Prescribing exercise intensity to elicit a fixed heat production

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Prescribing exercise intensity to elicit a fixed heat production

Contributed by: Peta Forsyth, Australian Institute of Sport and Ollie Jay, University of Sydney

Project: Assessing thermoregulatory deficits of trained individuals with a spinal cord injury exercising in the heat
# Table of contents

1 Introduction/theoretical basis.................................................................................................................. 3  
2 Key papers .................................................................................................................................................. 4  
3 Ethical considerations ................................................................................................................................. 4  
4 Facility and equipment................................................................................................................................. 4  
  4.1 Testing facility ......................................................................................................................................... 4  
  4.2 Equipment ............................................................................................................................................. 5  
  4.2.1 Laboratory-based equipment ............................................................................................................. 5  
  4.2.2 Smaller equipment/instruments ......................................................................................................... 5  
5 Training/qualifications/competencies ......................................................................................................... 5  
6 Workflow..................................................................................................................................................... 6  
  6.1 Pre-experimental visit ............................................................................................................................... 6  
  6.2 Prior to testing .......................................................................................................................................... 6  
  6.3 During experimentation ............................................................................................................................. 7  
  6.4 Data handling and management ............................................................................................................. 7  
7 Appendices .................................................................................................................................................. 8
1 Introduction/theoretical basis

Recent investigation by Cramer and Jay\(^1\) has identified the traditional approach of prescribing exercise intensity based on maximal oxygen consumption (VO\(_2\)\(_{\max}\)) as being inappropriate when comparing thermoregulatory measures between groups that differ based on factors such as injury, disease, sex or age. Exercise intensity set as a percentage of VO\(_2\)\(_{\max}\) fails to account for individual differences in body mass and body surface area (BSA), thus leading to variation in metabolic heat production (H\(_{\text{prod}}\)), evaporative heat balance requirements and ultimately, changes in core temperature. Instead, when investigating time-dependent changes in core temperature in groups that differ in body mass, intensity should be prescribed in W/kg. For comparisons of local sweat rates during steady state exercise in groups that differ in body surface area, intensity should be prescribed in W/m\(^2\). Finally, investigations comparing whole-body sweat loss should be done so with a fixed absolute heat production in W (Figure 1, Jay & Cramer, Temperature. 2014)\(^2\). This methodology is critical for establishing an unbiased understanding thermoregulatory deficits in various populations.

![Different body size and fitness between participants](image)

**Figure 1.** Proposed methods for selecting heat production (in brackets) for comparing local sweat rate in mg/cm\(^2\)/min, changes in core temperature in °C, and whole-body sweat rate in g/min or L/h.
2 Key papers

References:


3 Ethical considerations

A participant information sheet and consent form has been attached as appendices. No challenges were encountered in gaining ethical approval for this measure.

4 Facility and equipment

4.1 Testing facility

Calculating metabolic heat production requires an arm crank ergometer (or different type of ergometer depending on the mode of exercise being used for testing) and a metabolic cart. Measuring VO₂ and RER throughout exercise is critical to ensure that the target metabolic heat production is maintained.
4.2 Equipment

4.2.1 Laboratory-based equipment

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Photo/description</th>
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</thead>
<tbody>
<tr>
<td>Arm ergometer (or different ergometer for other modes of exercise)</td>
<td><img src="image1" alt="Arm ergometer" /></td>
</tr>
<tr>
<td>Metabolic cart</td>
<td><img src="image2" alt="Metabolic cart" /></td>
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4.2.2 Smaller equipment/instruments

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Photo/description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excel spreadsheet calculator</td>
<td>An in-house calculator was created to allow for easy monitoring of metabolic heat production during exercise, to ensure that target heat production is maintained (Appendix C)</td>
</tr>
</tbody>
</table>

5 Training/qualifications/competencies

This section should provide details of any training and inductions that must be completed prior to undertaking this method.

Please indicate (check the box) to indicate which of the following is required prior to undertaking this method:

- [ ] Yes
- [x] No

---

Health and Safety training
6 Workflow

The following instructions describe the steps required to ensure individuals unmatched for body mass exercise at the same relative intensity (taken from Cramer & Jay, J Appl Physiol. 2014):

6.1 Pre-experimental visit

Step 1. During a pre-experimental visit, height and body mass must first be measured if prescribing $H_{prod}$ in W/kg. BSA can be estimated using equation of DuBois and DuBois$^3$.

6.2 Prior to testing

Step 2. Before testing, identify the target absolute $H_{prod}$ (in W) to be used. For example, if a fixed $H_{prod}$ of 7.0 W/kg is required and the individual is 75 kg, the target absolute $H_{prod}$ is $7.0 \times 75 = 525$ W.

Step 3. The exercise intensity required to elicit each target absolute $H_{prod}$ may be estimated from the relationship between the VO$_2$ and external work rate. To establish this relationship, have each participant perform a submaximal incremental exercise test that includes a range of work rates that will incorporate the experimental target absolute $H_{prod}$. The work rates in this test may be estimated based on pilot testing, previous research, or, in the case of cycling, assumed gross efficiency values. For example, if $H_{prod}$ values of 400 and 600 W will be targeted, assuming a gross efficiency of 17%, work rates of $\sim 80$ and $\sim 125$ W, respectively, would be expected. Therefore, during the preliminary test, the initial work rate may be set to 80 W and increased by 20 W/stage for four stages (i.e., up to 140 W) to include all estimated target work rates. The duration of each stage should be sufficient to attain steady-state VO$_2$ values (i.e., 3–5 min). Metabolic data (i.e., VO$_2$ and RER) should be collected throughout this test.

Step 4. Take the final 1-min (i.e., steady-state) VO$_2$ value of each stage and, using conventional equations (Equation 1 in the methods section of the full text), calculate metabolic energy expenditure (M) and then subtract W to obtain $H_{prod}$ for each stage. As the $H_{prod}$–work rate relationship is linear at submaximal intensities, the work rate required to elicit each target absolute $H_{prod}$ may be estimated using the equation of a straight line ($y = mx + b$). It is also important to note the corresponding VO$_2$ value for each required work rate.
6.3 During experimentation

*Step 5.* During experimentation, set the initial work rate as that predicted to elicit the target absolute $H_{prod}$. The actual $H_{prod}$ should be verified using real-time VO$_2$ measurements, with slight work rate adjustments potentially necessary to ensure a constant $H_{prod}$ throughout exercise. To this end, it is crucial that VO$_2$ is monitored closely.

6.4 Data handling and management

For the calculation of metabolic heat production, there are no data handling or management considerations. However, when monitoring during exercise, metabolic heat production should be maintained as closely as possible to the target heat production. If metabolic heat production during exercise becomes too low or high, the external workload should be adjusted accordingly and the change should also be noted on the trial recording sheet. The excel spreadsheet for calculating metabolic heat production can be used during the trial and updated if any adjustments in external workload are made. Furthermore, changes in VO$_2$ and RER throughout the trial can also be updated with the calculator to ensure that the target heat production is maintained.

Metabolic data should be saved following the completion of exercise within the program, then exported and saved as 30-sec averages. Data should be saved immediately after each test to a secure network storage location. Metabolic data can be copied into the template provided.
7 Appendices

Appendix A: Participant Information Sheet

ASSESSING THERMOREGULATORY DEFICITS OF TRAINED INDIVIDUALS WITH A SPINAL CORD INJURY DURING EXERCISE IN THE HEAT

Dear Participant,

You are invited to participate in a study funded by the Collaborative Research Network for Advancing Exercise and Sport Science, the Australian Institute of Sport, University of Canberra and the University of Sydney. This research is being conducted within the School of Exercise Science at the University of Sydney, Cumberland Campus.

What is the project about?

The research aims to assess the tolerance of heat for people with a spinal cord injury whilst performing physical activity. You will undergo testing at the Cumberland Campus of the University of Sydney on three occasions, the first for 75 minutes, and the second and third for approximately 2 1/4 hours (~5 3/4 hour total time commitment).

Who can participate?

- Males who have a spinal cord injury and who are exercising at least 3 times per week in a Paralympic sport such as wheelchair basketball, wheelchair tennis, wheelchair rugby, or wheelchair track and road.
- Males between the age of 18 – 49 years

Who cannot participate?

- People with hypertension, cardiovascular, respiratory and/or metabolic disorders
- Current smokers, as well as individuals who regularly smoked within the past two years.
- Females

What will you be asked to do?

You will be required to participate in 1 preliminary session, 1 familiarisation session and 1 experimental session using the following equipment and methods:

- Submaximal and maximal aerobic capacity test
- Fitness questionnaire
- Dual-Energy X-ray Absorptiometry (DXA) Scan (full body x-ray)
- Core temperature sensor (a small capsule will need to be swallowed prior to the exercise session)
- Esophageal temperature probe (inserted through the nose)
- Thermal skin sensors
- Non-invasive blood flow and local sweating measures
- Ventilated sweat capsules
- Laser Doppler probes
- Blood pressure

Author: Antoinette Cass
• Forearm blood flow
• Heart rate
• Body weight measurement
• Perceptual ratings of thermal sensitivity
• Ingestion of ice slurry/thermoneutral fluid

All information is described in detail below.

**Preliminary session:** The time involvement will be approximately 75 minutes for the preliminary session. You will complete a Physical Activity Readiness Questionnaire (Par-Q). We will measure your height, mass, and body composition. You will be asked to perform a short submaximal exercise protocol, then a maximum oxygen consumption (VO\textsubscript{2}\text{max}) test on an arm crank ergometer (described below). You will be given approximately 15 minutes to rest between the submaximal exercise and the VO\textsubscript{2}\text{max} test.

**Familiarisation session:** The purpose of the familiarisation session is to allow you to gain a better understanding of the measures and exercise protocol that will be used during the experimental sessions. Approximately 6 hours prior to arriving at the laboratory, you will be asked to swallow a core temperature sensor. This can be done at home and is very similar to swallowing a tablet/pill. On arrival, you will be fitted with an esophageal thermometer, and will be asked to sit quietly for 30 minutes in cool conditions (22 °C, 50% relative humidity). Proceeding this, you will spend 10 minutes resting in the chamber, then 30 minutes exercising on an arm crank ergometer in a seated position, at a fixed metabolic rate, also inside the chamber. The 30 minutes of exercise will be broken up into three 10 minute bouts, with 2 minutes rest in between each bout. In the middle of the second 10 minute bout, you will consume a thermoneutral drink of water (37 °C, 3.2 mL.Kg\textsuperscript{-1}), then resume exercise. Similarly, you will consume an ice slurry drink of water (-1.5 °C, 3.2 mL.Kg\textsuperscript{-1}) in the middle of the third 10 minute exercise bout. Immediately pre-exercise and during the rest intervals, blood pressure will be measured, and a thermal probe will be placed on the back of your neck and you will be asked to rate how hot or cold it feels on a visual scale when a direct stimulus of 34 °C, 38 °C, 22 °C and 26 °C is applied. Immediately pre- and post-exercise, forearm blood flow will also be measured. Following exercise, you will remain in the chamber for 45 minutes where you will continue to be monitored while resting in a seated position (passive recovery). Throughout exercise and passive recovery, ambient conditions will be regulated at 35.0°C, and 50% relative humidity, using a state-of-the-art climate chamber housed in the Thermal Ergonomics Laboratory. Once the trial is completed, you will rest in cool conditions (22 °C, 50 %RH) while being de-instrumented. Following this, you will be given the opportunity to shower in the adjacent facility.

**Experimental session:** You will be asked to abstain from alcohol and caffeine and avoid strenuous exercise in the 12 h before the experimental session. You should also consume a light meal along with 500 ml of water, 2 h before arriving at the laboratory. Just as you did in the familiarisation session, there will be a 30 minute baseline period in cool conditions, 10 minute baseline period in the chamber, then the same exercise protocol and passive recovery period detailed above. The only difference with the experimental session is that you will not be required to drink a thermoneutral or ice slurry drink during exercise.

The equipment and methods used for this study are as follows:

**Submaximal exercise stages:** You will complete four submaximal stages on an arm crank ergometer which will incorporate the target metabolic heat production to be used in the familiarisation and experimental trials. You will be fitted with a mouthpiece which will be used to measure metabolic heat production and mechanical efficiency throughout each stage. Each stage will last four minutes, therefore the total submaximal exercise duration will be 16 minutes.
Maximum oxygen consumption fitness test (VO$_{2\text{max}}$ test): You will be fitted with a mouthpiece and begin to cycle at an external work rate of 10 W and a cadence of 60 rpm. The resistance of the arm crank ergometer will then be increased by 10 W every minute until exhaustion while oxygen consumption is measured.

Fitness questionnaires: These questionnaires are standard questionnaires that have been developed to help us assess your readiness for exercise and are also used to assist us in evaluating your general physical health and level of physical activity.

Dual-Energy X-ray Absorptiometry (DXA) Scan: During the preliminary session, you will undergo a DXA scan to determine the amount of muscle, fat, and bone in your body. These scans will be performed at the University of Sydney, Cumberland Campus, Lidcombe. The DXA measure will require that you lay on a table whilst the images will be obtained. Each scan will expose you to a very small dose of ionizing radiation.

Metabolic data: In order to measure metabolic heat production, you will be equipped with a mouth piece and nose clip and will breathe through the mouth piece for the duration of exercise and at regular intervals during passive recovery (Vmax® Encore Metabolic Cart).

Esophageal probes: In order to monitor central body temperature, the researcher will insert a flexible esophageal temperature probe (2 mm in diameter) through one of your nostrils, during which time you will be asked to swallow sips of water. The tip of the probe, once fully inserted in your esophagus, will rest approximately at the level of the heart. There can be mild discomfort and mild gagging reflex from swallowing the probe. However, this sensation soon passes (5-10 seconds). Please note that the probe will be inserted by Dr. Ollie Jay who has been trained to perform this procedure and has done so on hundreds of occasions.

Core temperature sensor: You will be asked to swallow a core temperature sensor, that essentially looks like a pill. You will swallow this sensor ~6 hours prior to arriving at the laboratory, so that the sensor has progressed past the stomach by the time the experimental session begins. You may find it easiest to swallow the sensor if you do so whilst drinking a glass of water.

Skin temperature probes: Eight skin probes will be taped to your skin surface with hypoallergenic tape. These probes give an indication of skin temperature and heat loss from the skin surface. Some hair may need to be shaved (by the use of disposable razors) in order to secure the probes adequately to the skin surface.

Ventilated sweat capsules: A small plastic capsule connected to plastic tubing will be secured onto your upper back, forearm and forehead using surgical tape. By passing dry air through the capsule and over the skin, we can measure the second-by-second changes in your sweat rate, as well as observing how it changes over time.

Laser Doppler probes: A flexible laser probe will measure skin blood flow non-invasively on the upper back, forearm and forehead. This measuring device does not result in any discomfort or residual medical effects.

Blood pressure: Blood pressure will be measured with an automated inflatable cuff around your upper left arm (similar to a normal blood pressure machine)

Forearm blood flow: Forearm blood flow will be determined using venous occlusion plethysmography. This technique involves rapidly inflating a cuff around your upper arm to a relatively
AIS/USyd: Prescribing exercise intensity to elicit a fixed heat production

Last saved: 6-Apr-17 by Antoinette Cass

low pressure (~60 mmHg: much lower than with a typical blood pressure measurement) that is above that of venous blood but below arterial pressure. In this way, blood is allowed to flow into the limb, but not out, causing minor increases in limb volume that is detected by a strain gauge, which resembles an elastic band that is placed around your forearm. This test lasts about ~1 minute.

**Heart rate:** Heart rate will be monitored by a strap placed around the chest (Polar Vantage heart rate monitor).

**Body weight measurement:** You will be weighed on a platform scale (Combics 2, Sartorius, Canada) immediately before the start of exercise, at 15 min intervals throughout exercise and immediately after exercise has stopped.

**Rating of thermal sensation:** You will be asked to provide a perceptual rating of thermal sensation on an ASHRAE scale of zero (unbearably cold) to eight (unbearably hot) immediately before the start of exercise, at 15 min intervals throughout exercise and immediately after exercise has stopped and at 15 min intervals throughout passive recovery.

**Thermal sensitivity:** A thermal probe will be placed on the back of your neck and you will be asked to rate how hot or cold the stimulus feels using a visual analogue scale at temperatures of 34°C, 38°C, 26°C and 22°C.

**Ice slurry/thermoneutral fluid ingestion:** You will be asked to ingest 3.2 mL.Kg⁻¹ (approximately 1 cup) of thermoneutral water (37 °C) and also 3.2 mL.Kg⁻¹ of ice slurry water (-1.5 °C) to assess whether fluid temperature ingested during exercise influences sweat responses.

**What are the risks?**

**Physical activity:** There are some minor physical risks associated with any form of exercise. There is essentially no major risk for people while performing the submaximal exercises. During all experimental protocols, you will be under close examination by the investigators. Further, core body temperatures will be monitored continuously during the experimental trials, and exercise will be terminated if an esophageal temperature of 39.5°C is reached. If you become light-headed or dizzy, exercise will be terminated and an examination bed will be readily available in an adjacent room maintained at a comfortable ambient temperature you will be laid in the supine position, cooled with cold towels.

Some effects of maximal exercise testing are nausea, dizziness, fainting, abnormal blood pressure, chest pain, and leg cramps. You may stop at any time during these tests. However, we also continually monitor your heart rate, blood pressure and rate of perceived exertion during exercises to ensure these factors are within normal levels. All exercise testing will be conducted as recommended by American College of Sports Medicine and Sports Medicine Australia.

*NB: Exacerbation of medical conditions caused from exercising in heat may have a delay in their onset. It is encouraged that you contact your general practitioner if you do notice any symptoms that are not typical to your current symptoms.*

**Esophageal probes:** Perforation of the esophagus can occur during insertion of an esophageal probe, potentially causing inflammation and infection. Perforation of the esophagus is very rare and no such incident has ever occurred in a laboratory the principal investigator has worked in, which has involved hundreds of these types of insertions. The risk of transmission of infectious disease is negligible as each subject has his or her own sterile probes that will be disposed of once all tests have been completed.
Headaches associated with ingesting ice slurry: You may experience a mild headache from the ingestion of the ice slurry (sphenopalatine ganglioneuralgia) which should pass shortly after ingestion (3 to 5-min).

Radiation: This research study involves exposure to a very small amount of radiation from x-rays. The effective dose of radiation from this study is about 0.03 millisieverts (mSv). For comparison, everyone receives a dose of about 2 mSv each year from natural sources as part of everyday living, so the study is equivalent to a few days of natural "background" radiation. No harmful effects have been demonstrated at this level and the risk is minimal.

Please inform our researchers if you have participated in any research study in the last five years where you were exposed to radiations. If you volunteered for another research study in the next 5 years, you should take this statement with you and show it to the researcher.

Adverse Effects
During each test procedure, and on the day following the experimental sessions, we will ask you to inform us of any side effects that you may experience. It is important that you contact the study staff immediately if there are any unusual health experiences, injury or bad effects. This notification should take place whether or not you believe that the problem is related to the exercise program or from some other cause. Prior to any testing, you will complete two health questionnaires that will help ensure you are in adequate physical health to participate in this study.

Participation
Being in this study is completely voluntary - you are not under any obligation to consent and - if you do consent - you can withdraw at any time without affecting your relationship with The University of Sydney or endure any other negative repercussions.

Payment for Participation
If you are required to take a full day off work to participate, you will be compensated $100/day for your time.

Travel Costs
If you have travelled interstate to participate in this study, you will be reimbursed for the cost of flights/transport (up to $500), travel to/from the airport if required (up to $100), and accommodation (up to $120/night for 4 nights) and food ($100/day for 4 days) for your stay.

If you are a local participant, you will be provided with $25/day for transport related costs to the laboratory where testing will take place.

Who will see my personal information?
All aspects of the study, including results, will be strictly confidential and only the researchers will have access to information on participants. Additionally, participant confidentiality will be maintained by the assignment of a study ID number. This will be used on all data collection sheets. Records from the study that identify participants by name will be treated as strictly confidential and will be kept in a locked filing cabinet in a locked office away from all other study data. Only staff directly involved in the study will have access to participant records. If the results of this study lead to publication in a research thesis, scientific journal or are represented at scientific meetings, individual participants will not be identified by name.

What are the benefits of participating?
While it is not expected that your involvement in this research will accrue any long-term personal benefits, this research is seeking to establish an understanding on how trained individuals with a spinal...
cord injury respond to the heat during physical activity. Your participation in this study will assist in improving the understanding of how individuals with varying spinal cord lesion levels differ in their ability to tolerate the heat. We would like to know how tetraplegic, paraplegic and able-bodied persons compare, so that we can identify who may benefit most from interventions, such as cooling strategies, to help tolerate the exercise in warm conditions.

**Further Information**
When you have read this information, Dr. Ollie Jay or Ms Peta Forsyth will discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact Ms Peta Forsyth by emailing her at Peta.Forsyth@ausport.gov.au.

**Complaints and Concerns**
Any person with concerns or complaints about the conduct of a research study can contact The Manager, Human Ethics Administration, University of Sydney on +61 2 8627 8176 (Telephone); +61 2 8627 8177 (Facsimile) or ro.humanethics@sydney.edu.au (Email).
Appendix B: Participant Consent form

PARTICIPANT CONSENT FORM

I, .............................................................................[PRINT NAME], give consent to my participation in the research project

TITLE: ASSESSING THERMOREGULATORY DEFICITS OF TRAINED INDIVIDUALS WITH A SPINAL CORD INJURY EXERCISING IN THE HEAT

In giving my consent I acknowledge that:

1. The procedures required for the project and the time involved have been explained to me, including any inconvenience, risk, discomfort or side effect, and their implications, and any questions I have about the project have been answered to my satisfaction.

2. I have read the Participant Information Statement and have been given the opportunity to discuss the information and my involvement in the project with the researcher/s.

3. I understand that being in this study is completely voluntary – I am not under any obligation to consent.

4. I understand that my involvement is strictly confidential. I understand that any research data gathered from the results of the study may be published however no information about me will be used in any way that is identifiable.

5. I understand that I can withdraw from the study at any time, without affecting my relationship with the researcher(s) or the University of Sydney now or in the future.

6. I consent to receiving feedback about the study

   YES □ NO □

7. I consent to being contacted about opportunities to participate in future studies

   YES □ NO □
8. I consent to the researchers keeping my unidentifiable data in perpetuity and approve its use in future publications, as described in the participant information sheet

   YES ☐   NO ☐

   If you answered YES to questions 6 or 7, please provide your details i.e. mailing address, email address.

   Feedback Option

   Address: ________________________________________________________________
   ________________________________________________________________

   Email: ________________________________________________________________

   ..............................................................................................................
   Signature

   ..............................................................................................................
   Please PRINT name

   ..............................................................................................................
   Date
Appendix C: Metabolic Heat Production Calculator

Attached as a separate excel file. View of calculator below.

<table>
<thead>
<tr>
<th>EE</th>
<th>Hprod</th>
<th>VO₂</th>
<th>RER</th>
<th>WK</th>
<th>Efficiency</th>
<th>TARGET Hprod</th>
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![Bar chart showing VO₂ and Hprod values]
Appendix D: Spreadsheet template for analysing data

Attached as a separate excel file. View of part of the spreadsheet below.

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