037	-2.248	-.085
	4	-.611	.378	.134	-1.443	.221

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Pairwise Comparisons

Measure: MEASURE_1

(I) freq	(J) freq	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	1.417*	.572	.031	.158	2.675
	3	3.817*	.867	.001	1.909	5.724
2	1	-1.417*	.572	.031	-2.675	-.158
	3	2.400*	.388	.000	1.547	3.253
3	1	-3.817*	.867	.001	-5.724	-1.909
	2	-2.400*	.388	.000	-3.253	-1.547

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

RPE

Within-Subjects Factors

Measure: MEASURE_1

env	freq	Dependent Variable
1	1	tn1rpe
	2	tn4.3rpe
	3	tn6.7rpe
2	1	wd1rpe
	2	wd4.3rpe
	3	wd6.7rpe
3	1	wh1rpe
	2	wh4.3rpe
	3	wh6.7rpe
4	1	hd1rpe
	2	hd4.3rpe
	3	hd6.7rpe
5	1	hh1rpe
	2	hh4.3rpe
	3	hh6.7rpe

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
env	.178	16.241	9	.066	.530	.660	.250
freq	.465	7.663	2	.022	.651	.703	.500
env * freq	.002	48.788	35	.098	.456	.711	.125

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept
Within Subjects Design: env+freq+env*freq

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
env	Sphericity Assumed	84.000	4	21.000	15.750	.000
	Greenhouse-Geisser	84.000	2.119	39.638	15.750	.000
	Huynh-Feldt	84.000	2.638	31.839	15.750	.000
	Lower-bound	84.000	1.000	84.000	15.750	.002
Error(env)	Sphericity Assumed	58.667	44	1.333		
	Greenhouse-Geisser	58.667	23.311	2.517		
	Huynh-Feldt	58.667	29.021	2.022		
	Lower-bound	58.667	11.000	5.333		
freq	Sphericity Assumed	119.478	2	59.739	25.945	.000
	Greenhouse-Geisser	119.478	1.303	91.715	25.945	.000
	Huynh-Feldt	119.478	1.406	84.989	25.945	.000
	Lower-bound	119.478	1.000	119.478	25.945	.000
Error(freq)	Sphericity Assumed	50.656	22	2.303		
	Greenhouse-Geisser	50.656	14.330	3.535		
	Huynh-Feldt	50.656	15.464	3.276		
	Lower-bound	50.656	11.000	4.605		
env * freq	Sphericity Assumed	9.133	8	1.142	1.448	.188
	Greenhouse-Geisser	9.133	3.651	2.501	1.448	.239
	Huynh-Feldt	9.133	5.690	1.605	1.448	.214
	Lower-bound	9.133	1.000	9.133	1.448	.254
Error(env*freq)	Sphericity Assumed	69.400	88	.789		
	Greenhouse-Geisser	69.400	40.164	1.728		
	Huynh-Feldt	69.400	62.592	1.109		
	Lower-bound	69.400	11.000	6.309		

4. env * freq

Measure: MEASURE_1

env	freq	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
1	1	10.000	.508	8.883	11.117
	2	10.750	.351	9.978	11.522
	3	11.583	.313	10.895	12.272
2	1	10.167	.441	9.196	11.137
	2	11.250	.305	10.580	11.920
	3	11.417	.499	10.318	12.516
3	1	10.167	.458	9.159	11.174
	2	11.500	.417	10.581	12.419
	3	12.500	.597	11.187	13.813
4	1	10.250	.446	9.268	11.232
	2	11.500	.314	10.809	12.191
	3	12.833	.458	11.826	13.841
5	1	11.500	.314	10.809	12.191
	2	13.000	.522	11.851	14.149
	3	13.667	.829	11.843	15.491

Non-Parametric Tests. Friedman Tests

Ranks

	Mean Rank
RPEtn	1.71
RPEwd	2.17
RPEwh	2.88
RPEhd	3.50
RPEhh	4.75

Test Statistics[a]

N	12
Chi-Square	28.259
df	4
Asymp. Sig.	.000

a. Friedman Test

Ranks

	Mean Rank
RPE1	1.00
RPE43	2.04
RPE67	2.96

Test Statistics[a]

N	12
Chi-Square	23.532
df	2
Asymp. Sig.	.000

a. Friedman Test

Chapter 5 – The Effects of Cold Environments on Performance of an Intermittent Lifting Task

Heart Rate

Within-Subjects Factors

Measure: MEASURE_1

env	freq	Dependent Variable
1	1	tn1hr
	2	tn4.3hr
	3	tn6.7hr
2	1	ten1hr
	2	ten4.3hr
	3	ten6.7hr
3	1	five1hr
	2	five43hr
	3	five67hr
4	1	zstd1hr
	2	zsd43hr
	3	zsd67hr
5	1	zenh1hr
	2	zen43hr
	3	zen67hr

Tests of Normality

	Kolmogorov-Smirnov [a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
tn1hr	.124	12	.200*	.944	12	.551
tn4.3hr	.179	12	.200*	.924	12	.319
tn6.7hr	.123	12	.200*	.967	12	.876
ten1hr	.195	12	.200*	.946	12	.578
ten4.3hr	.125	12	.200*	.917	12	.263
ten6.7hr	.174	12	.200*	.949	12	.629
five1hr	.120	12	.200*	.936	12	.453
five43hr	.131	12	.200*	.957	12	.744
five67hr	.120	12	.200*	.976	12	.965
zstd1hr	.141	12	.200*	.938	12	.469
zsd43hr	.137	12	.200*	.958	12	.757
zsd67hr	.135	12	.200*	.967	12	.879
zenh1hr	.233	12	.071	.830	12	.021
zen43hr	.227	12	.088	.885	12	.101
zen67hr	.128	12	.200*	.972	12	.927
tn1tc	.150	12	.200*	.955	12	.718
tn4.3tc	.203	12	.183	.906	12	.187
tn6.7tc	.229	12	.081	.906	12	.189
ten1tc	.140	12	.200*	.927	12	.353
ten4.3tc	.189	12	.200*	.954	12	.695
ten6.7tc	.117	12	.200*	.973	12	.939
five1tc	.151	12	.200*	.963	12	.824
fiv4.3tc	.130	12	.200*	.966	12	.868
fiv6.7tc	.209	12	.157	.928	12	.361
zstd1tc	.165	12	.200*	.946	12	.578
zsd4.3tc	.178	12	.200*	.896	12	.139
zsd6.7tc	.146	12	.200*	.938	12	.467
zenh1tc	.166	12	.200*	.971	12	.925
zen4.3tc	.151	12	.200*	.969	12	.897
zen6.7tc	.184	12	.200*	.919	12	.276
tn1rpe	.201	12	.194	.877	12	.080
tn4.3rpe	.297	12	.004	.816	12	.014
tn6.7rpe	.145	12	.200*	.948	12	.615
ten1rpe	.275	12	.013	.830	12	.021
ten43rpe	.264	12	.020	.903	12	.172
ten67rpe	.323	12	.001	.856	12	.044
five1rpe	.241	12	.053	.910	12	.213
fiv43rpe	.200	12	.198	.914	12	.242
fiv67rpe	.171	12	.200*	.953	12	.682
zsd1rpe	.191	12	.200*	.935	12	.440
zsd43rpe	.277	12	.012	.826	12	.019
zsd67rpe	.217	12	.125	.925	12	.333
zen1rpe	.174	12	.200*	.886	12	.104
zen43rpe	.216	12	.127	.901	12	.162
zen67rpe	.323	12	.001	.856	12	.044
tn1mwl	.136	12	.200*	.958	12	.754
tn4.3mwl	.132	12	.200*	.934	12	.420
tn6.7mwl	.156	12	.200*	.969	12	.901
ten1mwl	.166	12	.200*	.939	12	.479
ten43mwl	.128	12	.200*	.972	12	.930
ten67mwl	.195	12	.200*	.930	12	.381
five1mwl	.196	12	.200*	.921	12	.298
fiv43mwl	.172	12	.200*	.961	12	.803
fiv67mwl	.156	12	.200*	.943	12	.532
zsd1mwl	.148	12	.200*	.961	12	.799
zsd43mwl	.170	12	.200*	.948	12	.603
zsd67mwl	.176	12	.200*	.955	12	.708
zenh1mwl	.179	12	.200*	.922	12	.299
zen43mwl	.114	12	.200*	.956	12	.720
zen67mwl	.151	12	.200*	.935	12	.440

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
env	.587	5.018	9	.836	.796	1.000	.250
freq	.125	20.755	2	.000	.533	.544	.500
env * freq	.016	33.669	35	.621	.577	1.000	.125

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept
Within Subjects Design: env+freq+env*freq

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
env	Sphericity Assumed	100.922	4	25.231	.446	.775
	Greenhouse-Geisser	100.922	3.182	31.715	.446	.733
	Huynh-Feldt	100.922	4.000	25.231	.446	.775
	Lower-bound	100.922	1.000	100.922	.446	.518
Error(env)	Sphericity Assumed	2491.078	44	56.615		
	Greenhouse-Geisser	2491.078	35.004	71.166		
	Huynh-Feldt	2491.078	44.000	56.615		
	Lower-bound	2491.078	11.000	226.462		
freq	Sphericity Assumed	68809.244	2	34404.622	65.644	.000
	Greenhouse-Geisser	68809.244	1.067	64491.796	65.644	.000
	Huynh-Feldt	68809.244	1.088	63266.122	65.644	.000
	Lower-bound	68809.244	1.000	68809.244	65.644	.000
Error(freq)	Sphericity Assumed	11530.356	22	524.107		
	Greenhouse-Geisser	11530.356	11.736	982.444		
	Huynh-Feldt	11530.356	11.964	963.772		
	Lower-bound	11530.356	11.000	1048.214		
env * freq	Sphericity Assumed	836.144	8	104.518	1.425	.197
	Greenhouse-Geisser	836.144	4.612	181.279	1.425	.234
	Huynh-Feldt	836.144	8.000	104.518	1.425	.197
	Lower-bound	836.144	1.000	836.144	1.425	.258
Error(env*freq)	Sphericity Assumed	6454.256	88	73.344		
	Greenhouse-Geisser	6454.256	50.737	127.210		
	Huynh-Feldt	6454.256	88.000	73.344		
	Lower-bound	6454.256	11.000	586.751		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	2027146.689	1	2027146.689	493.296	.000
Error	45203.311	11	4109.392		

env * freq

Measure: MEASURE_1

env	freq	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
1	1	83.833	2.229	78.928	88.739
	2	108.417	5.414	96.501	120.333
	3	127.917	7.413	111.602	144.232
2	1	79.583	3.071	72.824	86.343
	2	112.583	6.866	97.471	127.696
	3	125.167	6.068	111.812	138.521
3	1	80.083	3.175	73.094	87.072
	2	114.333	6.979	98.973	129.693
	3	124.000	6.235	110.276	137.724
4	1	78.250	2.541	72.657	83.843
	2	111.167	7.498	94.663	127.670
	3	131.750	7.141	116.034	147.466
5	1	78.417	2.589	72.718	84.115
	2	109.667	6.957	94.355	124.979
	3	126.667	6.966	111.335	141.998

Core Temperature

Within-Subjects Factors

Measure: MEASURE_1

env	freq	Dependent Variable
1	1	tn1tc
	2	tn4.3tc
	3	tn6.7tc
2	1	ten1tc
	2	ten4.3tc
	3	ten6.7tc
3	1	five1tc
	2	fiv4.3tc
	3	fiv6.7tc
4	1	zstd1tc
	2	zsd4.3tc
	3	zsd6.7tc
5	1	zenh1tc
	2	zen4.3tc
	3	zen6.7tc

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
env	.202	15.054	9	.094	.639	.848	.250
freq	.995	.049	2	.976	.995	1.000	.500
env * freq	.002	48.869	35	.096	.576	1.000	.125

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept
Within Subjects Design: env+freq+env*freq

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
env	Sphericity Assumed	2.901	4	.725	15.737	.000
	Greenhouse-Geisser	2.901	2.555	1.135	15.737	.000
	Huynh-Feldt	2.901	3.393	.855	15.737	.000
	Lower-bound	2.901	1.000	2.901	15.737	.002
Error(env)	Sphericity Assumed	2.028	44	.046		
	Greenhouse-Geisser	2.028	28.101	.072		
	Huynh-Feldt	2.028	37.325	.054		
	Lower-bound	2.028	11.000	.184		
freq	Sphericity Assumed	7.762	2	3.881	50.777	.000
	Greenhouse-Geisser	7.762	1.990	3.900	50.777	.000
	Huynh-Feldt	7.762	2.000	3.881	50.777	.000
	Lower-bound	7.762	1.000	7.762	50.777	.000
Error(freq)	Sphericity Assumed	1.682	22	.076		
	Greenhouse-Geisser	1.682	21.893	.077		
	Huynh-Feldt	1.682	22.000	.076		
	Lower-bound	1.682	11.000	.153		
env * freq	Sphericity Assumed	.646	8	.081	1.321	.244
	Greenhouse-Geisser	.646	4.610	.140	1.321	.272
	Huynh-Feldt	.646	8.000	.081	1.321	.244
	Lower-bound	.646	1.000	.646	1.321	.275
Error(env*freq)	Sphericity Assumed	5.381	88	.061		
	Greenhouse-Geisser	5.381	50.712	.106		
	Huynh-Feldt	5.381	88.000	.061		
	Lower-bound	5.381	11.000	.489		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	240401.050	1	240401.050	145578.7	.000
Error	18.165	11	1.651		

env * freq

Measure: MEASURE_1

				95% Confidence Interval	
env	freq	Mean	Std. Error	Lower Bound	Upper Bound
1	1	36.492	.086	36.303	36.680
	2	36.810	.103	36.584	37.036
	3	36.883	.080	36.708	37.059
2	1	36.258	.079	36.083	36.432
	2	36.710	.113	36.462	36.958
	3	36.881	.117	36.624	37.137
3	1	36.281	.117	36.024	36.538
	2	36.653	.107	36.419	36.888
	3	36.736	.121	36.469	37.002
4	1	36.023	.136	35.723	36.323
	2	36.355	.162	35.998	36.712
	3	36.685	.149	36.358	37.012
5	1	36.255	.098	36.040	36.470
	2	36.578	.123	36.307	36.849
	3	36.580	.135	36.282	36.878

MAWL

Within-Subjects Factors

Measure: MEASURE_1

env	freq	Dependent Variable
1	1	tn1mwl
	2	tn4.3mwl
	3	tn6.7mwl
2	1	ten1mwl
	2	ten43mwl
	3	ten67mwl
3	1	five1mwl
	2	fiv43mwl
	3	fiv67mwl
4	1	zsd1mwl
	2	zsd43mwl
	3	zsd67mwl
5	1	zenh1mwl
	2	zen43mwl
	3	zen67mwl

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
env	.247	13.169	9	.161	.608	.793	.250
freq	.521	6.523	2	.038	.676	.737	.500
env * freq	.001	53.911	35	.039	.434	.659	.125

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: env+freq+env*freq

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
env	Sphericity Assumed	27.700	4	6.925	1.510	.216
	Greenhouse-Geisser	27.700	2.431	11.392	1.510	.238
	Huynh-Feldt	27.700	3.172	8.733	1.510	.228
	Lower-bound	27.700	1.000	27.700	1.510	.245
Error(env)	Sphericity Assumed	201.767	44	4.586		
	Greenhouse-Geisser	201.767	26.746	7.544		
	Huynh-Feldt	201.767	34.890	5.783		
	Lower-bound	201.767	11.000	18.342		
freq	Sphericity Assumed	1712.878	2	856.439	34.362	.000
	Greenhouse-Geisser	1712.878	1.352	1266.824	34.362	.000
	Huynh-Feldt	1712.878	1.474	1161.714	34.362	.000
	Lower-bound	1712.878	1.000	1712.878	34.362	.000
Error(freq)	Sphericity Assumed	548.322	22	24.924		
	Greenhouse-Geisser	548.322	14.873	36.867		
	Huynh-Feldt	548.322	16.219	33.808		
	Lower-bound	548.322	11.000	49.847		
env * freq	Sphericity Assumed	129.233	8	16.154	1.784	.091
	Greenhouse-Geisser	129.233	3.474	37.198	1.784	.160
	Huynh-Feldt	129.233	5.274	24.505	1.784	.127
	Lower-bound	129.233	1.000	129.233	1.784	.209
Error(env*freq)	Sphericity Assumed	796.900	88	9.056		
	Greenhouse-Geisser	796.900	38.216	20.853		
	Huynh-Feldt	796.900	58.012	13.737		
	Lower-bound	796.900	11.000	72.445		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	116688.272	1	116688.272	151.294	.000
Error	8483.928	11	771.266		

env * freq

Measure: MEASURE_1

				95% Confidence Interval	
env	freq	Mean	Std. Error	Lower Bound	Upper Bound
1	1	30.950	2.694	25.020	36.880
	2	23.617	2.098	18.999	28.234
	3	21.283	2.141	16.572	25.995
2	1	28.200	2.539	22.612	33.788
	2	25.283	2.130	20.595	29.972
	3	21.117	1.612	17.569	24.664
3	1	28.617	2.670	22.740	34.493
	2	25.033	2.378	19.799	30.268
	3	22.450	1.970	18.114	26.786
4	1	29.533	2.415	24.219	34.848
	2	24.200	2.314	19.106	29.294
	3	23.950	1.923	19.717	28.183
5	1	30.783	2.524	25.228	36.339
	2	24.533	2.299	19.473	29.593
	3	22.367	1.720	18.580	26.153

RPE

Within-Subjects Factors

Measure: MEASURE_1

env	freq	Dependent Variable
1	1	tn1rpe
	2	tn4.3rpe
	3	tn6.7rpe
2	1	ten1rpe
	2	ten43rpe
	3	ten67rpe
3	1	five1rpe
	2	fiv43rpe
	3	fiv67rpe
4	1	zsd1rpe
	2	zsd43rpe
	3	zsd67rpe
5	1	zen1rpe
	2	zen43rpe
	3	zen67rpe

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
env	.489	6.739	9	.670	.798	1.000	.250
freq	.394	9.305	2	.010	.623	.664	.500
env * freq	.002	50.796	35	.069	.492	.799	.125

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: env+freq+env*freq

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
env	Sphericity Assumed	2.300	4	.575	1.474	.226
	Greenhouse-Geisser	2.300	3.192	.721	1.474	.237
	Huynh-Feldt	2.300	4.000	.575	1.474	.226
	Lower-bound	2.300	1.000	2.300	1.474	.250
Error(env)	Sphericity Assumed	17.167	44	.390		
	Greenhouse-Geisser	17.167	35.109	.489		
	Huynh-Feldt	17.167	44.000	.390		
	Lower-bound	17.167	11.000	1.561		
freq	Sphericity Assumed	20.933	2	10.467	10.404	.001
	Greenhouse-Geisser	20.933	1.246	16.806	10.404	.004
	Huynh-Feldt	20.933	1.327	15.771	10.404	.004
	Lower-bound	20.933	1.000	20.933	10.404	.008
Error(freq)	Sphericity Assumed	22.133	22	1.006		
	Greenhouse-Geisser	22.133	13.702	1.615		
	Huynh-Feldt	22.133	14.601	1.516		
	Lower-bound	22.133	11.000	2.012		
env * freq	Sphericity Assumed	3.733	8	.467	.909	.513
	Greenhouse-Geisser	3.733	3.933	.949	.909	.466
	Huynh-Feldt	3.733	6.395	.584	.909	.499
	Lower-bound	3.733	1.000	3.733	.909	.361
Error(env*freq)	Sphericity Assumed	45.200	88	.514		
	Greenhouse-Geisser	45.200	43.261	1.045		
	Huynh-Feldt	45.200	70.344	.643		
	Lower-bound	45.200	11.000	4.109		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	22311.200	1	22311.200	992.277	.000
Error	247.333	11	22.485		

env * freq

Measure: MEASURE_1

				95% Confidence Interval	
env	freq	Mean	Std. Error	Lower Bound	Upper Bound
1	1	10.833	.474	9.790	11.877
	2	10.833	.405	9.942	11.725
	3	11.417	.452	10.423	12.411
2	1	10.417	.336	9.677	11.157
	2	11.417	.358	10.629	12.205
	3	11.500	.359	10.710	12.290
3	1	10.917	.484	9.851	11.982
	2	11.167	.386	10.317	12.016
	3	11.667	.432	10.715	12.618
4	1	10.833	.322	10.125	11.542
	2	11.250	.429	10.307	12.193
	3	11.750	.429	10.807	12.693
5	1	10.667	.482	9.606	11.728
	2	10.833	.386	9.984	11.683
	3	11.500	.359	10.710	12.290

Non-Parametric Tests. Friedman Tests

Ranks

	Mean Rank
RPEtn	2.46
RPEten	3.00
RPEfive	3.42
RPEzsd	3.67
RPEzen	2.46

Test Statistics[a]

N	12
Chi-Square	7.422
df	4
Asymp. Sig.	.115

a. Friedman Test

Ranks

	Mean Rank
RPE1	1.38
RPE43	1.75
RPE67	2.88

Test Statistics[a]

N	12
Chi-Square	16.714
df	2
Asymp. Sig.	.000

a. Friedman Test

Finger Surface Temperature

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
tn1	.323	6	.050	.797	6	.056
tn43	.224	6	.200*	.869	6	.222
tn67	.312	6	.069	.857	6	.181
ten1	.230	6	.200*	.921	6	.516
ten43	.245	6	.200*	.843	6	.138
ten67	.227	6	.200*	.891	6	.324
five1	.244	6	.200*	.849	6	.155
five43	.373	6	.009	.734	6	.014
five67	.223	6	.200*	.908	6	.420
zerostd1	.231	6	.200*	.883	6	.284
zerostd43	.211	6	.200*	.968	6	.881
zerostd67	.338	6	.031	.810	6	.073
zeroenh1	.215	6	.200*	.922	6	.516
zeroenh43	.174	6	.200*	.954	6	.771
zeroenh67	.225	6	.200*	.892	6	.326

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Within-Subjects Factors

Measure: MEASURE_1

env	freq	Dependent Variable
1	1	tn1
	2	tn43
	3	tn67
2	1	ten1
	2	ten43
	3	ten67
3	1	five1
	2	five43
	3	five67
4	1	zerostd1
	2	zerostd43
	3	zerostd67
5	1	zeroenh1
	2	zeroenh43
	3	zeroenh67

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
env	.002	20.960	9	.023	.323	.387	.250
freq	.283	5.046	2	.080	.582	.651	.500
env * freq	.000	.	35	.	.320	.685	.125

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: env+freq+env*freq

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
env	Sphericity Assumed	1369.229	4	342.307	56.132	.000
	Greenhouse-Geisser	1369.229	1.291	1060.748	56.132	.000
	Huynh-Feldt	1369.229	1.549	884.042	56.132	.000
	Lower-bound	1369.229	1.000	1369.229	56.132	.001
Error(env)	Sphericity Assumed	121.966	20	6.098		
	Greenhouse-Geisser	121.966	6.454	18.897		
	Huynh-Feldt	121.966	7.744	15.749		
	Lower-bound	121.966	5.000	24.393		
freq	Sphericity Assumed	6.056	2	3.028	.178	.839
	Greenhouse-Geisser	6.056	1.165	5.198	.178	.725
	Huynh-Feldt	6.056	1.301	4.654	.178	.750
	Lower-bound	6.056	1.000	6.056	.178	.690
Error(freq)	Sphericity Assumed	169.942	10	16.994		
	Greenhouse-Geisser	169.942	5.825	29.175		
	Huynh-Feldt	169.942	6.506	26.123		
	Lower-bound	169.942	5.000	33.988		
env * freq	Sphericity Assumed	16.123	8	2.015	.471	.869
	Greenhouse-Geisser	16.123	2.561	6.297	.471	.680
	Huynh-Feldt	16.123	5.478	2.943	.471	.809
	Lower-bound	16.123	1.000	16.123	.471	.523
Error(env*freq)	Sphericity Assumed	171.096	40	4.277		
	Greenhouse-Geisser	171.096	12.803	13.364		
	Huynh-Feldt	171.096	27.390	6.247		
	Lower-bound	171.096	5.000	34.219		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	25230.529	1	25230.529	1629.683	.000
Error	77.409	5	15.482		

env * freq

Measure: MEASURE_1

env	freq	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
1	1	23.175	1.137	20.253	26.097
	2	22.867	1.284	19.567	26.167
	3	24.408	1.089	21.610	27.207
2	1	18.650	1.014	16.044	21.256
	2	18.200	1.287	14.891	21.509
	3	18.217	1.339	14.776	21.658
3	1	16.433	1.109	13.582	19.285
	2	15.717	.884	13.445	17.989
	3	15.050	.795	13.007	17.093
4	1	13.725	1.476	9.930	17.520
	2	13.325	.947	10.891	15.759
	3	12.717	1.349	9.248	16.185
5	1	13.567	1.087	10.771	16.362
	2	12.742	.590	11.224	14.259
	3	12.358	.584	10.857	13.860

Grip Strength Change

Within-Subjects Factors

Measure: MEASURE_1

time	env	freq	Dependent Variable
1	1	1	tn1pre
		2	tn43pre
		3	tn67pre
	2	1	ten1pre
		2	ten43pre
		3	ten67pre
	3	1	five1pre
		2	five43pre
		3	five67pre
	4	1	zsd1pre
		2	zsd43pre
		3	zsd67pre
	5	1	zen1pre
		2	zen43pre
		3	zen67pre
2	1	1	tn1post
		2	tn43post
		3	tn67post
	2	1	ten1post
		2	ten43post
		3	ten67post
	3	1	five1post
		2	five43post
		3	five67post
	4	1	zsd1post
		2	zsd43post
		3	zsd67post
	5	1	zen1post
		2	zen43post
		3	zen67post

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
time	1.000	.000	0	.	1.000	1.000	1.000
env	.631	4.331	9	.890	.835	1.000	.250
freq	.588	5.303	2	.071	.708	.783	.500
time * env	.364	9.506	9	.399	.761	1.000	.250
time * freq	.889	1.180	2	.554	.900	1.000	.500
env * freq	.000	75.163	35	.000	.412	.609	.125
time * env * freq	.006	41.388	35	.289	.424	.635	.125

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept

Within Subjects Design: time+env+freq+time*env+time*freq+env*freq+time*env*freq

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
time	Sphericity Assumed	337.561	1	337.561	3.315	.096
	Greenhouse-Geisser	337.561	1.000	337.561	3.315	.096
	Huynh-Feldt	337.561	1.000	337.561	3.315	.096
	Lower-bound	337.561	1.000	337.561	3.315	.096
Error(time)	Sphericity Assumed	1119.956	11	101.814		
	Greenhouse-Geisser	1119.956	11.000	101.814		
	Huynh-Feldt	1119.956	11.000	101.814		
	Lower-bound	1119.956	11.000	101.814		
env	Sphericity Assumed	24.801	4	6.200	.696	.599
	Greenhouse-Geisser	24.801	3.342	7.422	.696	.575
	Huynh-Feldt	24.801	4.000	6.200	.696	.599
	Lower-bound	24.801	1.000	24.801	.696	.422
Error(env)	Sphericity Assumed	392.018	44	8.910		
	Greenhouse-Geisser	392.018	36.758	10.665		
	Huynh-Feldt	392.018	44.000	8.910		
	Lower-bound	392.018	11.000	35.638		
freq	Sphericity Assumed	13.751	2	6.876	.946	.403
	Greenhouse-Geisser	13.751	1.417	9.705	.946	.379
	Huynh-Feldt	13.751	1.566	8.784	.946	.386
	Lower-bound	13.751	1.000	13.751	.946	.352
Error(freq)	Sphericity Assumed	159.837	22	7.265		
	Greenhouse-Geisser	159.837	15.586	10.255		
	Huynh-Feldt	159.837	17.221	9.282		
	Lower-bound	159.837	11.000	14.531		
time * env	Sphericity Assumed	12.561	4	3.140	.396	.811
	Greenhouse-Geisser	12.561	3.046	4.124	.396	.760
	Huynh-Feldt	12.561	4.000	3.140	.396	.811
	Lower-bound	12.561	1.000	12.561	.396	.542
Error(time*env)	Sphericity Assumed	349.292	44	7.938		
	Greenhouse-Geisser	349.292	33.502	10.426		
	Huynh-Feldt	349.292	44.000	7.938		
	Lower-bound	349.292	11.000	31.754		
time * freq	Sphericity Assumed	4.314	2	2.157	.402	.674
	Greenhouse-Geisser	4.314	1.800	2.397	.402	.653
	Huynh-Feldt	4.314	2.000	2.157	.402	.674
	Lower-bound	4.314	1.000	4.314	.402	.539
Error(time*freq)	Sphericity Assumed	118.172	22	5.371		
	Greenhouse-Geisser	118.172	19.797	5.969		
	Huynh-Feldt	118.172	22.000	5.371		
	Lower-bound	118.172	11.000	10.743		
env * freq	Sphericity Assumed	106.756	8	13.344	1.031	.419
	Greenhouse-Geisser	106.756	3.293	32.418	1.031	.395
	Huynh-Feldt	106.756	4.868	21.930	1.031	.408
	Lower-bound	106.756	1.000	106.756	1.031	.332
Error(env*freq)	Sphericity Assumed	1138.793	88	12.941		
	Greenhouse-Geisser	1138.793	36.225	31.437		
	Huynh-Feldt	1138.793	53.549	21.266		
	Lower-bound	1138.793	11.000	103.527		
time * env * freq	Sphericity Assumed	102.808	8	12.851	1.975	.059
	Greenhouse-Geisser	102.808	3.388	30.341	1.975	.128
	Huynh-Feldt	102.808	5.079	20.241	1.975	.095
	Lower-bound	102.808	1.000	102.808	1.975	.187
Error(time*env*freq)	Sphericity Assumed	572.515	88	6.506		
	Greenhouse-Geisser	572.515	37.272	15.360		
	Huynh-Feldt	572.515	55.871	10.247		
	Lower-bound	572.515	11.000	52.047		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	883972.003	1	883972.003	716.439	.000
Error	13572.261	11	1233.842		

time * env * freq

Measure: MEASURE_1

time	env	freq	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
1	1	1	51.008	1.909	46.807	55.210
		2	50.700	2.285	45.670	55.730
		3	50.508	1.806	46.533	54.484
	2	1	51.150	1.584	47.663	54.637
		2	49.392	1.916	45.175	53.609
		3	51.133	2.032	46.661	55.606
	3	1	51.025	1.595	47.514	54.536
		2	50.008	1.935	45.750	54.266
		3	49.642	1.885	45.493	53.791
	4	1	50.533	1.998	46.137	54.930
		2	50.767	2.008	46.346	55.187
		3	50.175	2.339	45.026	55.324
	5	1	50.325	2.443	44.947	55.703
		2	50.342	2.504	44.830	55.854
		3	51.108	1.827	47.088	55.129
2	1	1	49.217	1.751	45.363	53.071
		2	48.142	2.414	42.829	53.454
		3	50.008	1.849	45.940	54.077
	2	1	48.242	2.253	43.283	53.200
		2	49.483	1.568	46.032	52.934
		3	48.683	1.946	44.399	52.967
	3	1	48.975	2.025	44.517	53.433
		2	47.717	2.511	42.191	53.242
		3	48.867	2.653	43.028	54.705
	4	1	48.858	2.032	44.386	53.330
		2	49.525	2.401	44.241	54.809
		3	45.142	2.753	39.082	51.201
	5	1	48.958	2.461	43.543	54.374
		2	48.050	2.025	43.593	52.507
		3	48.900	1.390	45.841	51.959

Chapter 6 – The Effects of Face Cooling on Physiological Strain During an Intermittent Lifting Task in a Warm-Humid Environment

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
osmolcon	.228	10	.150	.878	10	.124
osmoltreat	.218	10	.197	.918	10	.341
mawlcont	.276	10	.030	.787	10	.010
mawltreat	.209	10	.200*	.908	10	.270
heart rate start-control	.131	10	.200*	.983	10	.978
heart rate end-control	.254	10	.066	.866	10	.091
heart rate start-treatment	.155	10	.200*	.967	10	.860
heart rate end-treatment	.114	10	.200*	.990	10	.996
mean rpe for last 15 minutes-control	.300	10	.011	.749	10	.003
mean rpe for last 15 minutes-treatment	.244	10	.092	.845	10	.051
core temp start-control	.112	10	.200*	.963	10	.824
core temp end-control	.205	10	.200*	.917	10	.335
core temp start-treatment	.157	10	.200*	.941	10	.561
core temp end-treatment	.211	10	.200*	.972	10	.908
starttscon	.171	10	.200*	.971	10	.903
endtscon	.198	10	.200*	.939	10	.543
starttstre	.181	10	.200*	.948	10	.644
endtstre	.175	10	.200*	.933	10	.481
serum prolactin pre-control	.144	10	.200*	.954	10	.718
serum prolactin post-control	.141	10	.200*	.973	10	.917
serum prolactin pre-treatment	.206	10	.200*	.965	10	.845
serum prolactin post-treatment	.176	10	.200*	.943	10	.585

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Heart Rate

Within-Subjects Factors

Measure: MEASURE_1

time	treat	Dependent Variable
1	1	hrstartcon
	2	hrstarttre
2	1	hrendcon
	2	hrendtre

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
time	Sphericity Assumed	20475.625	1	20475.625	109.790	.000
	Greenhouse-Geisser	20475.625	1.000	20475.625	109.790	.000
	Huynh-Feldt	20475.625	1.000	20475.625	109.790	.000
	Lower-bound	20475.625	1.000	20475.625	109.790	.000
Error(time)	Sphericity Assumed	1678.485	9	186.498		
	Greenhouse-Geisser	1678.485	9.000	186.498		
	Huynh-Feldt	1678.485	9.000	186.498		
	Lower-bound	1678.485	9.000	186.498		
treat	Sphericity Assumed	544.644	1	544.644	18.934	.002
	Greenhouse-Geisser	544.644	1.000	544.644	18.934	.002
	Huynh-Feldt	544.644	1.000	544.644	18.934	.002
	Lower-bound	544.644	1.000	544.644	18.934	.002
Error(treat)	Sphericity Assumed	258.886	9	28.765		
	Greenhouse-Geisser	258.886	9.000	28.765		
	Huynh-Feldt	258.886	9.000	28.765		
	Lower-bound	258.886	9.000	28.765		
time * treat	Sphericity Assumed	1.444	1	1.444	.033	.859
	Greenhouse-Geisser	1.444	1.000	1.444	.033	.859
	Huynh-Feldt	1.444	1.000	1.444	.033	.859
	Lower-bound	1.444	1.000	1.444	.033	.859
Error(time*treat)	Sphericity Assumed	388.386	9	43.154		
	Greenhouse-Geisser	388.386	9.000	43.154		
	Huynh-Feldt	388.386	9.000	43.154		
	Lower-bound	388.386	9.000	43.154		

Core Temperature

Within-Subjects Factors

Measure: MEASURE_1

time	treat	Dependent Variable
1	1	starttccon
	2	starttctre
2	1	endtccon
	2	endtctre

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
time	Sphericity Assumed	5.256	1	5.256	110.982	.000
	Greenhouse-Geisser	5.256	1.000	5.256	110.982	.000
	Huynh-Feldt	5.256	1.000	5.256	110.982	.000
	Lower-bound	5.256	1.000	5.256	110.982	.000
Error(time)	Sphericity Assumed	.426	9	.047		
	Greenhouse-Geisser	.426	9.000	.047		
	Huynh-Feldt	.426	9.000	.047		
	Lower-bound	.426	9.000	.047		
treat	Sphericity Assumed	.002	1	.002	.197	.668
	Greenhouse-Geisser	.002	1.000	.002	.197	.668
	Huynh-Feldt	.002	1.000	.002	.197	.668
	Lower-bound	.002	1.000	.002	.197	.668
Error(treat)	Sphericity Assumed	.103	9	.011		
	Greenhouse-Geisser	.103	9.000	.011		
	Huynh-Feldt	.103	9.000	.011		
	Lower-bound	.103	9.000	.011		
time * treat	Sphericity Assumed	.020	1	.020	.802	.394
	Greenhouse-Geisser	.020	1.000	.020	.802	.394
	Huynh-Feldt	.020	1.000	.020	.802	.394
	Lower-bound	.020	1.000	.020	.802	.394
Error(time*treat)	Sphericity Assumed	.227	9	.025		
	Greenhouse-Geisser	.227	9.000	.025		
	Huynh-Feldt	.227	9.000	.025		
	Lower-bound	.227	9.000	.025		

Local Skin Temperature

Within-Subjects Factors

Measure: MEASURE_1

time	treat	Dependent Variable
1	1	starttscon
	2	starttstre
2	1	endtscon
	2	endtstre

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
time	Sphericity Assumed	14.556	1	14.556	30.134	.000
	Greenhouse-Geisser	14.556	1.000	14.556	30.134	.000
	Huynh-Feldt	14.556	1.000	14.556	30.134	.000
	Lower-bound	14.556	1.000	14.556	30.134	.000
Error(time)	Sphericity Assumed	4.348	9	.483		
	Greenhouse-Geisser	4.348	9.000	.483		
	Huynh-Feldt	4.348	9.000	.483		
	Lower-bound	4.348	9.000	.483		
treat	Sphericity Assumed	18.320	1	18.320	155.933	.000
	Greenhouse-Geisser	18.320	1.000	18.320	155.933	.000
	Huynh-Feldt	18.320	1.000	18.320	155.933	.000
	Lower-bound	18.320	1.000	18.320	155.933	.000
Error(treat)	Sphericity Assumed	1.057	9	.117		
	Greenhouse-Geisser	1.057	9.000	.117		
	Huynh-Feldt	1.057	9.000	.117		
	Lower-bound	1.057	9.000	.117		
time * treat	Sphericity Assumed	11.524	1	11.524	106.599	.000
	Greenhouse-Geisser	11.524	1.000	11.524	106.599	.000
	Huynh-Feldt	11.524	1.000	11.524	106.599	.000
	Lower-bound	11.524	1.000	11.524	106.599	.000
Error(time*treat)	Sphericity Assumed	.973	9	.108		
	Greenhouse-Geisser	.973	9.000	.108		
	Huynh-Feldt	.973	9.000	.108		
	Lower-bound	.973	9.000	.108		

Within-Subjects Factors

Measure: MEASURE_1

time	treat	Dependent Variable
1	1	prlprecon
	2	prlpretreat
2	1	prlpostcon
	2	prlposttreat

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
time	Sphericity Assumed	801.025	1	801.025	.295	.600
	Greenhouse-Geisser	801.025	1.000	801.025	.295	.600
	Huynh-Feldt	801.025	1.000	801.025	.295	.600
	Lower-bound	801.025	1.000	801.025	.295	.600
Error(time)	Sphericity Assumed	24406.725	9	2711.858		
	Greenhouse-Geisser	24406.725	9.000	2711.858		
	Huynh-Feldt	24406.725	9.000	2711.858		
	Lower-bound	24406.725	9.000	2711.858		
treat	Sphericity Assumed	319.225	1	319.225	.222	.649
	Greenhouse-Geisser	319.225	1.000	319.225	.222	.649
	Huynh-Feldt	319.225	1.000	319.225	.222	.649
	Lower-bound	319.225	1.000	319.225	.222	.649
Error(treat)	Sphericity Assumed	12968.525	9	1440.947		
	Greenhouse-Geisser	12968.525	9.000	1440.947		
	Huynh-Feldt	12968.525	9.000	1440.947		
	Lower-bound	12968.525	9.000	1440.947		
time * treat	Sphericity Assumed	2.025	1	2.025	.003	.958
	Greenhouse-Geisser	2.025	1.000	2.025	.003	.958
	Huynh-Feldt	2.025	1.000	2.025	.003	.958
	Lower-bound	2.025	1.000	2.025	.003	.958
Error(time*treat)	Sphericity Assumed	6224.725	9	691.636		
	Greenhouse-Geisser	6224.725	9.000	691.636		
	Huynh-Feldt	6224.725	9.000	691.636		
	Lower-bound	6224.725	9.000	691.636		

MAWL and RPE – Paired t-tests

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	mawlcont	22.300	10	7.6041	2.4046
	mawltreat	21.500	10	6.4256	2.0320
Pair 2	mean rpe for last 15 minutes-control	13.0000	10	1.37437	.43461
	mean rpe for last 15 minutes-treatment	12.6250	10	1.11959	.35404

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	mawlcont & mawltreat	10	.965	.000
Pair 2	mean rpe for last 15 minutes-control & mean rpe for last 15 minutes-treatment	10	.916	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	mawlcont - mawltreat	.8000	2.2010	.6960	-.7745	2.3745	1.149	9	.280
Pair 2	mean rpe for last 15 minutes-control - mean rpe for last 15 minutes-treatment	.37500	.56826	.17970	-.03151	.78151	2.087	9	.067

Appendix D – All Hand Calculations

Tukey's tests were calculated using the following formula:

$$q = \frac{\text{mean 1 - mean 2}}{\sqrt{S^2\text{error}*½(1/n+1/n)}}$$

Hot Data - Tukeys Tests (HR_{max} - ENV)

1,2	$\frac{104.58 - 108.11}{\sqrt{72.28*½\,(1/12+1/12)}}$	$\frac{-3.53}{2.45}$	=	-1.44
1,3	104.58 – 112.78	-8.2	=	3.35
1,4	104.58 – 113.69	-9.11	=	3.72
1,5	104.58 – 130.03	-25.45	=	-10.39
2,3	108.11 – 112.78	-4.67	=	-1.9
2,4	108.11 – 113.69	-5.58	=	-2.28
2,5	108.11 – 130.03	-21.92	=	-8.94
3,4	112.78 – 113.69	-0.91	=	-0.37
3,5	112.78 – 130.03	-17.25	=	-7.04
4,5	113.69 – 130.03	-16.34	=	-6.67

q (5,44) ~4.04 at 0.05 level
~4.93 at 0.01 level

ENV 1= TN, 2=WD, 3=WH, 4=HD, 5=HH

Hot Data - Tukeys Tests (HR_{max} - FREQ)

1,2	$\frac{85.28 - 136.08}{\sqrt{428.6*½(1/12+1/12)}}$	$\frac{-50.8}{5.98}$	=	-8.49
1,3	85.28 – 120.15	-34.87	=	-5.83

2,3	136.08 – 120.15	15.93	=	2.66

q (3,22) ~3.53 at 0.05 level
~4.54 at 0.01 level

FREQ 1= 1 $lift.min^{-1}$
2= 6.7 $lifts.min^{-1}$
3= 4.3 $lifts.min^{-1}$

Hot Data - Tukeys Tests (Tc_{max})

0.0315 error term
0.051132 bottom line (denominator)

			wd	wh	hd	hh
	4.3	tn	-1.17343	-0.58671	-5.28043	**-13.1033**
		wd		0.586715	-4.107	**-11.9299**
		wh			-4.69372	**-12.5166**
5,44		hd				**-7.82286**
		hh				
	67	tn	-1.369	**-5.67157**	**-6.25829**	**-16.8192**
		wd		-4.30257	-4.88929	**-15.4502**
		wh			-0.58671	**-11.1476**
		hd				**-10.5609**
		hh				

			43	67
	wh	1	-3.12914	**-10.5609**
		43		**-7.43172**
3,22		67		
	hh	1	**-10.7564**	**-16.8192**
		43		**-6.06272**
		67		

16 tests 0.05/16= **0.003**

critical q at 0.01; 5,44 ~4.93

critical q at 0.01; 3,22 ~4.54

Hot Data - Tukeys Tests (RPE - ENV)

Pairs

1,2	$\frac{10.778 - 10.944}{\sqrt{1.333 * ½ (1/12+1/12)}}$	$\frac{-0.166}{0.333}$	=	-0.49
1,3	10.778 – 11.389	-0.611	=	-1.83
1,4	10.778 – 11.528	-0.75	=	-2.25

1,5	10.778 – 12.722	-1.94	=	-5.84
2,3	10.944 – 11.389	-0.45	=	-1.34
2,4	10.944 – 11.528	-0.58	=	-1.75
2,5	10.944 – 12.722	-1.78	=	-5.34
3,4	11.389 – 11.528	-0.139	=	-0.42
3,5	11.389 – 12.722	-1.33	=	-4.0
4,5	11.528 – 12.722	-1.19	=	-3.58

q (5,44) ~4.04 at 0.05 level
~4.93 at 0.01 level

ENV 1= TN, 2=WD, 3=WH, 4=HD, 5=HH

Hot Data - Tukeys Tests (RPE - FREQ)

Pairs				
1,2	$\frac{10.417 - 12.4}{\sqrt{3.535 * ½(1/12+1/12)}}$	$\frac{-1.98}{0.54}$	=	-3.66
1,3	10.417 – 11.6	-1.18	=	-2.18
2,3	12.4 – 11.6	0.8	=	1.48

q (3,17) ~3.65 at 0.05 level

FREQ 1= 1 $lift.min^{-1}$
2= 6.7 $lifts.min^{-1}$
3= 4.3 $lifts.min^{-1}$

Hot Data - Tukeys Tests (MAWL - ENV)

Pairs				
1,2	$\frac{21.144 - 21.339}{\sqrt{5.068 * ½ (1/12+1/12)}}$	$\frac{-0.195}{0.649}$	=	-0.3
1,3	21.144 – 20.894	0.25	=	0.39
1,4	21.144 – 20.339	0.805	=	1.24
1,5	21.144 – 19.728	1.416	=	2.18

2,3	21.339 – 20.894	0.445	=	0.69
2,4	21.339 – 20.339	1	=	1.54
2,5	21.339 – 19.728	1.611	=	2.48
3,4	20.894 – 20.339	0.555	=	0.86
3,5	20.894 – 19.728	1.166	=	1.8
4,5	20.339 – 19.728	0.611	=	0.94

q (5,28) ~4.1 at 0.05 level ENV 1= TN, 2=WD, 3=WH, 4=HD, 5=HH

Hot Data - Tukeys Tests (MAWL - FREQ)

Pairs				
1,2	$\frac{22.433 - 18.617}{\sqrt{21.601*½(1/12+1/12)}}$	$\frac{3.816}{1.34}$	=	2.85
1,3	22.433 – 21.017	1.416	=	1.06
2,3	18.617 – 21.017	-2.4	=	-1.8

q (3,12) ~3.77 at 0.05 level

FREQ 1= 1 lift.min^{-1}
2= 6.7 lifts.min^{-1}
3= 4.3 lifts.min^{-1}

Cold Data - Tukeys Tests (HR_{max} - FREQ)

Pairs				
1,2	$\frac{80.033 - 127.1}{\sqrt{982.444*½(1/12+1/12)}}$	$\frac{-47.07}{9.05}$	=	-5.2
1,3	80.033 – 111.233	-31.2	=	-3.45
2,3	127.1 – 111.233	15.87	=	1.75

q (3,22) ~3.53 at 0.05 level
~4.54 at 0.01 level

FREQ 1= 1 lift.min^{-1}
2= 6.7 lifts.min^{-1}
3= 4.3 lifts.min^{-1}

Cold Data - Tukeys Tests (Tc_{max} - ENV)

Pairs				
1,2	$\frac{36.728 - 36.616}{\sqrt{0.072 * ½ (1/12+1/12)}}$	$\frac{0.112}{0.08}$	=	1.4
1,3	36.728 – 36.557	0.17	=	2.13
1,4	36.728 – 36.354	0.37	=	4.63
1,5	36.728 – 36.471	0.26	=	3.25
2,3	36.616 – 36.557	0.06	=	0.75
2,4	36.616 – 36.354	0.26	=	3.25
2,5	36.616 – 36.471	0.15	=	1.88
3,4	36.557 – 36.354	0.2	=	2.5
3,5	36.557 – 36.471	0.09	=	1.13
4,5	36.354 – 36.471	-0.12	=	-1.5

q (5,44) ~4.04 at 0.05 level
~4.93 at 0.01 level

Cold Data - Tukeys Tests (Tc_{max} - FREQ)

Pairs				
1,2	$\frac{36.262 - 36.753}{\sqrt{0.076 * ½(1/12+1/12)}}$	$\frac{-0.49}{0.08}$	=	-6.1
1,3	36.262 – 36.621	-0.36	=	-4.5
2,3	36.753 – 36.621	0.132	=	1.65

q (3,22) ~3.53 at 0.05 level

FREQ 1= 1 $lift.min^{-1}$
2= 6.7 $lifts.min^{-1}$
3= 4.3 $lifts.min^{-1}$

Cold Data - Tukeys Tests (RPE - FREQ)

Pairs				
1,2	$\frac{10.733 - 11.567}{\sqrt{1.615 * ½(1/12+1/12)}}$	$\frac{-0.83}{0.37}$	=	-2.24

1,3	10.733 – 11.1	-0.37	=	-1
2,3	11.567 – 11.1	0.47	=	1.27

q (3,22) ~3.53 at 0.05 level

FREQ 1= 1 $lift.min^{-1}$
2= 6.7 $lifts.min^{-1}$
3= 4.3 $lifts.min^{-1}$

Cold Data - Tukeys Tests (MAWL - FREQ)

Pairs				
1,2	$\frac{29.617 - 22.233}{\sqrt{36.867 * ½(1/12+1/12)}}$	$\frac{7.38}{1.75}$	=	4.2
1,3	29.617 – 24.533	5.08	=	2.9
2,3	22.233 – 24.533	-2.3	=	-1.3

q (3,22) ~3.53 at 0.05 level

FREQ 1= 1 $lift.min^{-1}$
2= 6.7 $lifts.min^{-1}$
3= 4.3 $lifts.min^{-1}$

Cold Data - Tukeys Tests (Finger Temp ENV)

Pairs				
1,2	$\frac{23.48 - 18.36}{\sqrt{121.97 * ½ (1/12+1/12)}}$	$\frac{5.12}{10.16}$	=	0.5
1,3	23.48 – 15.73	7.75	=	0.76
1,4	23.48 – 13.26	10.22	=	1
1,5	23.48 – 12.89	10.59	=	1.04
2,3	18.36 – 15.73	2.63	=	0.26
2,4	18.36 – 13.26	5.1	=	0.5
2,5	18.36 – 12.89	5.47	=	0.53
3,4	15.73 – 13.26	2.47	=	0.24

3,5	15.73 – 12.89	2.84	=	0.28
4,5	13.26 – 12.89	0.37	=	0.04

q (5,44) ~4.04 at 0.05 level
~4.93 at 0.01 level

All q values taken from the table of Critical Values of the Studentized Range Statistic. Thomas, J.R., & Nelson, J.K. (1996). Research Methods in Physical Activity (3rd ed.). Human Kinetics: Champaign, IL.

Effect Sizes – ANOVA designs

The formulae for calculating $P\eta^2$ and $G\eta^2$ in a two-factor fully within-subjects ANOVA are as follows:

SS	F ratio	Partial Eta Squared	Generalised Eta Squared
SSA	MSA/MSAs	SSA/(SSA+SSAs)	SSA/(SSA+SSs+SSAs+SSBs+SSABs)
SSB	MSB/MSBs	SSB/(SSB+SSBs)	SSB/(SSB+SSs+SSAs+SSBs+SSABs)
SSAB	MSAB/MSABs	SSAB/(SSAB+SSABs)	SSAB/(SSAB+SSs+SSAs+SSBs+SSABs)
			0.02=small-0.13=medium-0.26=large

Where:

SS = sum of squares
A = factor A (environment)
B = factor B (frequency)
AB= interaction

MS = mean sum of squares
s = error term for factor
SSs= between subjects error term

(Bakeman, 2005)

Hot Study (Chapter 4)

					F	Partial Eta Squared	Generalised Eta Squared
	SSA	13741.19	MSA	3435.297	47.53		
	SSAs	3180.278	MSAs	72.27905		0.81	**0.22 medium**
HR	SSs		27967.93				
	SSB	81003.91	MSB	40501.96	94.50		
	SSBs	9429.289	MSBs	428.604		0.90	**0.63 large**
	SSAB	1156.978	MSAB	144.6223	1.68		
	SSABs	7565.156	MSABs	85.96768		0.13	**0.02 small**
	SSA	9.095	MSA	2.27375	72.08		
	SSAs	1.388	MSAs	0.031545		0.87	**0.46 large**
Tc	SSs		4.509				
	SSB	7.747	MSB	3.8735	80.24		
	SSBs	1.062	MSBs	0.048273		0.88	**0.42 large**
	SSAB	1.294	MSAB	0.16175	3.75		
	SSABs	3.798	MSABs	0.043159		0.25	**0.11 small**
	SSA	61.867	MSA	15.46675	4.72		
	SSAs	144.267	MSAs	3.278795		0.30	**0.01 none**
MAWL	SSs		8251.844				
	SSB	446.678	MSB	223.339	18.18		
	SSBs	270.256	MSBs	12.28436		0.62	**0.05 small**
	SSAB	31.767	MSAB	3.970875	0.75		
	SSABs	463.3	MSABs	5.264773		0.06	**0.00 none**
	SSA	84	MSA	21	15.75		
	SSAs	58.667	MSAs	1.333341		0.59	**0.16 medium**
RPE	SSs		259.528				
	SSB	119.478	MSB	59.739	25.94		
	SSBs	50.656	MSBs	2.302545		0.70	**0.21 medium**
	SSAB	9.133	MSAB	1.141625	1.45		
	SSABs	69.4	MSABs	0.788636		0.12	**0.02 small**

					F	Partial Eta Squared	Generalised Eta Squared	Pa
	SSA	100.922	MSA	25.2305	0.445647			
	SSAs	2491.078	MSAs	56.61541		0.04	**0.00 none**	
HR	SSs	45203.31						
	SSB	68809.24	MSB	34404.62	65.64426			
	SSBs	11530.36	MSBs	524.1071		0.86	**0.51 large**	
	SSAB	836.144	MSAB	104.518	1.425042			
	SSABs	6454.256	MSABs	73.34382		0.11	**0.01 none**	
	SSA	2.901	MSA	0.72525	15.73521			
	SSAs	2.028	MSAs	0.046091		0.59	**0.10 small**	
Tc	SSs	18.165						
	SSB	7.762	MSB	3.881	50.76219			
	SSBs	1.682	MSBs	0.076455		0.82	**0.22 medium**	
	SSAB	0.646	MSAB	0.08075	1.320572			
	SSABs	5.381	MSABs	0.061148		0.11	**0.02 small**	
	SSA	27.7	MSA	6.925	1.510158			
	SSAs	201.767	MSAs	4.585614		0.12	**0.00 none**	
MAWL	SSs	8483.928						
	SSB	1712.878	MSB	856.439	34.3624			
	SSBs	548.322	MSBs	24.92373		0.76	**0.15 medium**	
	SSAB	129.233	MSAB	16.15413	1.783866			
	SSABs	796.9	MSABs	9.055682		0.14	**0.01 none**	
	SSA	2.3	MSA	0.575	1.473758			
	SSAs	17.167	MSAs	0.390159		0.12	**0.01 none**	
RPE	SSs	247.333						
	SSB	20.933	MSB	10.4665	10.40361			
	SSBs	22.133	MSBs	1.006045		0.49	**0.06 small**	
	SSAB	3.733	MSAB	0.466625	0.908473			
	SSABs	45.2	MSABs	0.513636		0.08	**0.01 none**	
	SSA	1369.229	MSA	342.3073	56.13159			
	SSAs	121.966	MSAs	6.0983		0.92	**0.72 large**	
Finger	SSs	77.409						
	SSB	6.056	MSB	3.028	0.178178			
	SSBs	169.942	MSBs	16.9942		0.03	**0.01 none**	
	SSAB	16.123	MSAB	2.015375	0.471168			
	SSABs	171.096	MSABs	4.2774		0.09	**0.03 small**	

The formulae for calculating $P\eta^2$ and $G\eta^2$ in a three-factor fully within-subjects ANOVA are as follows:

SS	F ratio	Partial Eta Squared	Generalised Eta Squared
SSA	MSA/MSAs	SSA/(SSA+SSAs)	SSA/(SSA+SSs+SSAs+SSBs+SSCs+SSABsSSACs+SSBCs+SSABCs)
SSB	MSB/MSBs	SSB/(SSB+SSBs)	SSB/(SSB+SSs+SSAs+SSBs+SSCs+SSABsSSACs+SSBCs+SSABCs)
SSC	MSC/MSCs	SSC/(SSC+SSCs)	SSC/(SSC+SSs+SSAs+SSBs+SSCs+SSABsSSACs+SSBCs+SSABCs)
SSAB	MSAB/MSABs	SSAB/(SSAB+SSABs)	SSAB/(SSAB+SSs+SSAs+SSBs+SSCs+SSABsSSACs+SSBCs+SSABCs)
SSAC	MSAC/MSACs	SSAC/(SSAC+SSACs)	SSAC/(SSAC+SSs+SSAs+SSBs+SSCs+SSABsSSACs+SSBCs+SSABCs)
SSBC	MSBC/MSBCs	SSBC/(SSBC+SSBCs)	SSBC/(SSBC+SSs+SSAs+SSBs+SSCs+SSABsSSACs+SSBCs+SSABCs)
SSABC	MSABC/MSABCs	SSABC/(SSABC+SSABCs)	SSABC/(SSABC+SSs+SSAs+SSBs+SSCs+SSABsSSACs+SSBCs+SSABCs)

Where:
SS = sum of squares
A = factor A (time)
B = factor B (environment)
C = factor C (frequency)
AB AC BC ABC = interactions

MS = mean sum of squares
s = error term for factor
SSs= between subjects error term

(Bakeman, 2005)

Cold Study (Chapter 5) Grip Strength Change

					F	Partial Eta Squared	**Generalised Eta Squared**
	SSA	337.56	MSA	337.56	3.32		
	SSAs	1119.96	MSAs	101.81		0.23	**0.02 small**
Grip	SSs		13572.26				
	SSB	24.80	MSB	6.20	0.70		
	SSBs	392.02	MSBs	8.91		0.06	**0.00 none**
	SSC	13.75	MSC	6.88	0.95		
	SSCs	159.84	MSCs	7.27		0.08	**0.00 none**
	SSAB	12.56	MSAB	3.14	0.40		
	SSABs	349.29	MSABs	7.94		0.03	**0.00 none**
	SSAC	4.31	MSAC	2.16	0.40		
	SSACs	118.17	MSACs	5.37		0.04	**0.00 none**
	SSBC	106.76	MSBC	13.34	1.03		
	SSBCs	1138.79	MSBCs	12.94		0.09	**0.01 none**
	SSABC	102.81	MSABC	12.85	1.98		
	SSABCs	572.52	MSABCs	6.51		0.15	**0.01 none**

Face Cooling Study (Chapter 6)

					F	Partial Eta Squared	**Generalised Eta Squared**	
	SSA	20475.63	MSA	20475.63	109.79			
	SSAs	1678.485	MSAs	186.50		0.92	**0.73**	**large**
HR	SSs		5277.785					
	SSB	544.644	MSB	544.64	18.93			
	SSBs	258.886	MSBs	28.77		0.68	**0.07**	**small**
	SSAB	1.444	MSAB	1.44	0.03			
	SSABs	388.386	MSABs	43.15		0.00	**0.00**	**none**
	SSA	5.256	MSA	5.26	111.04			
	SSAs	0.426	MSAs	0.05		0.93	**0.82**	**large**
Tc	SSs		0.425					
	SSB	0.002	MSB	0.00	0.17			
	SSBs	0.103	MSBs	0.01		0.02	**0.00**	**none**
	SSAB	0.02	MSAB	0.02	0.79			
	SSABs	0.227	MSABs	0.03		0.08	**0.02**	**small**
	SSA	14.556	MSA	14.56	30.13			
	SSAs	4.348	MSAs	0.48		0.77	**0.58**	**large**
Tsk	SSs		4.027					
	SSB	18.32	MSB	18.32	155.99			
	SSBs	1.057	MSBs	0.12		0.95	**0.64**	**large**
	SSAB	11.524	MSAB	11.52	106.59			
	SSABs	0.973	MSABs	0.11		0.92	**0.53**	**large**
	SSA	801.03	MSA	801.03	0.30			
	SSAs	24406.73	MSAs	2711.86		0.03	**0.01**	**none**
PrL	SSs		51917.73					
	SSB	319.23	MSB	319.23	0.22			
	SSBs	12968.5	MSBs	1440.94		0.02	**0.00**	**none**
	SSAB	2.03	MSAB	2.03	0.00			
	SSABs	6224.7	MSABs	691.63		0.00	**0.00**	**none**

Factor A = Time
Factor B = Treatment

Effect Sizes – d for paired t-test designs

Face-Cooling Study

Using the formula:

$$d = t_r\,[2(1 - r)n]^{0.5}$$

Rating of Perceived Exertion

$t_r = 2.09$
$r = 0.916$

$$d = 0.19$$

Maximum Acceptable Weight of Lift

$t_r = 1.1$
$r = 0.965$

$$d = 0.09$$

Tests of Simple Main Effects – Hot Study (Chapter 4) Core Temperature

Frequency (B)

ABS	A1B1	A1B2	A1B3	sum	sum^2
1	36.1	36.77	36.48	109.35	11957.42
2	36.78	36.98	37.08	110.84	12285.51
3	36.53	37.1	37.45	111.08	12338.77
5	36.5	37.25	37.10	110.85	12287.72
7	36.6	37.12	37.47	111.19	12363.22
8	36.72	36.9	37.45	111.07	12336.54
9	36.27	36.55	36.52	109.34	11955.24
10	36.9	37	36.68	110.58	12227.94
11	36.33	36.17	36.80	109.3	11946.49
12	36.4	36.1	36.68	109.18	11920.27
13	36.23	36.72	36.60	109.55	12001.2
14	36.95	36.9	36.70	110.55	12221.3
sum	438.31	441.56	443.01	1322.88	145841.6
sum^2	192116	194975.234	196257.86	583349	
			1750011.49	48616.2	
SSB	0.9654	MSB	0.48		
SSBxS	1.3749	MSBxS	0.06		
		F	7.72		

ABS	A2B1	A2B2	A2B3	sum	sum^2
1	36.4	36.3	36.65	109.35	11957.423
2	37.05	36.85	37.05	110.95	12309.903
3	36.8	37.05	37.43	111.28	12383.238
5	36.65	36.95	37.05	110.65	12243.423
7	36.87	37.2	37.15	111.22	12369.888
8	36.42	37.05	37.43	110.9	12298.81
9	36.35	36.52	36.55	109.42	11972.736
10	37.05	37.27	37.35	111.67	12470.189
11	36.1	36.78	36.75	109.63	12018.737
12	36.37	36.6	36.9	109.87	12071.417
13	36.6	36.85	36.58	110.03	12106.601
14	36.78	36.78	36.95	110.51	12212.46
sum	439.44	442.2	443.84	1325.48	146414.82
sum^2	193107.51	195541	196993.9	585642	
			1756897	48806.5	
	SSB	0.82409	MSB	0.41204	
	SSBxS	0.71184	MSBxS	0.03236	
			F	12.7345	

ABS	A3B1	A3B2	A3B3	sum	sum^2
1	36.45	36.5	37.2	110.15	12133
2	36.8	36.8	37.47	111.07	12336.5
3	36.8	36.95	37.48	111.23	12372.1
5	36.65	36.9	36.92	110.47	12203.6
7	37.17	36.8	37.6	111.57	12447.9
8	37.05	37.32	37.62	111.99	12541.8
9	36.53	36.55	36.95	110.03	12106.6
10	37	37.05	37.5	111.55	12443.4
11	36.42	36.57	36.75	109.74	12042.9
12	36.2	36.95	36.83	109.98	12095.6
13	36.4	36.65	37.07	110.12	12126.4
14	36.55	36.85	37.07	110.47	12203.6
sum	440.02	441.89	446.46	1328.37	147053
sum^2	193618	195266.8	199326.5	588211	
			1764567	49020.3	
	SSB	1.829317	MSB	0.91466	
	SSBxS	0.614017	MSBxS	0.02791	
			F	32.7719	

ABS	A4B1	A4B2	A4B3	sum	sum^2
1	36.4	36.55	36.65	109.6	12012.2
2	36.9	36.98	37.78	111.66	12468
3	37.12	37.25	37.52	111.89	12519.4
5	37.08	37.2	37.03	111.31	12389.9
7	36.95	37.4	37.6	111.95	12532.8
8	37.02	37.67	37.98	112.67	12694.5
9	36.65	37	37.38	111.03	12327.7
10	37.12	37.25	37.5	111.87	12514.9
11	36.6	36.7	36.9	110.2	12144
12	36.87	37.05	36.68	110.6	12232.4
13	36.8	36.77	36.75	110.32	12170.5
14	36.8	37	37.1	110.9	12298.8
sum	442.31	444.82	446.87	1334	148305
sum^2	195638	197865	199693	593195.77	
			1779556	49436.812	
	SSB	0.86934	MSB	0.4346694	
	SSBxS	0.94046	MSBxS	0.0427482	
			F	10.168127	

ABS	A5B1	A5B2	A5B3	sum	sum^2
1	36.58	37.18	37.83	111.59	12452.328
2	36.9	37.93	38.1	112.93	12753.185
3	37.23	38	37.8	113.03	12775.781
5	36.95	37.05	37.7	111.7	12476.89
7	37.15	37.82	38.1	113.07	12784.825
8	37.03	38.23	38.28	113.54	12891.332
9	36.53	37.13	37.63	111.29	12385.464
10	37.07	37.78	38.25	113.1	12791.61
11	36.77	36.95	37.1	110.82	12281.072
12	36.98	36.98	37.73	111.69	12474.656
13	36.78	37.17	37.2	111.15	12354.323
14	36.95	37.3	37.52	111.77	12492.533
sum	442.92	449.52	453.24	1345.68	150914
sum^2	196178	202068	205426.5	603672.9	
			1810855	50310.44	
	SSB	4.5528	MSB	2.2764	
	SSBxS	1.21847	MSBxS	0.055385	
			F	41.10149	

Environment (A)

ABS	A1B1	A2B1	A3B1	A4B1	A5B1	sum	sum^2
1	36.1	36.4	36.45	36.4	36.58	181.93	33098.5
2	36.78	37.05	36.80	36.9	36.9	184.43	34014.4
3	36.53	36.8	36.80	37.12	37.23	184.48	34032.9
5	36.5	36.65	36.65	37.08	36.95	183.83	33793.5
7	36.6	36.87	37.17	36.95	37.15	184.74	34128.9
8	36.72	36.42	37.05	37.02	37.03	184.24	33944.4
9	36.27	36.35	36.53	36.65	36.53	182.33	33244.2
10	36.9	37.05	37.00	37.12	37.07	185.14	34276.8
11	36.33	36.1	36.42	36.6	36.77	182.22	33204.1
12	36.4	36.37	36.20	36.87	36.98	182.82	33423.2
13	36.23	36.6	36.40	36.8	36.78	182.81	33419.5
14	36.95	36.78	36.55	36.8	36.95	184.03	33867
sum	438.31	439.44	440.02	442.31	442.92	2203	404447
sum^2	192116	193107.514	193617.60	195638	196178.1	970657.03	
					4853209	80891.912	
SSA	1.2694	MSA	0.32				
SSAxS	1.1629	MSAxS	0.03				
		F	12.01				

ABS	A1B2	A2B2	A3B2	A4B2	A5B2	sum	sum^2
1	36.77	36.3	36.5	36.55	37.18	183.3	33598.9
2	36.98	36.85	36.8	36.98	37.93	185.54	34425.1
3	37.1	37.05	36.95	37.25	38	186.35	34726.3
5	37.25	36.95	36.9	37.2	37.05	185.35	34354.6
7	37.12	37.2	36.8	37.4	37.82	186.34	34722.6
8	36.9	37.05	37.32	37.67	38.23	187.17	35032.6
9	36.55	36.52	36.55	37	37.13	183.75	33764.1
10	37	37.27	37.05	37.25	37.78	186.35	34726.3
11	36.17	36.78	36.57	36.7	36.95	183.17	33551.2
12	36.1	36.6	36.95	37.05	36.98	183.68	33738.3
13	36.72	36.85	36.65	36.77	37.17	184.16	33914.9
14	36.9	36.78	36.85	37	37.3	184.83	34162.1
sum	441.56	442.2	441.89	444.82	449.52	2219.99	410717
sum^2	194975.2	195541	195266.77	197865	202068.2	985715.9	
					4928356	82149.28	
	SSA	3.73237	MSA	0.93			
	SSAxS	2.11855	MSAxS	0.05			
			F	19.38			

ABS	A1B3	A2B3	A3B3	A4B3	A5B3	sum	sum^2
1	36.48	36.65	37.2	36.65	37.83	184.81	34154.7
2	37.08	37.05	37.47	37.78	38.1	187.48	35148.8
3	37.45	37.43	37.48	37.52	37.8	187.68	35223.8
5	37.1	37.05	36.92	37.03	37.7	185.8	34521.6
7	37.47	37.15	37.6	37.6	38.1	187.92	35313.9
8	37.45	37.43	37.62	37.98	38.28	188.76	35630.3
9	36.52	36.55	36.95	37.38	37.63	185.03	34236.1
10	36.68	37.35	37.5	37.5	38.25	187.28	35073.8
11	36.8	36.75	36.75	36.9	37.1	184.3	33966.5
12	36.68	36.9	36.83	36.68	37.73	184.82	34158.4
13	36.6	36.58	37.07	36.75	37.2	184.2	33929.6
14	36.7	36.95	37.07	37.1	37.52	185.34	34350.9
sum	443.01	443.84	446.46	446.87	453.24	2233.42	415709
sum^2	196258	196994	199327	199693	205426.5	997698	
					4988164.9	83149	
	SSA	5.38771	MSA	1.34693			
	SSAxS	1.90405	MSAxS	0.04327			
			F	31.1257			

Appendix E – Psychophysics Script

"We want you to imagine that you are on piece work, getting paid for the amount of work that you do, but working a normal 8-hour shift that allows you to go home without feeling shattered.

In other words, we want you to work as hard as you can without straining yourself, or without becoming unusually tired, weakened, overheated, or out of breath.

You will adjust your own workload. You will lift only when you hear the audio tone. In some sessions you will be working fast, some sessions working slowly. Your job will be to adjust the weight of the box that you are lifting.

Adjusting your own workload is not an easy task. Only you know how you feel.

If you feel you are working too hard, reduce the load. Take some weight out of the box.

We don't want you loafing either. If you feel that you can work harder, increase the load. Put some weight into the box.

Don't be afraid to make adjustments. You have to make enough adjustments so that you get a good feeling for what is too heavy and what is too light. You can never make too many adjustments-but you can make too few.

Remember...

This is not a contest

Everyone is not expected to do the same amount of work

We want your judgement on how hard you can work without becoming unusually tired."

Adapted from Ciriello, Snook & Hughes (1993).

Appendix F – Calibration Data

Air Temperature Thermistors (C)									Relative Humidity (%)		
chan1	chan2	chan3	chan4	ref	ch1bias	ch2bias	ch3bias	ch4bias	shu	ref	bias
0.5	0.6	0.65	0.8	1.2	-0.70	-0.60	-0.55	-0.40	38.5	40.3	-1.8
0.5	0.6	0.6	0.75	1.1	-0.60	-0.50	-0.50	-0.35	37.5	39.3	-1.8
0.5	0.6	0.6	0.75	1.1	-0.60	-0.50	-0.50	-0.35	36.5	38.5	-2
0.5	0.55	0.6	0.75	1.1	-0.60	-0.55	-0.50	-0.35	35.8	37.6	-1.8
0.5	0.6	0.65	0.8	1.1	-0.60	-0.50	-0.45	-0.30	35.1	36.9	-1.8
0.5	0.6	0.65	0.8	1.1	-0.60	-0.50	-0.45	-0.30	34.3	36	-1.7
0.5	0.6	0.6	0.75	1.1	-0.60	-0.50	-0.50	-0.35	33.5	35.1	-1.6
0.45	0.5	0.55	0.7	1	-0.55	-0.50	-0.45	-0.30	32.7	34.3	-1.6
0.4	0.5	0.5	0.65	1	-0.60	-0.50	-0.50	-0.35	32	33.5	-1.5
0.4	0.45	0.5	0.65	1	-0.60	-0.55	-0.50	-0.35	31.4	32.9	-1.5
0.4	0.5	0.5	0.65	1	-0.60	-0.50	-0.50	-0.35	31	32.4	-1.4
0.45	0.5	0.55	0.7	1	-0.55	-0.50	-0.45	-0.30	30.8	32	-1.2
0.45	0.5	0.6	0.7	0.9	-0.45	-0.40	-0.30	-0.20	30.4	31.6	-1.2
0.45	0.5	0.55	0.7	0.9	-0.45	-0.40	-0.35	-0.20	30	31.1	-1.1
0.45	0.5	0.55	0.7	0.9	-0.45	-0.40	-0.35	-0.20	29.5	30.7	-1.2
0.4	0.5	0.5	0.65	0.9	-0.50	-0.40	-0.40	-0.25	29.4	30.5	-1.1
0.4	0.45	0.5	0.6	0.9	-0.50	-0.45	-0.40	-0.30	29.3	30.2	-0.9
0.35	0.4	0.45	0.6	0.8	-0.45	-0.40	-0.35	-0.20	29.1	29.9	-0.8
0.35	0.4	0.45	0.6	0.8	-0.45	-0.40	-0.35	-0.20	29	29.8	-0.8
0.35	0.4	0.45	0.6	0.8	-0.45	-0.40	-0.35	-0.20	28.9	29.7	-0.8
0.3	0.4	0.4	0.55	0.8	-0.50	-0.40	-0.40	-0.25	28.7	29.5	-0.8
0.3	0.4	0.4	0.55	0.8	-0.50	-0.40	-0.40	-0.25	28.6	29.4	-0.8
0.3	0.4	0.4	0.55	0.8	-0.50	-0.40	-0.40	-0.25	28.6	29.3	-0.7
0.3	0.4	0.45	0.6	0.8	-0.50	-0.40	-0.35	-0.20	28.4	29.2	-0.8
0.35	0.4	0.45	0.6	0.7	-0.35	-0.30	-0.25	-0.10	28.4	29.1	-0.7
0.3	0.4	0.4	0.6	0.7	-0.40	-0.30	-0.30	-0.10	28.3	29	-0.7
0.3	0.4	0.4	0.55	0.8	-0.50	-0.40	-0.40	-0.25	28.3	29	-0.7
0.3	0.35	0.4	0.55	0.7	-0.40	-0.35	-0.30	-0.15	28.4	29	-0.6
0.3	0.35	0.4	0.5	0.7	-0.40	-0.35	-0.30	-0.20	28.3	29	-0.7
0.3	0.35	0.4	0.5	0.7	-0.40	-0.35	-0.30	-0.20	28.3	29	-0.7
				Mean Bias	**-0.51**	**-0.44**	**-0.40**	**-0.26**		**Mean Bias**	**-1.16**
95% LoA at 0 C				**Std**	0.08	0.08	0.08	0.08		**Std**	0.45
				1.96*std	**0.17**	**0.15**	**0.16**	**0.15**		**1.96*std**	**0.87**

0 C	Mean Bias	± 95%	Range
Ch 1	**-0.51**	**0.17**	-0.68 to -0.34
Ch 2	**-0.44**	**0.15**	-0.59 to -0.29
Ch 3	**-0.4**	**0.16**	-0.56 to -0.24
Ch 4	**-0.26**	**0.15**	-0.41 to -0.11
RH	**-1.16**	**0.87**	-2.03 to -0.29

21.6	21.6	21.6	21.65	21.4	0.20	0.20	0.20	0.25	48.7	49.4	-0.7
21.6	21.6	21.65	21.65	21.4	0.20	0.20	0.25	0.25	48.7	49.5	-0.8
21.65	21.65	21.65	21.7	21.4	0.25	0.25	0.25	0.30	48.8	49.5	-0.7
21.65	21.7	21.7	21.7	21.4	0.25	0.30	0.30	0.30	48.7	49.5	-0.8
21.65	21.65	21.65	21.65	21.4	0.25	0.25	0.25	0.25	48.8	49.6	-0.8
21.6	21.6	21.65	21.65	21.4	0.20	0.20	0.25	0.25	48.8	49.6	-0.8
21.65	21.65	21.65	21.65	21.4	0.25	0.25	0.25	0.25	48.8	49.6	-0.8
21.65	21.65	21.65	21.7	21.4	0.25	0.25	0.25	0.30	48.8	49.5	-0.7
21.65	21.65	21.65	21.7	21.5	0.15	0.15	0.15	0.20	48.8	49.5	-0.7
21.65	21.65	21.7	21.7	21.5	0.15	0.15	0.20	0.20	48.8	49.6	-0.8
21.65	21.65	21.7	21.7	21.5	0.15	0.15	0.20	0.20	48.8	49.5	-0.7
21.65	21.65	21.65	21.7	21.5	0.15	0.15	0.15	0.20	48.8	49.6	-0.8
21.65	21.65	21.65	21.7	21.5	0.15	0.15	0.15	0.20	48.9	49.7	-0.8
21.65	21.65	21.65	21.7	21.5	0.15	0.15	0.15	0.20	48.8	49.5	-0.7
21.65	21.65	21.65	21.7	21.5	0.15	0.15	0.15	0.20	49	49.7	-0.7
21.65	21.7	21.7	21.7	21.5	0.15	0.20	0.20	0.20	48.9	49.6	-0.7
21.7	21.7	21.7	21.75	21.5	0.20	0.20	0.20	0.25	48.9	49.6	-0.7
21.7	21.7	21.75	21.75	21.6	0.10	0.10	0.15	0.15	49	49.7	-0.7
21.7	21.75	21.75	21.75	21.6	0.10	0.15	0.15	0.15	49	49.7	-0.7
21.7	21.75	21.75	21.75	21.6	0.10	0.15	0.15	0.15	49	49.7	-0.7
21.7	21.7	21.75	21.75	21.6	0.10	0.10	0.15	0.15	49	49.7	-0.7
21.7	21.7	21.75	21.75	21.6	0.10	0.10	0.15	0.15	49	49.7	-0.7
21.7	21.7	21.75	21.75	21.6	0.10	0.10	0.15	0.15	49.1	49.7	-0.6
21.7	21.75	21.75	21.75	21.6	0.10	0.15	0.15	0.15	49	49.7	-0.7
21.7	21.75	21.75	21.75	21.6	0.10	0.15	0.15	0.15	49.2	49.8	-0.6
21.75	21.75	21.75	21.75	21.6	0.15	0.15	0.15	0.15	49.1	49.8	-0.7
21.7	21.75	21.75	21.75	21.6	0.10	0.15	0.15	0.15	49.2	49.9	-0.7
21.7	21.7	21.75	21.75	21.6	0.10	0.10	0.15	0.15	49.2	49.9	-0.7
21.7	21.75	21.75	21.75	21.6	0.10	0.15	0.15	0.15	49.2	49.8	-0.6
21.7	21.7	21.75	21.75	21.6	0.10	0.10	0.15	0.15	49.1	49.9	-0.8
				Mean Bias	**0.15**	**0.17**	**0.18**	**0.20**		**Mean Bias**	**-0.72**
95% LoA at 22 C, 45% RH				**Std**	0.06	0.05	0.05	0.05		**Std**	0.06
				1.96*std	**0.11**	**0.10**	**0.09**	**0.10**		**1.96*std**	**0.12**

22 C 45%	Mean Bias	± 95%	Range
Ch 1	**0.15**	**0.11**	+0.04 to +0.26
Ch 2	**0.17**	**0.1**	+0.07 to +0.27
Ch 3	**0.18**	**0.09**	+0.09 to +0.27
Ch 4	**0.2**	**0.1**	+0.1 to +0.3
RH	**-0.72**	**0.12**	-0.84 to -0.60

39.55	39.5	39.45	39.45	38.4	1.15	1.10	1.05	1.05	74.9	74.3	0.6
39.55	39.5	39.45	39.4	38.5	1.05	1.00	0.95	0.90	75.2	74.5	0.7
39.5	39.45	39.45	39.4	38.6	0.90	0.85	0.85	0.80	75.3	75.3	0
39.55	39.5	39.45	39.45	38.6	0.95	0.90	0.85	0.85	75.4	75.1	0.3
39.55	39.5	39.5	39.45	38.6	0.95	0.90	0.90	0.85	75.7	75.6	0.1
39.55	39.5	39.5	39.5	38.7	0.85	0.80	0.80	0.80	75.9	76	-0.1
39.55	39.5	39.5	39.45	38.7	0.85	0.80	0.80	0.75	76.2	76.2	0
39.55	39.5	39.5	39.45	38.8	0.75	0.70	0.70	0.65	76.4	76.7	-0.3
39.6	39.55	39.5	39.5	38.8	0.80	0.75	0.70	0.70	76.9	77	-0.1
39.65	39.6	39.55	39.55	38.8	0.85	0.80	0.75	0.75	76.9	77.2	-0.3
39.65	39.6	39.6	39.55	38.9	0.75	0.70	0.70	0.65	77.3	77.4	-0.1
39.65	39.6	39.6	39.55	38.9	0.75	0.70	0.70	0.65	77.4	77.6	-0.2
39.65	39.6	39.6	39.55	39	0.65	0.60	0.60	0.55	77.4	77.5	-0.1
39.65	39.6	39.6	39.55	39	0.65	0.60	0.60	0.55	77.6	77.6	0
39.65	39.6	39.6	39.55	39	0.65	0.60	0.60	0.55	77.7	77.9	-0.2
39.65	39.6	39.6	39.55	39	0.65	0.60	0.60	0.55	77.8	77.9	-0.1
39.65	39.6	39.6	39.55	39	0.65	0.60	0.60	0.55	77.8	77.8	0
39.65	39.65	39.6	39.6	39	0.65	0.65	0.60	0.60	77.8	78	-0.2
39.65	39.65	39.65	39.6	39	0.65	0.65	0.65	0.60	77.9	78	-0.1
39.7	39.65	39.65	39.6	39.1	0.60	0.55	0.55	0.50	78.1	78.1	0
39.65	39.65	39.65	39.6	39.1	0.55	0.55	0.55	0.50	78.2	78.4	-0.2
39.65	39.65	39.65	39.6	39.1	0.55	0.55	0.55	0.50	78.3	78.3	0
39.65	39.65	39.6	39.6	39.1	0.55	0.55	0.50	0.50	78.2	78.2	0
39.65	39.65	39.65	39.6	39.1	0.55	0.55	0.55	0.50	78.3	78.2	0.1
39.7	39.65	39.65	39.6	39.1	0.60	0.55	0.55	0.50	77.8	77.8	0
39.65	39.6	39.6	39.55	39	0.65	0.60	0.60	0.55	77.7	77.8	-0.1
39.6	39.6	39.55	39.55	39	0.60	0.60	0.55	0.55	77.4	77.6	-0.2
39.6	39.55	39.55	39.5	39.1	0.50	0.45	0.45	0.40	77.3	77.5	-0.2
39.6	39.55	39.55	39.5	39.1	0.50	0.45	0.45	0.40	77.4	77.4	0
39.6	39.6	39.6	39.55	39.1	0.50	0.50	0.50	0.45	77.2	77.4	-0.2
				Mean Bias	**0.71**	**0.67**	**0.66**	**0.62**		**Mean Bias**	**-0.03**
95% LoA at 40 C, 80% RH				**Std**	0.17	0.16	0.15	0.16		**Std**	0.22
				1.96*std	**0.33**	**0.31**	**0.30**	**0.31**		**1.96*std**	**0.44**

40 C 80%	Mean Bias	± 95%	Range
Ch 1	**0.71**	**0.33**	+0.38 to +1.04
Ch 2	**0.67**	**0.31**	+0.36 to +0.98
Ch 3	**0.66**	**0.3**	+0.36 - +0.96
Ch 4	**0.62**	**0.31**	+0.31 to +0.93
RH	**-0.03**	**0.44**	-0.47 to +0.41

Surface Thermistors (C)

Run 1 - Bath at 36 C

Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ref	Ch1 Bias	Ch2 Bias	Ch3 Bias	Ch4 Bias	Ch5 Bias	Ch6 Bias
35.9	35.8	36	36	36	36	36	-0.15	-0.2	0	-0.05	-0.05	-0.05
35.9	35.8	36	35.9	36	36	36	-0.15	-0.25	-0.05	-0.1	-0.05	-0.05
35.8	35.7	36	35.9	35.9	35.9	35.9	-0.1	-0.2	0.05	-0.05	0	0
35.8	35.7	35.9	35.8	35.9	35.9	35.9	-0.15	-0.25	0	-0.1	-0.05	-0.05
35.7	35.7	35.9	35.8	35.8	35.8	35.9	-0.2	-0.25	-0.05	-0.15	-0.1	-0.1
35.7	35.6	35.8	35.8	35.8	35.8	35.8	-0.15	-0.2	0	-0.05	-0.05	-0.05
35.7	35.6	35.8	35.7	35.8	35.7	35.8	-0.15	-0.25	-0.05	-0.1	-0.05	-0.1
35.6	35.5	35.8	35.7	35.7	35.7	35.7	-0.1	-0.2	0.05	-0.05	0	0
35.6	35.5	35.7	35.6	35.7	35.7	35.7	-0.15	-0.2	0	-0.1	-0.05	-0.05
35.5	35.5	35.7	35.6	35.6	35.6	35.7	-0.2	-0.25	-0.05	-0.15	-0.1	-0.1
35.5	35.4	35.6	35.5	35.6	35.6	35.6	-0.1	-0.2	0	-0.1	-0.05	-0.05
35.5	35.4	35.6	35.5	35.5	35.5	35.6	-0.15	-0.2	-0.05	-0.1	-0.1	-0.1
35.5	35.4	35.6	35.5	35.5	35.5	35.5	-0.05	-0.15	0.05	-0.05	0	0
35.4	35.3	35.5	35.5	35.5	35.5	35.5	-0.1	-0.2	0	-0.05	-0.05	-0.05
35.4	35.3	35.5	35.4	35.5	35.5	35.5	-0.15	-0.25	0	-0.1	-0.05	-0.05
35.3	35.3	35.5	35.4	35.4	35.4	35.4	-0.1	-0.15	0.05	-0.05	0	0
35.3	35.2	35.4	35.4	35.4	35.4	35.4	-0.1	-0.2	0	-0.05	-0.05	-0.05
35.3	35.2	35.4	35.3	35.3	35.3	35.4	-0.15	-0.25	-0.05	-0.1	-0.1	-0.1
35.2	35.1	35.4	35.3	35.3	35.3	35.3	-0.1	-0.2	0.05	-0.05	0	0
35.2	35.1	35.3	35.2	35.3	35.3	35.3	-0.15	-0.2	0	-0.1	-0.05	-0.05
						Mean Bias	**-0.13**	**-0.21**	**0.00**	**-0.08**	**-0.05**	**-0.05**
95% LoA at 36 C						**Std**	0.04	0.03	0.04	0.03	0.03	0.04
						Std*2	**0.07**	**0.06**	**0.07**	**0.07**	**0.07**	**0.07**

	Mean Bias	36? C ± 95%	Range
Ch 1	**-0.13**	**0.07**	-0.2 to -0.06
Ch 2	**-0.21**	**0.06**	-0.27 to -0.15
Ch 3	**0**	**0.07**	-0.07 to +0.07
Ch 4	**-0.08**	**0.07**	-0.15 to -0.01
Ch 5	**-0.05**	**0.07**	-0.12 to +0.02
Ch 6	**-0.05**	**0.07**	-0.12 to +0.02

Run 2 - Bath at 28 C

Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ref	Ch1 Bias	Ch2 Bias	Ch3 Bias	Ch4 Bias	Ch5 Bias	Ch6 Bias
27.7	27.6	27.8	27.7	27.8	27.8	27.7	-0.05	-0.1	0.05	0	0.05	0.05
27.7	27.6	27.8	27.7	27.8	27.8	27.7	-0.05	-0.1	0.05	0	0.05	0.05
27.7	27.6	27.8	27.7	27.8	27.8	27.7	-0.05	-0.1	0.05	0	0.05	0.05
27.7	27.6	27.8	27.7	27.8	27.8	27.7	-0.05	-0.1	0.05	0	0.05	0.05
27.7	27.6	27.8	27.7	27.7	27.8	27.7	-0.05	-0.15	0.05	0	0	0.05
27.7	27.6	27.8	27.7	27.7	27.7	27.7	-0.05	-0.15	0.05	0	0	0
27.7	27.6	27.8	27.7	27.7	27.8	27.7	-0.05	-0.15	0.05	0	0	0.05
27.7	27.6	27.8	27.7	27.7	27.7	27.7	-0.05	-0.15	0.05	0	0	0
27.7	27.6	27.8	27.7	27.7	27.7	27.7	-0.05	-0.15	0.05	-0.05	0	0
27.7	27.6	27.8	27.7	27.7	27.7	27.7	-0.05	-0.15	0.05	-0.05	0	0
27.7	27.6	27.8	27.7	27.7	27.7	27.7	-0.05	-0.15	0.05	-0.05	0	0
27.7	27.6	27.7	27.7	27.7	27.7	27.7	-0.05	-0.15	0	-0.05	0	0
27.7	27.6	27.7	27.7	27.7	27.7	27.7	-0.05	-0.15	0	-0.05	0	0
27.7	27.6	27.7	27.7	27.7	27.7	27.7	-0.05	-0.15	0	-0.05	0	0
27.6	27.6	27.7	27.7	27.7	27.7	27.7	-0.1	-0.15	0	-0.05	0	0
27.6	27.6	27.7	27.7	27.7	27.7	27.7	-0.1	-0.15	0	-0.05	0	0
27.6	27.6	27.7	27.7	27.7	27.7	27.7	-0.1	-0.15	0	-0.05	0	0
27.6	27.6	27.7	27.7	27.7	27.7	27.7	-0.1	-0.15	0	-0.05	0	0
27.6	27.5	27.7	27.7	27.7	27.7	27.7	-0.1	-0.2	0	-0.05	0	0
27.6	27.5	27.7	27.7	27.7	27.7	27.7	-0.1	-0.2	0	-0.05	0	0
						Mean Bias	**-0.06**	**-0.14**	**0.03**	**-0.03**	**0.01**	**0.02**
95% LoA at 28 C						**Std**	0.02	0.03	0.03	0.03	0.02	0.02
						Std*1.96	**0.05**	**0.05**	**0.05**	**0.05**	**0.04**	**0.05**

	Mean Bias	28? C ± 95%	Range
Ch 1	**-0.06**	**0.05**	-0.11 to -0.01
Ch 2	**-0.14**	**0.05**	-0.19 to -0.09
Ch 3	**0.03**	**0.05**	-0.08 - +0.02
Ch 4	**-0.03**	**0.05**	-0.08 - +0.02
Ch 5	**0.01**	**0.04**	-0.05 - +0.03
Ch 6	**0.02**	**0.05**	-0.07 - +0.03

ch1	ch2	ch3	ch4	ch5	ref		ch1bias	ch2bias	ch3 bias	ch4 bias	ch5 bias
5.1	4.95	4.9	5.05	5		5.2	-0.1	-0.25	-0.3	-0.15	-0.2
5.1	4.95	4.9	5.05	5		5.2	-0.1	-0.25	-0.3	-0.15	-0.2
5.1	4.95	4.9	5	5		5.2	-0.1	-0.25	-0.3	-0.2	-0.2
5.05	4.95	4.9	5	5		5.2	-0.15	-0.25	-0.3	-0.2	-0.2
5.05	4.95	4.9	5	5		5.2	-0.15	-0.25	-0.3	-0.2	-0.2
5.05	4.95	4.9	5	5		5.2	-0.15	-0.25	-0.3	-0.2	-0.2
5.05	4.95	4.9	5	5		5.2	-0.15	-0.25	-0.3	-0.2	-0.2
5	4.95	4.9	5	5		5.2	-0.2	-0.25	-0.3	-0.2	-0.2
5	4.95	4.9	5	5		5.2	-0.2	-0.25	-0.3	-0.2	-0.2
5	4.95	4.85	5	4.95		5.2	-0.2	-0.25	-0.35	-0.2	-0.25
5	4.95	4.85	4.95	4.9		5.2	-0.2	-0.25	-0.35	-0.25	-0.3
5	4.95	4.85	4.95	4.9		5.2	-0.2	-0.25	-0.35	-0.25	-0.3
5	4.9	4.85	4.95	4.9		5.2	-0.2	-0.3	-0.35	-0.25	-0.3
5	4.9	4.85	4.95	4.9		5.2	-0.2	-0.3	-0.35	-0.25	-0.3
4.95	4.9	4.85	4.95	4.9		5.1	-0.15	-0.2	-0.25	-0.15	-0.2
4.95	4.9	4.85	4.95	4.9		5.1	-0.15	-0.2	-0.25	-0.15	-0.2
4.95	4.9	4.85	4.95	4.9		5.1	-0.15	-0.2	-0.25	-0.15	-0.2
4.95	4.9	4.85	4.95	4.9		5.1	-0.15	-0.2	-0.25	-0.15	-0.2
4.95	4.9	4.85	4.95	4.9		5.1	-0.15	-0.2	-0.25	-0.15	-0.2
4.95	4.9	4.85	4.9	4.9		5.1	-0.15	-0.2	-0.25	-0.2	-0.2
4.95	4.9	4.85	4.9	4.9		5.1	-0.15	-0.2	-0.25	-0.2	-0.2
					Mean Bias		-0.1595	-0.2381	-0.2952	-0.1929	-0.22143
					SD		0.03398	0.03124	0.03842	0.03635	0.04053
					SD*1.96		0.07	0.06	0.08	0.07	0.08

		5? C	
	Mean Bias	± 95%	Range
ch1	-0.2	0.07	-0.27 to -0.13
ch2	-0.2	0.06	-0.26 to -0.14
ch3	-0.3	0.08	-0.38 to -0.22
ch4	-0.2	0.07	-0.27 to -0.13
ch5	-0.2	0.08	-0.28 to -0.12

ch1	ch2	ch3	ch4	ch5	ref		ch1bias	ch2bias	ch3 bias	ch4 bias	ch5 bias
19.1	19	18.95	19.1	19.05		19.2	-0.1	-0.2	-0.25	-0.1	-0.15
19.15	19	18.95	19.1	19.05		19.2	-0.05	-0.2	-0.25	-0.1	-0.15
19.15	19	18.95	19.1	19.05		19.2	-0.05	-0.2	-0.25	-0.1	-0.15
19.15	19	18.95	19.1	19.05		19.2	-0.05	-0.2	-0.25	-0.1	-0.15
19.15	19	18.95	19.1	19.05		19.2	-0.05	-0.2	-0.25	-0.1	-0.15
19.15	19	18.95	19.1	19.05		19.2	-0.05	-0.2	-0.25	-0.1	-0.15
19.15	19	18.95	19.1	19.1		19.2	-0.05	-0.2	-0.25	-0.1	-0.1
19.15	19	18.95	19.15	19.1		19.3	-0.15	-0.3	-0.35	-0.15	-0.2
19.15	19	18.95	19.15	19.1		19.2	-0.05	-0.2	-0.25	-0.05	-0.1
19.15	19	18.95	19.15	19.1		19.2	-0.05	-0.2	-0.25	-0.05	-0.1
19.15	19	19	19.15	19.1		19.2	-0.05	-0.2	-0.2	-0.05	-0.1
19.15	19	19	19.15	19.15		19.2	-0.05	-0.2	-0.2	-0.05	-0.05
19.15	19	18.95	19.15	19.2		19.2	-0.05	-0.2	-0.25	-0.05	0
19.15	19.05	19	19.15	19.2		19.2	-0.05	-0.15	-0.2	-0.05	0
19.15	19.05	19	19.15	19.25		19.2	-0.05	-0.15	-0.2	-0.05	0.05
19.15	19.05	19	19.15	19.25		19.2	-0.05	-0.15	-0.2	-0.05	0.05
19.15	19.05	19	19.15	19.25		19.2	-0.05	-0.15	-0.2	-0.05	0.05
19.15	19.05	19	19.15	19.3		19.2	-0.05	-0.15	-0.2	-0.05	0.1
19.2	19.05	19	19.15	19.3		19.2	0	-0.15	-0.2	-0.05	0.1
19.2	19.05	19	19.2	19.3		19.25	-0.05	-0.2	-0.25	-0.05	0.05
19.2	19.05	19	19.2	19.35		19.3	-0.1	-0.25	-0.3	-0.1	0.05
19.2	19.05	19	19.2	19.35		19.3	-0.1	-0.25	-0.3	-0.1	0.05
					Mean Bias		-0.06	-0.20	-0.24	-0.07	-0.05
					SD		0.03	0.04	0.04	0.03	0.10
					SD*1.96		0.06	0.07	0.08	0.06	0.19

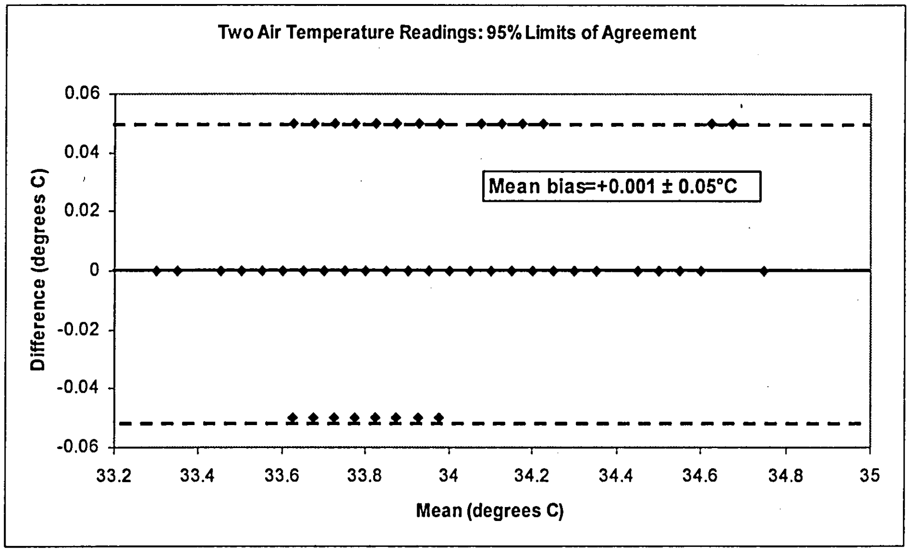
		19? C	
	Mean Bias	± 95%	Range
ch1	-0.06	0.06	-0.12 to 0 C
ch2	-0.2	0.07	-0.27 to -0.13 C
ch3	-0.24	0.08	-0.32 to -0.16 C
ch4	-0.07	0.06	-0.13 to -0.01 C
ch5	-0.05	0.19	-0.24 to 0.14 C

Environmental Chamber – Reproducibility of Measures

Comparison of air temperature at two locations

	Air 1	Air 2	
mean	33.909	33.907	0.1125 sum of differences
sd	0.211	0.208	
count	188	188	

Absolute TEM	**0.02°C**
Relative TEM	**0.05%**
Limits of Agreement	
mean bias	**0.001°C**
1 sd	**0.02**
95% loa	**0.048**
upper	**0.049**
lower	**-0.046**



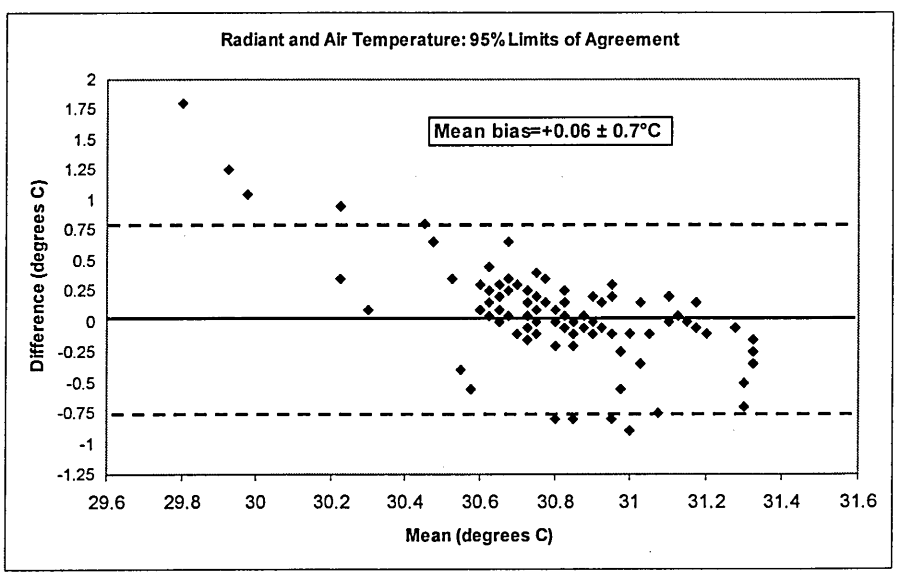
Comparison of radiant and air temperature

	Radiant	Air	
mean	30.84	30.78	16.1475 sum of differences
sd	0.19	0.399	
count	120	120	

Absolute TEM	0.26°C
Relative TEM	0.84%

Limits of Agreement

mean bias	0.06°C
1 sd	0.36
95% loa	0.71
upper	0.77
lower	-0.65



Appendix G – Site Visits (Example data)

Company name has been removed to protect anonymity.

<u>Name of Company Here - April 16th 2003</u>

A facility in Salford producing pies of all descriptions for the freezer. Overall, the environment was comfortable throughout the food preparation areas. According to the staff, the environment tended to vary with the seasons. Staff admitted that it could get hot in the summer and often wore nothing under their overalls. Where air extraction was present there were localised variations in temperature and air velocity. Because of the flour-dust content in the air it was decided not to take readings.

Staff worked two shift patterns, 0500-1300 and 1300-2100, at that time of year. Breaks were flexible depending on job demand. They also worked within one process area but rotated around periodically within their teams to alleviate boredom.

In the first area we visited, pastry was cut to length and rolled onto pins weighing ~25kg. The pins were then lifted off the conveyor belt (height=94 cm) and transferred to storage racks with heights of 46, 80 and 112 cm respectively. Between three and four pins were lifted per minute. No environmental monitoring was conducted by the company, they did however test the pastry temperature with a probe periodically. At the beginning of this process, trays of pastry were lifted off a pallet and tipped into the mixer (height=95 cm) at a frequency of around 3.min^{-1}. The trays measured 75x45x16 cm with handles cut into the sides 17cm from the edge. When loaded they weighed between 20 - 25 kg.

In the cook room, pie fillings were made according to recipes. Wheeled bins of mince were lifted by electric hoist into the vats. Bags of cornflow (25 kg) and seasoning (8.5 kg) were poured into mixers at chest height. There was low ventilation apart from the middle of the room that benefited from the air-flow from a large extractor from the main process area. Only two vats were in use when we visited but there were a number of others both large and small and we were told that it got very hot when they were all in use.

In the weighing room batches of dry mix were weighed out and poured into trays for use in the main area. Rusk bags weighing 20 kg were stored on pallets up to a height of 150 cm. Grit bags (25 kg, 60x40x15 cm) were stored on pallets to the same approximate height. A worker might make up around 60-70 batches a day during an eight hour shift. Trays of mix were around 20 kg. Room temperature was fairly constant but there was some air movement by the scales caused by an extractor removing dust from the local environment.

In the de-boxing area, boxes of frozen meat (27.2 kg) were unloaded onto trays.

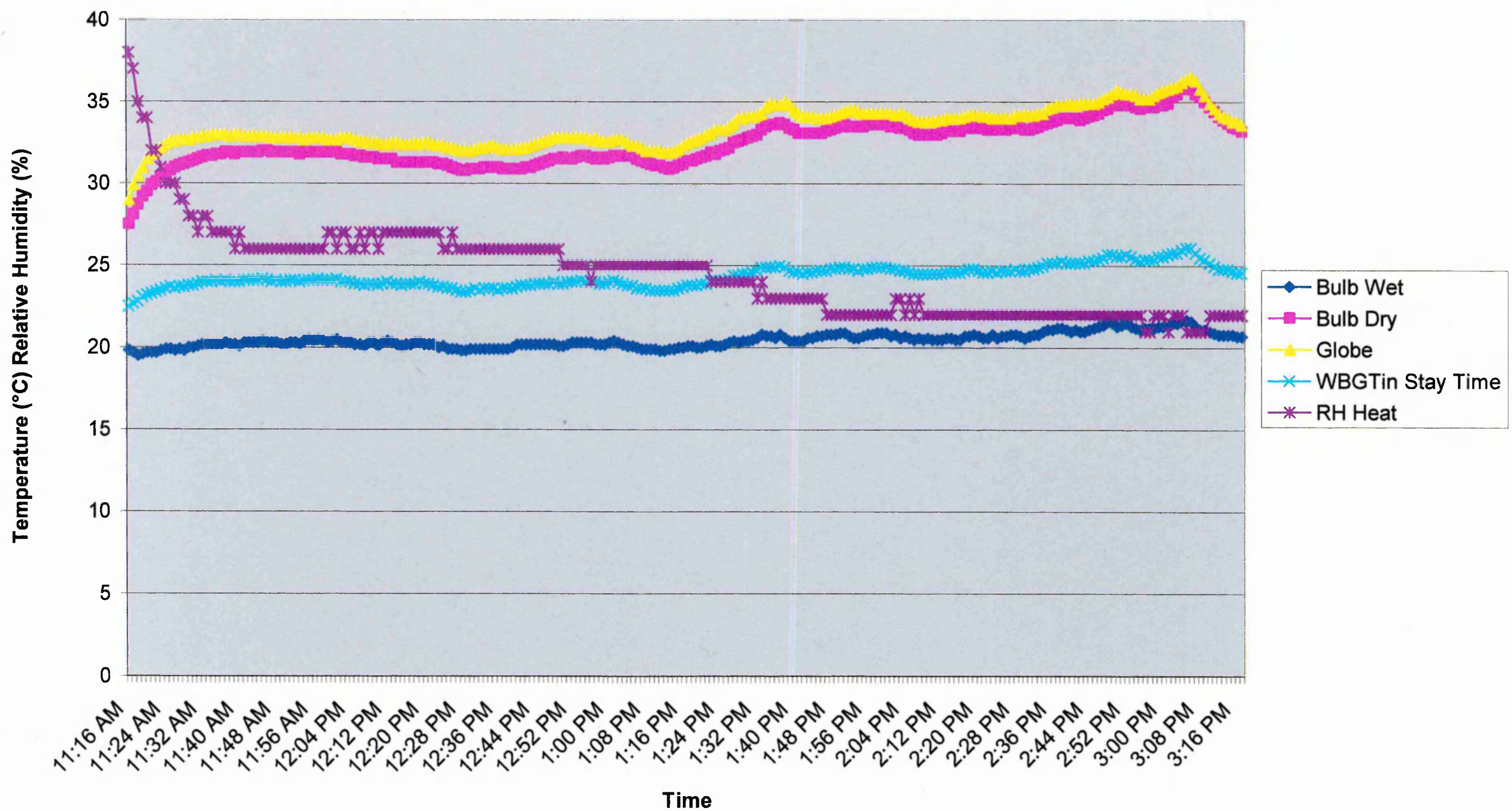
All food was put through a microwave to tenderise it. While we were there, 10 kg boxes of rhubarb were unloaded from a pallet onto a conveyer (height=100cm) and lifted off at the end (85 cm) after going through the microwave. Lift frequency was around 2.min^{-1}. Box dimensions were 38x30x20 cm.

In the rolling out area, pastry on pins (from the first area) was loaded onto conveyers from the storage racks. The heights of these conveyers varied between 74 cm and 88 cm in the shepherds pie area.

At the end of the processes, boxes of produce were loaded onto pallets from conveyers (height= 65 cm). These varied in weight from 4 kg to 9 kg.

Overall impressions. An effort had been made to limit single lifts to around 25 kg maximum. No-one seemed to do the same task for more than an hour at a time (except in the weighing room). Lift frequencies were up to around 4.min^{-1}. The temperature of the food was more important than the temperature of the environment. Workers compensated for changes in temperature by varying the amount of clothes that they wore under their PPE.

Environmental Conditions company name removed (Head Height)

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2


3

4

Figure 1. Boxes of frozen meat lifted from floor (pallet) level to (figure 2) roughly knuckle-height. Boxes weighed 25kg.

Figure 3. A lift and carry of seasoning mix for pies. This is an example of an intermittent lift. The seasonings were dispensed by a machine approximately once a minute.

Figure 4. Trays of sausage rolls being palletized.

5

Figure 5. The author with environmental monitoring equipment at a bakery in 2003. Note the uncomfortable plastic over-garment.

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