Impact of sympathetic nervous system activity on post-exercise flow-mediated dilatation in humans

http://researchonline.ljmu.ac.uk/2696/

Citation (please note it is advisable to refer to the publisher's version if you intend to cite from this work)


LJMU has developed LJMU Research Online for users to access the research output of the University more effectively. Copyright © and Moral Rights for the papers on this site are retained by the individual authors and/or other copyright owners. Users may download and/or print one copy of any article(s) in LJMU Research Online to facilitate their private study or for non-commercial research. You may not engage in further distribution of the material or use it for any profit-making activities or any commercial gain.

The version presented here may differ from the published version or from the version of the record. Please see the repository URL above for details on accessing the published version and note that access may require a subscription.

For more information please contact researchonline@ljmu.ac.uk

http://researchonline.ljmu.ac.uk/
IMPACT OF SYMPATHETIC NERVOUS SYSTEM ACTIVITY ON POST-EXERCISE FLOW-MEDIATED DILATION IN HUMANS

Atkinson, Ceri L.1 Lewis, Nia C.S.2 Carter, Howard H.1 Thijssen, Dick H.J.3,4 Ainslie, Philip N.2 Green, Daniel J.1,3

1School of Sports Science, Exercise and Health
The University of Western Australia, Crawley, Western Australia
2School of Health and Exercise Sciences
University of British Columbia Okanagan, Kelowna, British Columbia, Canada
3Research Institute for Sport and Exercise Science
Liverpool John Moores University, Liverpool, United Kingdom
4Radboud Institute for Health Sciences, Department of Physiology, Nijmegen, Netherlands

Running Title:
Sympathetic Activity, Shear Rate and Flow-Mediated Dilation

Keywords: exercise, sympathetic nervous activity, shear rate

Author for Correspondence:
Daniel J Green
School of Sport Science, Exercise and Health, The University of Western of Australia, Crawley, Western Australia, 6019
Email: danny.green@uwa.edu.au
KEY POINTS SUMMARY

- Previous studies indicate a transient reduction in arterial function following large muscle group exercise, but the mechanisms are unknown.

- Sympathetic nervous system activation may contribute to such reductions through direct effects in the artery wall, or because of decreases in arterial shear stress.

- Administration of Prazosin (an $\alpha_1$-adrenoreceptor blocker) abolished the transient reduction in vascular function observed under placebo conditions following exercise. This effect could not be explained by drug-induced changes in arterial shear stress.

- These results suggest that sympathetic vasoconstriction directly competes with endothelium-dependent dilator activity to influence post-exercise vascular function.

- These findings have implications for understanding the stimuli responsible for exercise-induced adaptations in arterial function and health in humans.

Word Count: 111
ABSTRACT

Transient reduction in vascular function following systemic large muscle group exercise has previously been reported in humans. The mechanisms responsible are currently unknown. We hypothesised that sympathetic nervous system activation, induced by cycle ergometer exercise, would contribute to post-exercise reductions in flow-mediated dilation (FMD). Ten healthy male subjects (28±5 years) undertook two 30 minute sessions of cycle exercise at 75% HRmax. Prior to exercise, individuals ingested either a placebo or an α1-adrenoreceptor blocker (Prazosin; 0.05mg.kg⁻¹). Central hemodynamics, brachial artery shear rate (SR) and blood flow profiles were assessed throughout each exercise bout and in response to brachial artery FMD, measured prior to-, immediately after, and 60-minutes post-exercise. Cycle exercise increased both mean and antegrade SR (P<0.001) with retrograde SR also elevated under both conditions (P<0.001). Pre-exercise FMD was similar on both occasions, and significantly reduced (27%) immediately following exercise in the placebo condition (t-test, P=0.03). In contrast, FMD increased (37%) immediately following exercise in the Prazosin condition (t-test, P=0.004, interaction effect P=0.01). Post-exercise FMD remained different between conditions after correction for baseline diameters preceding cuff deflation and also post-deflation shear rate. No differences in FMD or other variables were evident 60-minutes following recovery. Our results indicate that sympathetic vasoconstriction competes with endothelium-dependent dilator activity to determine post-exercise arterial function. These findings have implications for understanding the chronic impacts of interventions, such as exercise training, which affect both sympathetic activity and arterial shear stress.
ABBREVIATIONS

ANOVA, analysis of variance;
BF, blood flow;
CO, cardiac output;
FMD, flow-mediated dilation;
HR, heart rate;
LBNP; lower body negative pressure;
LMM, linear mixed model;
MAP, mean arterial pressure;
SNS, sympathetic nervous system;
SR, shear rate;
SR_{AUC}, shear rate area under curve;
SV, stroke volume;
TPRi, total peripheral resistance index.
INTRODUCTION

Flow-mediated dilation (FMD) is a widely used method of assessment of vascular function that provides a surrogate index for arterial health (Takase et al., 1998; Gocke et al., 2003; Thijssen et al., 2011). Whilst the chronic effect of exercise training on FMD has been documented in a wide range of individuals (Maiorana et al., 2001; Green et al., 2004; Watts et al., 2004; Tinken et al., 2008; Tinken et al., 2010; Birk et al., 2012), the impact of acute exercise on FMD responses is less clear (Dawson et al., 2013). The acute FMD response to large muscle mass exercise has therefore been a focus for recent studies, with a number of these documenting a transient reduction in FMD (Goel et al., 2007; Dawson et al., 2008; Jones et al., 2010; Johnson et al., 2012b; Birk et al., 2013) which may be intensity-dependent (Johnson et al., 2012b; Birk et al., 2013). In addition, studies focusing on the impact of cycle ergometer exercise have demonstrated reductions in FMD in the upper limb vasculature (Jones et al., 2010; Johnson et al., 2012b; Birk et al., 2013), which returns to baseline levels approximately 1-hr following the exercise bout, invoking the concept of “hormesis” (Padilla et al., 2011a). The mechanisms responsible for this apparent reduction in FMD immediately following exercise are currently unknown, but may include oxidative stress, changes in blood pressure, arterial shear rate (in particular retrograde shear rate (Dawson et al., 2013)), and/or sympathetic nervous system (SNS) activation.

We have previously published studies pertaining to the impact of distinct patterns of blood flow and shear rate on FMD responses (Thijssen et al., 2009b; Tinken et al., 2009; Carter et al., 2013; Thijssen et al., 2014). Retrograde shear rate has been linked to a pro-atherogenic phenotype (Chappell et al., 1998; Ziegler et al., 1998; Hastings et al., 2007; Laughlin et al., 2008; Conway et al., 2010) and reductions in arterial diameter (Carter et al., 2013) and FMD (Thijssen et al., 2009b; Tinken et al., 2009; Schreuder et al., 2014). Exercise which predominantly activates the lower limbs, for example cycle ergometry, increases retrograde shear rate in the brachial artery (Green et al., 2002; Green et al., 2005; Thijssen et al., 2009a; Padilla et al., 2011b), particularly during the initial phase of exercise. It was recently suggested by Padilla and colleagues that this may be linked to increased vasoconstrictor outflow (Padilla et al., 2010; Simmons et al.,
However, the systemic impact of elevations in retrograde shear rate mediated by SNS activation during lower limb exercise has not been directly studied.

Sympathetic nervous system activation, independent of exercise, has also been linked to reduction in FMD (Ghiadoni et al., 2000; Hijmering et al., 2002; Lind et al., 2002; Speiker et al., 2002; Dyson et al., 2006). Hijmering et al. utilised lower body negative pressure (LBNP: -20mmHg) to increase sympathetic outflow and demonstrated an acute reduction in FMD that was abolished by intra-arterial infusion of phentolamine (Hijmering et al., 2002). Whilst other studies could not replicate LBNP-induced reductions in FMD (Dyson et al., 2006), reduced FMD responses have been observed following mental stress (Ghiadoni et al., 2000; Speiker et al., 2002) and cold pressor tests (Lind et al., 2002; Dyson et al., 2006). We recently demonstrated that LBNP of -35mmHg reduced brachial artery FMD (Thijssen et al., 2014) and that this response was mitigated when the increase in retrograde shear rate induced by LBNP was abolished by the simultaneous application of a heating stimulus. We concluded that SNS activation induced by LBNP may cause a reduction in FMD which is, at least partly, due to changes in arterial shear rate patterns. This experiment was performed in resting subjects.

The impact of exercise-mediated SNS activation on brachial artery FMD remains unclear, as does the extent to which any such impact can be attributed to changes in arterial (especially retrograde) shear rate. We therefore hypothesised that SNS activation as a result of cycle exercise would contribute to reductions in post-exercise FMD, an effect mediated by changes in brachial artery shear rate.

**METHODS**

**Ethical Approval**

All study procedures were approved by the University of British Columbia (Okanagen) institutional ethics committee and adhered to the Declaration of Helsinki. All participants provided written, informed consent before participating in the study.
Participants
Ten healthy, recreationally active male subjects (age: 28±5 years, height: 1.91±0.40m, weight: 80.1±14.7kg) volunteered for the study. Subjects were normotensive (SBP<130 and DBP<85mmHg), medication free and non-smokers, with no previous history of cardiovascular disease/s.

Experimental Design
Participants were required to report to our laboratory on two occasions. All participants arrived in a fasted state (>6hrs) (Thijssen et al., 2011), having avoided strenuous exercise, alcohol and caffeine for a minimum of 8hrs prior to testing. Time of day of testing sessions was kept consistent for each participant with a minimum of 48 hrs and maximum of 7 days between sessions. Ninety minutes before commencing the experimental protocol participants orally ingested a capsule containing either an α₁-adrenoreceptor blocker (Prazosin; 0.05mg.kg⁻¹ body mass) or a placebo (empty capsule) and were instructed to lie down. This dosage of Prazosin provides ~80% alpha blockade and has previously been utilised in research studies similar in nature (Jones et al., 2011; Lewis et al., 2013; Lewis et al., 2014). Following 90-minutes rest, individuals were placed on a semi-supine bike (Lode Ergometer, Lode, Groningen, Netherlands) and their arm was extended and secured ~80° from the torso. An initial assessment of brachial artery endothelial function, using the flow-mediated dilation technique (Thijssen et al., 2011), was then conducted. Each subject then completed 30 minutes of cycle exercise at 75% max heart rate (mean workloads were 161±16 W in the placebo condition and 140±20 W in the Prazosin condition). During every 5-minute period of exercise, a 1-minute measurement of brachial artery shear rate and blood flow was recorded, whilst blood pressure parameters were recorded continuously (Finometer Pro, Finapres Medical Systems, Amsterdam, Netherlands). Previous data from our laboratory indicates that the CV associated with repeated Finometer measures collected at rest is ~5% (Lewis et al., 2015) and others have validated model flow approaches during exercise (Sugawara et al., 2003). Post-exercise FMD was then measured immediately, and 60 minutes following, exercise cessation. The order of the conditions i.e. Prazosin vs placebo, was randomised.
Experimental Measurements

Central hemodynamics

Changes in mean arterial pressure (MAP), heart rate (HR), cardiac output (CO), stroke volume (SV) and total peripheral resistance index (TPRi) were continuously measured using a Finometer PRO (Finapres Medical Systems, Netherlands), with data exported into PowerLab (Labchart 7, AD Instruments, Sydney, Australia).

Assessment of brachial artery endothelial function

After extending the arm to an ~80° angle from the torso, a rapid inflation/deflation pneumatic cuff (D.E. Hokanson, Bellevue, WA) was placed on the forearm, distal to the olecranon process. With the use of a 10-15 MHz multi-frequency-linear array probe attached to a high-resolution ultrasound machine (T3200; Terason, Burlington, MA), a B-mode image of the brachial artery was obtained. Following optimal acquisition of an image and a one-minute baseline recording of artery diameter and velocity, the forearm cuffs were inflated to 220 mmHg for 5 minutes. Recordings of diameter and velocity continued 30 second prior to cuff deflation and continued for 3 minutes thereafter, in accordance with previous studies (Woodman et al., 2001). This procedure was repeated immediately, and 60-minutes following, cycle ergometer exercise.

Brachial artery diameter and blood flow/shear rate analysis

Brachial artery diameter and velocity were analysed using a custom-designed edge-detection and wall-tracking software, which is largely independent of investigator bias (Woodman et al., 2001), described in detail elsewhere (Black et al., 2008; Thijssen et al., 2011). Diameter measurements collected using this software are more reliable and observer-independent than manual methods and reduce observer error, whilst possessing an intra-observer coefficient of variation of 6.7% (Woodman et al., 2001). Continuous (30 Hz) diameter and velocity data were used to calculate blood flow (BF) (the product of lumen cross-sectional are and Doppler velocity). Shear rate (SR) was calculated as 4 times mean blood velocity divided by vessel diameter. Finally, FMD was calculated in absolute (mm) and relative (%) terms as the increase from resting baseline diameter to peak diameter, described elsewhere (Black et al., 2008; Thijssen et al., 2011).
Statistics
Statistical analysis was performed using SPSS 22.0 (SPSS, Chicago, IL). All data are reported as mean ± SD unless otherwise stated and the statistical significance was assumed at \( P<0.05 \). A two-way repeated measures analysis of variance (ANOVA) was used to compare mean SR & BF across ‘time’ (9 time points throughout- and post-exercise) and between ‘conditions’ (Placebo & Prazosin). Similar analysis was performed on each of the following variables: antegrade SR & BF, retrograde SR & BF, MAP, HR, SV, CO, TPRi, vascular conductance and brachial artery diameter. Additional two-way repeated measures ANOVA was completed for the assessment across time (pre, post & post 60) and condition (Placebo & Prazosin) for baseline brachial artery diameter, change in diameter during the FMD, FMD%, and FMD SR area under curve (\( \text{SR}_{\text{AUC}} \)). Post-hoc analysis was performed using the least significant difference (LSD) methods. Finally, we analysed the effects of time (Pre, Post & Post60) and condition (Placebo & Prazosin) for FMD variables, on the change in logarithmically transformed diameter using a linear mixed model (LMM) using baseline arterial diameter and \( \text{SR}_{\text{AUC}} \) as covariates (Atkinson et al., 2013). This approach accounts for any changes in FMD that may be related to baseline diameter or SR differences between conditions.

RESULTS
There were no differences in pre-exercise measures of brachial artery diameter, SR, FMD\%, or \( \text{SR}_{\text{AUC}} \) between the two testing conditions (placebo vs. alpha) (Table 1, all \( P>0.05 \)).

Exercise hemodynamics
Mean arterial pressure increased in response to exercise in both the placebo and Prazosin conditions (time \( P<0.001 \), Figure 1). Whilst higher values were evident under the placebo condition during exercise, these differences were statistically insignificant (\( P=0.06 \) for condition; \( P=0.12 \) interaction effect). HR was significantly elevated throughout exercise, with elevations higher under the Prazosin condition (condition effect \( P=0.04 \), Figure 1). Stroke volume was also elevated throughout exercise, with
higher values under the placebo condition (P=0.03) and no interaction effect (interaction effect P=0.10). Cardiac output and TPRi did not differ between conditions (Figure 1).

**Brachial artery shear rate and blood flow**

Mean SR was elevated significantly in both conditions during exercise (P<0.001) with a significant condition*time interaction (P=0.01). Post hoc tests revealed significantly higher mean SR at the 5 minute exercise time point under the Prazosin condition (P=0.02, Figure 2), with no significant differences at any other exercise time point.

Antegrade SR increased in both conditions during exercise (time P<0.001), with a significant condition*time interaction (P=0.03). Similar to mean SR, post hoc tests demonstrated a significantly higher antegrade SR at the 5 minute exercise time point in the Prazosin condition. Retrograde SR also increased significantly in both conditions (time both P<0.001), although no difference was evident in this increase between the conditions (interaction effect P=0.08, Figure 2).

Both mean and antegrade BF increased with exercise in both conditions (both P<0.001) with both demonstrating a significant condition*time interaction (P=0.02 and P=0.01, respectively). Post hoc tests revealed that at the 5 and 10 minute exercise time points, both mean and antegrade flows were higher in the Prazosin condition. Finally, retrograde BF increased under both conditions (P<0.001), with no condition or interaction effects apparent (P=0.22 and P=0.14 respectively).

Vascular conductance increased in both conditions (P<0.001) but this increase was not significant between the two conditions (condition effect P=0.24, Figure 3). Finally, brachial artery diameter increased during the exercise session in both conditions (P<0.001) but this effect was not different between the two conditions (condition effect P=0.80, Figure 3).

**FMD Parameters**

Two-way ANOVA performed on baseline brachial artery diameter revealed a significant time effect (P=0.04), but no condition or interaction effects (Table 1).
significant time*condition interaction was evident for FMD (%) \( P=0.01 \), Figure 4).
Post-hoc tests indicated a significant FMD reduction immediately following the 30 minute exercise intervention \( P=0.03 \) under the placebo condition, whereas an increase in FMD was observed with Prazosin \( P=0.004 \), Figure 4). In terms of the post cuff deflation SR stimulus to FMD \([\text{FMD SR}_{\text{AUC}} (10^{3}\cdot\text{s}^{-1})]\), Prazosin was associated with elevated values both before and after exercise (condition effect \( P < 0.01 \)). However, when corrected for changes in both diameter and \( \text{SR}_{\text{AUC}} \) [CORRECTED FMD (%), Table 1], the interaction effect for FMD remained \( P<0.01 \).

**DISCUSSION**

In keeping with several previous studies examining large muscle group exercise (Goel *et al.*, 2007; Dawson *et al.*, 2008; Jones *et al.*, 2010; Johnson *et al.*, 2012b; Birk *et al.*, 2013), we observed a transient post-exercise reduction in brachial artery FMD following 30 minutes of cycle ergometer exercise in the present study. This effect was abolished by the ingestion of Prazosin, a specific \( \alpha_1 \)-adrenoceptor blocker, suggesting that exercise-induced increases in SNS activation contribute to the acute effects of exercise on arterial function \textit{in vivo}.

Whilst an acute impact of exercise on arterial function has been previously reported (Goel *et al.*, 2007; Dawson *et al.*, 2008; Jones *et al.*, 2010; Johnson *et al.*, 2012b; Birk *et al.*, 2013), these studies have not fully addressed the mechanisms responsible. The impact of SNS activation on FMD may be due to direct interactions between neurotransmitters and endothelium-dependent vasodilators (Kolo *et al.*, 2004) or secondary impacts of sympathetic vasoconstriction on arterial SR during exercise, or both. In this context, we recently demonstrated that FMD reduction during LBNP was ameliorated by applying a forearm heating stimulus that normalised the brachial artery retrograde shear rate (Thijssen *et al.*, 2014). These findings indicated that changes in FMD may, at least partly, result from LBNP effects on retrograde shear rather than direct impacts on endothelium-mediated dilation \textit{per se}. In the present study, the impact of Prazosin on FMD cannot be ascribed to impacts of this drug on SR responses during exercise, as it was associated with small but significant \textit{increases} in retrograde shear.
across the exercise period. These findings therefore infer that the α₁-blockade may have direct impacts on the nitric oxide-dilator pathway and FMD response during large muscle group lower limb exercise. Indeed, a number of studies in animals have indicated that nitric oxide interacts with noradrenaline, thereby directly modifying arterial vasoactivity (Vo et al., 1991; Chowdhary & Townend, 1999; Zanzinger, 1999; Kolo et al., 2004). Our data suggests that a balance exists between SNS-mediated vasoconstriction and endothelium-dependent dilation, with large muscle group lower limb exercise associated with a transient increase in systemic SNS activation, and consequent reduction in FMD. Prazosin-induced blockade of α₁-adrenoceptors altered this balance in favour of nitric oxide-mediated vasodilation and consequent increased FMD, as observed immediately post-exercise in the present experiment.

By virtue of its α-blocking action, Prazosin is a vasodilator and it is possible that the stimulus to brachial arterial dilation following cuff deflation during the FMD tests was affected by this drug. Indeed, directly measured SR$_{AUC}$ following cuff deflation was higher in the Prazosin condition, although no interaction effect existed for SR$_{AUC}$ between the conditions and the magnitude of change in SR after exercise was similar between the conditions (15.87 to 30.34 s$^{-1} \cdot 10^3$: 90% increase; 20.15 to 37.42 s$^{-1} \cdot 10^3$: a 86% increase). Furthermore, the significant impact of Prazosin on FMD% persisted after we corrected for differences in the SR stimulus pre- and post-exercise. It seems unlikely that the effect of Prazosin on FMD that we observed can be fully or even largely explained by effects on the SR stimulus per se.

Vascular function and FMD can be modulated by inflammation and oxidative stress and several studies have reported improvements in FMD following treatments that ameliorate oxidation and inflammation (Ellis et al., 2000; Silvestro et al., 2002; Donato et al., 2010; Johnson et al., 2012a; Wray et al., 2012; Johnson et al., 2013). Improvements in FMD following the ingestion of anti-oxidants have been observed in the elderly (Donato et al., 2010; Johnson et al., 2012a), patients with hypertension (Plantinga et al., 2007), peripheral artery disease (Silvestro et al., 2002) and heart failure (Ellis et al., 2000). Conversely, studies in healthy individuals have typically not demonstrated increases in FMD with oral antioxidants administration (Richardson et al.,
2007; Donato et al., 2010), although Johnson and colleagues suggested that vitamin C supplementation in the presence of increased retrograde SR induced by either cuff placement (Johnson et al., 2013) or cycle exercise (Johnson et al., 2012a), can enhance FMD responses. We cannot exclude the possibility that the exercise performed in our study had impacts on inflammatory or oxidative factors. However, the acute impact of Prazosin is specific to α₁-adrenoceptor blockade and we are unaware of any direct effects of this agent on inflammation or oxidative stress. The complete reversal in FMD we observed with Prazosin strongly implies that interaction between SNS activation and nitric oxide plays a role in the acute impact of exercise on arterial function in humans.

It is an important limitation of our study that no direct assessment of sympathetic nervous system activation was undertaken. Whilst it is not technically possible to perform muscle sympathetic nerve activity (MSNA) assessments from the common peroneal nerve during cycle exercise, and upper limb MSNA assessments are also challenging to maintain at higher cycle exercise intensities, whilst it is possible that any impact of whole body exercise would be greater during the immediate post-exercise period, than at latter time points (eg 1 hr), and some human evidence exists to support this contention (Cleroux et al., 1992), there is also evidence that muscle sympathetic nerve activity is lower following large muscle mass exercise (Halliwill et al., 1996; Kulics et al., 1999) and this question has not been resolved in the literature. Another limitation is that Prazosin provides specific α₁-receptor blockade and, therefore, we cannot exclude the possibility that differential β-adrenoceptor mediated dilation or α₂-mediated vasoconstriction occurred in the downstream microvasculature in our study. Some studies suggest that functional sympatholysis is mainly due to blunting of α₂-adrenoceptor mediated vasoconstriction (Wray et al., 2004) although both α₁- and α₂-adrenergic receptor mediated vasoconstriction are blunted in contracting human skeletal muscle (Rosenmeier et al., 2003). Our findings indicate that, at the level of the conduit arteries, α₁-blockade impacts on FMD and this effect is not due to changes in arterial shear stress (as a result of downstream vascular effects), since the impact of Prazosin on flows and shear were directionally opposite to those that might enhance FMD.
Nonetheless, there remains a possibility that increases in retrograde shear with Prazosin may be due to greater $\alpha_2$-mediated constriction when $\alpha_1$-receptors are blocked, and multiple blockade with non-specific $\alpha$- and $\beta$-blockade could address possibility in future studies.

A final limitation of our study relates to differences between the conditions in exercise intensity. We exercised subjects to a target HR (75% HR max), due mainly to our previous study (Birk et al., 2013) which indicated that exercise at ~70%HRmax resulted in a significant decrease in FMD post-cycling. We didn't anticipate that Prazosin would induce differences in workload of ~20W between the conditions. This could theoretically contribute to the differences we observed in post-exercise FMD. However, in Birk et al. (Birk et al., 2013) cycling performed at lower workloads resulted in a decrease in FMD, whereas in our study post-exercise FMD increased when Prazosin was administered. Furthermore, a correlation performed between differences between conditions in workload and exercise-impact on FMD, revealed no relationship ($r=0.18$, $P=0.62$). We suggest that, whilst distinct workloads may have contributed to some extent to the FMD differences between conditions, it seems that a primary impact of Prazosin on nitric oxide mediated dilator function predominated.

Conclusions. Our findings suggest that changes in vascular function following cycle exercise reflect a balance between sympathetically-driven vasoconstriction and nitric oxide-mediated vasodilation. The acute impairment on FMD observed post-exercise in the current study suggests that cycle exercise, at the intensity used in this study, transiently alters this balance in favour of SNS-mediated vasoconstriction. When taken in context with previous studies utilising LBNP, the findings of the present study suggest that a direct interaction between noradrenaline and endothelium-dependent dilators, and/or SNS-mediated changes in SR patterns, can both influence artery function in vivo. The contribution of these direct and indirect pathways may differ according to which stimulus of SNS activation is adopted: previous studies suggest that
LBNP contributes to FMD changes via shear stress related mechanisms, whereas our current results cannot be explained via this secondary impact.
REFERENCES


Conway DE, Williams MR, Eskin SG & McIntire LV. (2010). Endothelial cell responses to atheroprone flow are driven by two separate flow components: low


COMPETING INTERESTS

None of the authors have any competing interests to disclose.

AUTHOR CONTRIBUTIONS
C.L.A, P.N.A, D.H.J.T & D.J.G conceived and designed the experiment. C.L.A contributed to the collection and analysis of date along with the writing of the manuscript, with the aid of D.J.G, N.C.L., H.H.C., D.H.J.T. and P.N.A. All authors helped draft and/or revise the manuscript critically and have approved the final submitted version.

FUNDING
W. Prof. Green is funded by the Australian Research Council (DP 130103793).
Table 1. Baseline (pre-exercise) and post exercise FMD, shear rate and blood flow, on each day.

<table>
<thead>
<tr>
<th></th>
<th>PLACEBO</th>
<th>PRAZOSIN</th>
<th>2-way ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Post 60mins</td>
</tr>
<tr>
<td>Baseline diameter (mm)</td>
<td>4.43±0.28</td>
<td>4.78±0.66</td>
<td>4.41±0.33</td>
</tr>
<tr>
<td>Change in diameter during FMD (mm)</td>
<td>0.22±0.07</td>
<td>0.15±0.05</td>
<td>0.25±0.07</td>
</tr>
<tr>
<td>FMD (%)</td>
<td>5.09±1.65</td>
<td>3.22±1.13</td>
<td>5.78±1.69</td>
</tr>
<tr>
<td>FMD SR&lt;sub&gt;AUC&lt;/sub&gt; (10&lt;sup&gt;3&lt;/sup&gt;·s&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>15.87±9.05</td>
<td>30.34±9.30</td>
<td>17.71±4.36</td>
</tr>
<tr>
<td>CORRECTED FMD (%)</td>
<td>2.10±0.56</td>
<td>1.69±0.62</td>
<td>2.47±0.63</td>
</tr>
</tbody>
</table>
FIGURE LEGENDS

FIGURE 1 Mean arterial pressure (MAP), heart rate (HR), stroke volume (SV), cardiac output (CO) and total peripheral resistance index (TPRi) across 30 minutes of cycle exercise at 75%HR max. Grey squares denote ‘Placebo’ condition and black squares denote ‘Prazosin’ condition. Error bars represent SE. Statistical significance assumed at $P \leq 0.05$ and # representing statistical significance between conditions. (NB: subjects were exercised at a target HR of 75%HRmax, resulting in mean workloads of 161±16 W in the placebo condition and 140±20 W in the Prazosin condition)

FIGURE 2 Mean, antegrade and retrograde shear rate (SR) comparisons across 30 minutes of cycle exercise at 75%HR max under ‘Placebo’ (grey squares) and ‘Prazosin’ (black squares). Error bars represent SE. Statistical significance assumed at $P \leq 0.05$ and # represents statistical significance between conditions. (NB: subjects were exercised at a target HR of 75%HRmax, resulting in mean workloads of 161±16 W in the placebo condition and 140±20 W in the Prazosin condition)

FIGURE 3 Blood flow, conductance, brachial artery velocity and arterial diameter across 30 minutes of cycle exercise at 75%HR max under ‘Placebo’ (grey squares) and ‘Prazosin’ (black squares). Error bars represent SE. Statistical significance assumed at $P \leq 0.05$ and # represents statistical significance between conditions. (NB: subjects were exercised at a target HR of 75%HRmax, resulting in mean workloads of 161±16 W in the placebo condition and 140±20 W in the Prazosin condition)

FIGURE 4 Brachial artery flow-mediated dilation (FMD) prior to, immediately post and 60 minutes following 30 minutes cycle exercise at 75%HRmax in the (A) Placebo condition (grey bars) and (B) Prazosin condition (black bars). Error bars represent SE. Statistical significance assumed at $P \leq 0.05$ and * represents statistical significance from ‘Pre’ value. (NB: subjects were exercised at a target HR of 75%HRmax, resulting in mean workloads of 161±16 W in the placebo condition and 140±20 W in the Prazosin condition)
2-way ANOVA:
Time: \( P<0.001 \)
Condition: \( P=0.06 \)
Time*condition \( P=0.12 \)

2-way ANOVA:
Time: \( P=0.001 \)
Condition: \( P=0.04 \)
Time*condition \( P=0.33 \)

2-way ANOVA:
Time: \( P<0.001 \)
Condition: \( P=0.03 \)
Time*condition \( P=0.10 \)

2-way ANOVA:
Time: \( P<0.001 \)
Condition: \( P=0.13 \)
Time*condition \( P=0.06 \)

2-way ANOVA:
Time: \( P<0.001 \)
Condition: \( P=0.98 \)
Time*condition \( P=0.41 \)
Two-way ANOVA:
Condition $P=0.06$
Time $P=0.12$
Time*Condition $P=0.01$