THE EFFECT OF EXERCISE INTENSITY ON CALF VOLUME AND THERMOREGULATORY RESPONSES DURING UPPER BODY EXERCISE

Abstract
During upper body exercise the vascular adaptations of the leg have been reported to play an important thermoregulatory role. This study examined the effect of exercise intensity on thermoregulation during upper body exercise. Nine healthy male participants undertook an incremental exercise test on an arm crank ergometer to determine peak power (W_{peak}). The participants performed four experimental trials involving 5 minutes of arm exercise at either 45, 60, 75, or 90% W_{peak} (70 rev.min^{-1}) followed by 30 minutes of passive recovery. Aural and skin temperatures, upper arm and calf heat flow were recorded. Calf volume was measured during exercise using plethysmography. During exercise at 45, 60, 75 and 90% W_{peak} calf volume decreased (P<0.05) by -0.7±0.8, -1.4±0.9, -1.2±0.6 and -1.6±0.7% respectively. Differences were observed between 45 and 60% W_{peak} and 45 and 90% W_{peak} (P<0.05). The results of this study suggest a redistribution of blood from the relatively inactive lower body during arm exercise of intensities up to 60% W_{peak} after which point calf volume does not significantly decrease further. Therefore, the redistribution of blood from the inactive lower body does not produce a similar intensity dependent response to visceral blood flow during lower body exercise.

Keywords: ARM CRANK ERGOMETRY / BLOOD FLOW / CALF TEMPERATURE / THERMOREGULATION / EXERCISE INTENSITY

INTRODUCTION
During lower body exercise of moderate intensity in cool conditions skin blood flow increases (Johnson and Rowell, 1975), this in turn increases the thermal gradient between the skin and the atmosphere. An increased gradient provides heat for convection, radiation and evaporation of sweat enabling an improved heat exchange (Rowell, 1974). In contrast during upper body exercise in cool conditions calf volume has been demonstrated to decrease (Hopman, Verheifen & Binkhorst, 1993) suggesting arterial blood flow to the calf decreases. This is supported by a decrease in calf skin temperature during prolonged upper body exercise (Price and Campbell, 1997, 2002). It has been suggested therefore that blood flow to the calf is being redistributed to the active upper body during arm exercise (Hopman, Verheifen & Binkhorst, 1993). This redistribution of blood has been demonstrated to occur during lower body exercise from inactive tissue to augment cardiac output and supply the exercising muscles with blood (Ho et al., 1997; Sawka, 1986; Ahlborg & Felig, 1982). Consequently, the active muscles receive a greater percentage of the cardiac output whereas the viscera receive less (Sawka, 1986; Rowell, Blackmon & Bruce, 1964; Rowell et al., 1965).
During lower body exercise forearm skin blood flow, which is often used to represent whole body cutaneous blood flow (Johnson & Rowell, 1975), has been observed to increase linearly with oesophageal temperature (Smolander et al., 1987; Nadel et al., 1979) up to an exercise intensity of 80% VO_{2max}. After this point the relationship is attenuated with no further increases in skin blood flow (Smolander et al., 1987). The same relationship has not been found for upper body exercise and lower body responses. In particular research has found a decrease in calf volume (representing skin, muscle and bone blood flow) during 10 min of upper body exercise at 50% W_{peak} suggesting a decrease in calf blood flow (Humphrey, Verheifen & Binkhorst, 1993). However, little is known regarding changes in calf volume at a range of exercise intensities and potential skin blood flow responses during upper body exercise. Blood pooling in the lower body could potentially cause thermoregulatory and cardiovascular stability problems during upper body exercise. As exercise intensity increases and the demand for increased blood flow at the active muscle and skin occurs, a greater redistribution of blood from the inactive muscles will be required. If blood pooling occurs in the lower body this could potentially cause an increased thermal strain on the body. Consequently, the vascular adaptations of the leg during upper body exercise have been suggested to play an important physiological and, more specifically, thermoregulatory role during upper body exercise, but has yet to be fully examined (Price & Campbell, 1997).

During lower body exercise, changes in visceral blood flow are intensity dependent (Rowell, 1974) and it is possible that the reported decreases in calf volume may also exhibit the same intensity dependent response. Establishing the thermoregulatory responses in the lower body of able bodied individuals during upper body exercise at different intensities of exercise will help establish a thermoregulatory model that could assist in future exercise recommendations for individuals with for example spinal cord injuries or Multiple Sclerosis. Therefore, the principal aim of this study was to examine the effect of exercise intensity on calf volume changes during upper body exercise in order to examine the redistribution of blood during upper body exercise. It was hypothesised that as exercise intensity increased calf volume would decrease.

**METHOD**

**Participants**

Nine male participants (Mean±s age 22.9±3.6 yrs, weight 78.4±13.7kg) generally but not specifically upper body trained, volunteered to participate in the study. University Ethics Committee approval for the study’s experimental procedures was obtained along with written informed consent and followed the principles outlined in the Declaration of Helsinki.

**Preliminary Tests**

Participants attended the laboratory on five separate occasions. On the first visit, participants performed an incremental exercise test using an electronically braked arm crank ergometer (Lode, Angio, Groningen, the Netherlands), to determine peak oxygen uptake (V_{O2peak}) and peak power output (W_{peak}). The latter was used to determine the exercise intensity for each subsequent experimental trial. Following a ten minute cool down, participants were familiarised with the four different exercise intensities, which were to be undertaken in the following four visits.

Each subject’s V_{O2peak} was determined using a discontinuous incremental exercise protocol (Smith, Price & Doherty, 2001). Participants sat with their shoulder joint in line with the crank shaft of the ergometer. Their feet were positioned flat on the floor in metal cups to ensure the knee joint was at 90°. The protocol consisted of four, four-minute submaximal exercise stages (30, 50, 70, and 90W respectively) with two minutes rest between stages. Subjects were required to maintain a cadence of 70 rev.min^{-1} throughout exercise. After the final four minute stage and rest period, the protocol increased by 20W every two minutes from 110W until volitional fatigue, or when participants were unable to maintain 70 rev. min^{-1}. Expired gas (Metamax 3B, Leipzig, Germany) and heart rate (HR; Polar Accurex Plus, Kempele, Finland) were continually monitored.

**Submaximal Trials**

All exercise trials were performed at an ambient temperature of 20.5±1.4°C and 63.8±5.8% humidity. Participants arrived at the laboratory after fasting for two hours and abstaining from strenuous exercise during the previous 24 hours. The study was
conducted as a cross-over design. Each subject was tested on four separate occasions with at least three days separating each trial. The trials consisted of 5 minutes of arm exercise at either 45, 60, 75 or 90% of $W_{\text{peak}}$, followed by 30 minutes of passive recovery.

On arrival at the laboratory, body mass was recorded using a balance beam scale (Seca, Hamburg, Germany). Participants wore shorts, socks, and training shoes and rested for 15 minutes while thermistors and sensors were attached. Aural and skin thermistors were continuously recorded via a data logger (Squirrel 1020 series, Cambridge, UK). Aural temperature was measured by an aural thermometer (Grant, Cambridge, UK) inserted into the subject's auditory canal and securely taped into position and insulated with cotton wool. Skin thermistors (Grant, Cambridge, UK) were attached to standard anatomical landmarks for the upper arm, back, chest, thigh, and calf. An additional thermistor was applied to the second toe on the right foot with the shoe and sock replaced. Thermistors were attached to the skin using strips of water permeable tape (3M Transpore, Loughborough, UK). Mean skin temperature ($T_{\text{ms}}$) was calculated using the equation of Ramanathan (1964) where: 

$$T_{\text{ms}} = 0.3(T_{\text{chea}}) + 0.3(T_{\text{upper arm}}) + 0.2(T_{\text{calf}}) + 0.2(T_{\text{diap}})$$

Heat flow was measured at the calf and the upper arm using heat flow sensors (Data Harvest Easy Sense Advanced, Bedfordshire, UK) and was recorded continuously. Sensors were attached adjacent to the skin thermistors on the calf and upper arm and were attached using water permeable tape according to the manufacturer’s guidelines.

During each submaximal trial expired gas was continuously analysed. Baseline data for all measures were obtained during the seated rest for five minutes prior to exercise and a resting capillary blood sample (80μl) taken from the earlobe for measurement of blood lactate (Analox GM7, London, UK). Strain gauge plethysmography was employed to measure relative volume changes of the calf during arm exercise. Lower leg blood flow was measured at rest using venous occlusion plethysmography and standard procedures (Hopman, Verheifen & Binkhorst, 1993). The strain gauge plethysmograph (Hokanson EC6, Bellevue, USA) consisted of two mercury filled tubes of silicon rubber, positioned around the thickest part of the left calf and taped into position. A contoured blood pressure cuff was placed on the left thigh, just above the knee, which was connected to a rapid cuff inflator (Hokanson E20, Bellevue, USA) set to inflate to 50mmHg for five seconds and deflate for eight seconds. The plethysmograph was connected to a personal computer via Powerlab (AD Instruments, Chalgrove, UK) and online recordings displayed through Chart4windows. An average of three inflations was used to determine blood flow at each time point.

Participants performed arm crank exercise for 5 minutes at 70 rev.min\(^{-1}\) at the randomly assigned exercise intensity. Heat flow and skin temperatures were recorded every minute during and on the cessation of exercise. Changes in calf volume from rest were recorded throughout exercise. RPE\(_{\text{central}}\) and RPE\(_{\text{local}}\) were recorded 30s before the cessation of exercise. Oxygen uptake ($\dot{V}O_2$), minute ventilation (VE) and respiratory exchange ratio (RER) were averaged over the last 30s of each minute during exercise and at five minute intervals during 30 minutes of passive recovery. Blood flow was recorded at rest and at the cessation of exercise. Immediately post exercise a further capillary blood sample was taken from the earlobe for the measurement of blood lactate. Participants then remained seated for 30 minutes of recovery. Heat flow, blood flow, aural and skin temperatures were recorded every 5 minutes of passive recovery. Body mass was recorded pre and post exercise to calculate sweat losses.

**Statistical Analysis**

All data were analysed via Minitab version 14.0. Data were analysed by Two-Way Analysis of Variance (time x intensity) with repeated measures. Where significance was obtained, Tukey post hoc was performed. Where appropriate Pearson’s correlation was performed to investigate non-causal relationships between variables e.g. blood lactate versus RPE. Data are represented as mean ± SEM in figures, and mean±s in tables. Significance was taken as P<0.05.
RESULTS

Preliminary Tests

The peak physiological responses obtained during the incremental test for $\dot{V}O_{2\text{peak}}$ are shown in Table 1.

Table 1: The mean (±s) physiological responses obtained during the incremental $\dot{V}O_{2\text{peak}}$ test (n=9)

<table>
<thead>
<tr>
<th></th>
<th>Mean (±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\dot{V}O_{2\text{peak}}$ (l.min$^{-1}$)</td>
<td>2.21 (±0.59)</td>
</tr>
<tr>
<td>$\dot{V}O_{2\text{peak}}$ (ml.kg$^{-1}$.min$^{-1}$)</td>
<td>28.6 (±7.1)</td>
</tr>
<tr>
<td>HR_{peak} (beats.min$^{-1}$)</td>
<td>184 (±12)</td>
</tr>
<tr>
<td>W_{peak} (W)</td>
<td>124 (±24)</td>
</tr>
<tr>
<td>E (l.min$^{-1}$)</td>
<td>73.9 (±16.7)</td>
</tr>
<tr>
<td>Bla_{peak} (mmol.L$^{-1}$)</td>
<td>7.33 (±1.34)</td>
</tr>
<tr>
<td>Respiratory Exchange Ratio</td>
<td>1.17 (±0.09)</td>
</tr>
<tr>
<td>RPE_{central} (Borg Scale)</td>
<td>18 (±2)</td>
</tr>
<tr>
<td>RPE_{local} (Borg Scale)</td>
<td>19 (±1)</td>
</tr>
</tbody>
</table>

Physiological responses during exercise and passive recovery

The physiological responses at the cessation of each submaximal arm exercise trial are shown in Table 2. A difference between exercise intensities was observed for both HR and $\dot{V}O_2$ during exercise and recovery (main effect; $P<0.05$). During passive recovery, HR decreased but remained higher ($P<0.01$) than rest in all but the 45% $W_{peak}$ trial. Blood lactate increased linearly with exercise intensity ($P<0.05$). Body mass decreased in all trials (-0.1 ±0.1, -0.2 ±0.1, -0.1 ±0.1 and -0.1 ±0.1kg for 45, 60, 75 and 90% $W_{peak}$ respectively) with no significant differences between the trials ($P>0.05$).

Table 2 Mean (±s) physiological responses at the cessation of arm exercise during each submaximal trial (n=9)

<table>
<thead>
<tr>
<th>% $W_{peak}$</th>
<th>$\dot{V}O_2$ (l.min$^{-1}$)</th>
<th>Heart Rate (beats. min$^{-1}$)</th>
<th>Blood lactate (mmol.L$^{-1}$)</th>
<th>RPE_{central} (Borg Scale)</th>
<th>RPE_{local} (Borg Scale)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45%</td>
<td>1.16±0.15 *</td>
<td>112±12 *</td>
<td>3.0±0.6 *</td>
<td>10±1 *</td>
<td>11±2 *</td>
</tr>
<tr>
<td>60%</td>
<td>1.46±0.21 *</td>
<td>128±10 *</td>
<td>5.0±1.2 *</td>
<td>12±1 *</td>
<td>14±1 *</td>
</tr>
<tr>
<td>75%</td>
<td>1.72±0.31 *</td>
<td>154±12 *</td>
<td>6.7±0.8 *</td>
<td>14±1 *</td>
<td>15±1 *</td>
</tr>
<tr>
<td>90%</td>
<td>2.09±0.49 *</td>
<td>170±18 *</td>
<td>8.1±1.0 *</td>
<td>16±1 *</td>
<td>18±2 *</td>
</tr>
</tbody>
</table>

*Significant ($P<0.05$) main effect between exercise intensities.
**Aural Temperature during Exercise and Passive Recovery**

A main effect for exercise intensity was observed for aural temperature \((P<0.05)\). Post hoc analysis revealed differences between 45 and 90% \(W_{\text{peak}}\) trials and, 60 and 90% \(W_{\text{peak}}\) trials. At the end of exercise in all trials aural temperature had decreased from resting values by -0.04 ±0.21, -0.03 ±0.20, -0.13 ±0.08 and -0.14 ±0.24°C for 45, 60, 75 and 90% respectively.

**Upper Body Skin Temperatures during Exercise and Passive Recovery**

Upper arm skin temperature initially decreased during the first minute of exercise \((P<0.05; \text{Figure 1})\).

Immediately post exercise upper arm skin temperature increased for all trials \((P<0.05; \text{main effect for time})\). There was a main effect for exercise intensity with a greater increase in temperature occurring during the higher intensity trials (75 and 90% \(W_{\text{peak}}\)) when compared to the lower intensity trials (45 and 60% \(W_{\text{peak}}\)). A main effect for time was observed \((P<0.05)\) for chest temperature which decreased during exercise followed by an increase post exercise for all trials. There was no difference between exercise intensities for chest temperature \((P>0.05)\). Back skin temperature remained relatively constant throughout exercise and passive recovery for each exercise intensity \((P>0.05)\).

**Lower Body Skin Temperatures during Exercise and Passive Recovery**

Thigh skin temperature decreased during exercise and passive recovery (main effect for time \(P<0.05)\). Differences were observed between 60 and 75% \(W_{\text{peak}}\) trials, 60 and 90% \(W_{\text{peak}}\) trials (main effect for intensity; \(P<0.05)\). During exercise calf temperature remained constant however, during recovery calf temperature decreased in all trials \((P<0.05)\), with a greater decrease in temperature during recovery from the higher exercise intensities (75 and 90% \(W_{\text{peak}}\)).

Calf skin temperature decreased by 1.0 ±0.6, 0.9 ±0.3, 1.0 ±0.3, and 1.0 ±0.5°C during 45, 60, 75 and 90% \(W_{\text{peak}}\) after 30 minutes of recovery, respectively \((P<0.05)\). Toe temperature remained constant throughout exercise, and immediately increased during passive recovery \((P<0.05)\). A significant difference between exercise intensities was observed between 45 and 60% \(W_{\text{peak}}\), 60 and 75% \(W_{\text{peak}}\), and 60 and 90% \(W_{\text{peak}}\).
However, there was a tendency for further increases in heat flow during exercise but not significant in any trial. On the cessation of exercise heat flow decreased ($P<0.05$) and remained constant throughout passive recovery. Heat flow during exercise and recovery at 90% $W_{\text{peak}}$ was greater than the other three intensities ($P<0.05$). No further differences were noted between trials. In contrast to the upper arm, heat flow from the calf remained constant throughout exercise and passive recovery at all exercise intensities ($P>0.05$; Figure 3b). However, heat flow was lower during the 45% $W_{\text{peak}}$ when compared to the other three intensities at rest and throughout both exercise and passive recovery (main effect for intensity; $P<0.05$).

**Mean Skin Temperature**

Mean skin temperatures obtained in the present study were similar at rest (30.6±0.9, 30.6±0.5, 30.3±1.1 and 30.5±1.1°C for 45, 60, 75 and 90% $W_{\text{peak}}$ respectively) when compared to those at the end of exercise in all trials (30.5±0.9, 30.6±0.8, 30.4±1.4 and 30.2±1.5°C respectively).

**Heat Flow during Exercise and Passive Recovery**

Heat flow from the upper arm increased from rest during the first minute of exercise (increased by 27 ±13, 21 ±7, 26 ±13 and 29 ±16 W.m$^{-2}$ for 45, 60, 75 and 90% $W_{\text{peak}}$, respectively; $P<0.05$; Figure 3a). However, there was a tendency for further increases in heat flow during exercise but not significant in any trial. On the cessation of exercise heat flow decreased ($P<0.05$) and remained constant throughout passive recovery. Heat flow during exercise and recovery at 90% $W_{\text{peak}}$ was greater than the other three intensities ($P<0.05$). No further differences were noted between trials. In contrast to the upper arm, heat flow from the calf remained constant throughout exercise and passive recovery at all exercise intensities ($P>0.05$; Figure 3b). However, heat flow was lower during the 45% $W_{\text{peak}}$ when compared to the other three intensities at rest and throughout both exercise and passive recovery (main effect for intensity; $P<0.05$).
flow values were greatest at the end of exercise when compared to rest (1.32±0.52, 1.91±0.58, 2.11±0.81 and 1.76±0.68 ml.min⁻¹.100ml⁻¹ respectively, *P*<0.05) returning to baseline during passive recovery (1.32±0.36, 1.36±0.47, 1.63±0.74 and 1.38±0.55 ml.min⁻¹.100ml⁻¹, respectively) for each trial. Examining the blood flow on an inflation by inflation basis immediately at the cessation of exercise the first measurement of calf blood flow was significantly greater than the second and third measurements (main ef-

**Calf Volume and Blood Flow during Exercise and Passive Recovery**

When compared to rest, calf volume decreased (*P*<0.05) during exercise at each exercise intensity (-0.7 ±0.8, -1.4 ±0.9, -1.2 ±0.6, and -1.6 ±0.7% respectively; Figure 4). Differences were observed between 45% and 60% W<sub>peak</sub> and 45 and 90% W<sub>peak</sub> (*P*<0.05). Calf volume returned to baseline within five minutes of passive recovery in all trials. Blood
The principal aim of the study was to determine the effects of exercise intensity on calf volume using strain gauge plethysmography as a means of examining the redistribution of blood during arm exercise. The main finding of the study was a decrease in calf volume during arm exercise of intensities up to 60% $W_{\text{peak}}$ after which point calf volume did not significantly decrease further. This decrease in calf volume was accompanied by an increase in calf blood flow from rest to the end of exercise.

**DISCUSSION**

During the first 5 minutes of passive recovery there was a significant increase in arm skin temperature in all trials due to decreased convective air currents and resultant decrease in arm heat flow. The 75 and 90% $W_{\text{peak}}$ trials demonstrated greater increases in arm skin temperature, most likely due to the greater metabolic heat production than 40 and 60% $W_{\text{peak}}$ trials. Consequently, greater local heat storage is likely to have occurred as changes in convective air currents would have been the same for each trial (i.e. all exercise performed at the same movement speed; 70rev.min$^{-1}$). Conversely, the initial decrease in arm temperature during exercise was probably due to increased heat flow as a result of convection current generation on the initiation of movement (Mitchell, 1977).

Sawka et al., (1984) suggested that heat flow values were representative of skin conductance and therefore provide a relative index of cutaneous blood flow. Therefore, in the present study blood flow to the upper arm must have increased based on the increased heat flow. Absolute arm heat flow was similar for the 45, 60 and 75% trials but greater for the 90% trial suggesting a greater increase in skin blood flow at the higher exercise intensity. This may repre-
sent the exercise intensity where direct heat transfer from the contracting muscle was greater. Indeed, if heat flow does represent skin blood flow (Sawka et al., 1984) then this would have allowed greater heat transfer from the upperarm to the environment in the 90% trial resulting in a similar absolute increase in skin temperature to the other trials.

**Lower Body Thermoregulatory Responses**

A decrease in calf volume was observed during all exercise intensities, however, after 60% $W_{\text{peak}}$ no further decreases were observed. Hopman, Verhoefen & Binkhorst (1993) measured calf volume during 10 min of arm exercise at 50% $W_{\text{max}}$ and observed a decrease in volume of 0.1% per minute at 5 min of exercise, which is the same rate of decrease in limb volume per minute as during the 45% $W_{\text{peak}}$ trial in the present study. However, the present study has expanded upon these data in observing that the decrease in calf volume was not linear with exercise intensity, and therefore does not express the same intensity dependent decrease as visceral blood flow. This would most likely be due to any further decrease in leg blood flow with higher exercise intensities resulting in a relatively small flow rate which may compromise oxygen delivery to the lower limb. The most likely role of calf vasoconstriction during the initial stages of exercise is to help maintain cardiovascular stability.

In contrast to the present study’s results and Hopman, Verhoefen & Binkhorst (1993), Theisen et al., (2001a, 2001b) observed that during arm exercise at 50% $W_{\text{peak}}$ and 80% $W_{\text{peak}}$ skin blood flow of the calf increased during exercise. These authors measured skin blood flow using Laser Doppler Flowmetry which only measures blood flow up to 1.5 mm below the skin (Johnson et al., 1984). Therefore, the decrease in calf volume observed in the present study using plethysmography, may be due to a reduction in predominantly muscle blood flow rather than blood flow to the superficial skin layers (Saumet et al., 1988). This is supported by Seals (1989) who suggested that during handgrip exercise skin blood flow increases while muscle blood flow to the calf decreases.

Although there was a decrease in calf volume during exercise, there was no significant difference in calf temperature or calf heat flow. Previous research (Price & Campbell, 1997) observed a decrease in calf temperature during exercise, but as previously mentioned the exercise duration was considerably longer (60-90 min). It was suggested in this instance that the decrease in calf temperature during prolonged arm exercise at constant exercise intensity (60% $V_{\text{O2peak}}$) and environmental temperature was due to decreased blood flow to the calf. Since the calf is relatively metabolically inactive during upper body exercise, longer durations of exercise may be required for significant changes in calf skin temperature to occur due to reduced blood flow and changes in thermal state. Therefore examining the relationship between calf volume and skin temperature over greater durations of exercise would contribute to our understanding of calf blood flow and skin temperature relationship.

Calf volume immediately began to return towards baseline once exercise ceased suggesting blood flow to the muscle was returning. This could be potentially explained by a rapid vasodilation at the calf occurring immediately at the cessation of exercise causing a rapid increase in blood flow (hyperaemia) to the calf. During the present study calf volume was observed to decrease during exercise which was most likely due to increased muscle sympathetic nerve activity (Saito et al. 1993) causing vasoconstriction in the calf. As soon as exercise ceased a rapid vasodilation occurred causing a rapid increase in calf blood flow as blood returned to the calf. This is demonstrated by the fact that blood flow was greatest on the first measurement post exercise compared to the second and third measurements however this only occurred during the 75 and 90% $W_{\text{peak}}$ trials. Muscle sympathetic nerve activity (MSNA) is exercise dependent (Saito et al. 1993) therefore the MSNA was only sufficient during exercise in the 75 and 90% $W_{\text{peak}}$ trials to cause this rapid hyperaemia as exercise ended. Blood flow decreased towards baseline values for the remainder of passive recovery, following this initial increase.

Several studies have determined the average volume of the calf and results have varied between 1.7 – 3.4 L (Hargens, 1983; Convertino et al. 1989; Moore & Thornton, 1987). Therefore using these approximate volumes the amount of blood being redirected away from the calf during upper body exercise in this study can be estimated. Calf volume decreased between 0.7-1.6% during exercise in all studies which equates to about 12-54 ml of blood being redirected away from the calf. Therefore, the results
demonstrate that the lower body appears to have a small contribution not only to thermoregulation but also to cardiovascular stability.

The decrease in calf skin temperature post exercise may possibly be explained by counter current heat exchange within vascular bundles of the leg. Blood flow to the arteries in the calf region post exercise would deliver warm blood from the core with heat most likely being transferred to the adjacent and cooler blood in the veins leaving the calf. The arterial blood would therefore be cooled, which on delivery to the cutaneous circulation of the leg would result in a decrease in skin temperature. Consequently flow and nutrient supply can be restored without any increase in limb temperature.

CONCLUSION

The results of this study suggest a redistribution of blood from the relatively inactive lower body during arm exercise of intensities up to 60%\(\text{W}_{\text{peak}}\) after which point calf volume does not significantly decrease further. Calf blood flow immediately at the end of exercise was greater than that at rest. The most likely explanation is that at the end of exercise rapid vasodilation occurred in the calf causing an increase in blood flow thus calf volume returned to baseline levels within 5 minutes of exercise ceasing. The calf volume decrease is therefore likely a result of vasoconstriction reducing blood pooling in the leg due to an increase in muscle sympathetic nerve activity. Reducing the venous pooling that is occurring during upper body exercise could substantially improve upper body exercise performance and may benefit sports which have a large upper body component such as kayaking.

Future research should focus upon the differentiation between calf muscle and calf skin blood flow during and following arm exercise, and the effects of longer durations of arm exercise on calf volume and skin temperature in order to examine further the thermoregulatory responses during upper body exercise.

REFERENCES


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