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Influence of Gender and Active Muscle Mass on Renal Vascular Responses During Static Exercise

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Abstract

During exercise, reflex renal vasoconstriction helps to maintain blood pressure and redistributes blood flow to the contracting muscle. Prior work has shown that gender and muscle mass can influence certain cardiovascular responses to exercise. Whether gender and/or muscle mass influence renal vasoconstrictor responses to exercise is unknown. We studied age and body mass index (BMI) matched healthy men ($n = 10$) and women ($n = 10$) during handgrip (HG, small muscle mass) and quadriceps contraction (QC, large muscle mass) as beat-to-beat changes in renal blood flow velocity (RBV; Duplex Ultrasound), mean arterial pressure (MAP; Finapres) and heart rate (ECG) were monitored. Renal vascular resistance index (RVR) was calculated by dividing MAP by RBV. Responses to HG vs. QC were compared in 13 subjects. We found that: 1) RVR responses to short bouts (15 sec) and fatiguing HG were similar in men and women (% change in RVR during 15 sec HG at 70% maximum voluntary contraction [MVC], male $23 \pm 4\%$ vs. female $31 \pm 4\%$, $P = \text{NS}$); 2) post-handgrip circulatory responses were also similar in men and women; and 3) HG and QC were similar during short bouts (15 sec; % change in RVR during HG at 50% MVC, arm $19 \pm 3\%$ vs. leg $18 \pm 5\%$, $P = \text{NS}$). Our findings suggest that muscle reflex mediated renal vasoconstriction is similar in men and women during static exercise. Moreover, muscle mass does not contribute to the magnitude of the reflex renal vasoconstrictor response seen with muscle contraction.

Keywords

Exercise; Renal Vasoconstriction; Sex

INTRODUCTION

Exercise causes activation of the sympathetic nervous system which leads to increases in heart rate (HR), blood pressure and peripheral vasoconstriction. As part of these processes, renal vasoconstriction helps to maintain blood pressure and redistribute blood flow to the active skeletal muscle. Two important neural mechanisms are believed to be involved in the sympathoexcitatory responses during exercise. One is central command, a feed forward system, stems from the higher brain center and causes parallel activation of motor and cardiovascular control centers (37). Another mechanism, a feed back system from exercising muscle, is called the exercise pressor reflex. This reflex mechanism is activated when mechanosensitive and

metabolite sensitive afferent nerve endings within the contracting skeletal muscle are stimulated (1,14). Activation of these neural mechanisms results in efferent sympathetic outflow to different effector organs. Studies have shown that different neural mechanisms have different onset latencies for increases in muscle sympathetic nerve activity (MSNA), an important index of sympathetic drive directed to skeletal muscle blood flow. Specifically, increases in MSNA during the initial several seconds of exercise are due to central command (36) and/or muscle mechanoreflex (10,11), whereas metabolite sensitive muscle afferent nerves activate sympathetic system in >60 s after initiation of muscle contraction (19,33–35).

Prior reports examining the effects of gender on sympathoexcitatory responses to exercise have yielded conflicting results. Some reports showed no effect of gender on cardiovascular responses during exercise (13,27), whereas other studies have observed reduced exercise induced pressor responses in women as compared to men (4–6). Ettinger et al. postulated that the muscle metaboreflex contribution to sympathetic outflow of exercise was reduced in women as compared to men. It was also suggested that the gender related differences in sympathetic outflow were not due to differences in muscle mass.

Considerable debate also exists regarding the effects of exercising muscle mass on sympathoexcitatory responses during exercise. A number of reports in healthy human subjects suggest that the magnitude of the pressor response seen during static exercise is dependent on the size of the active muscle mass (3,12,16,23,31). Other studies have suggested that increases in cardiovascular responses are dependent on the relative tension generated by the contracting muscle and not on the size of the active muscle mass (9,17,21,38).

Recently, studies from this lab have used Doppler ultrasound technology (Duplex Ultrasound) to measure renal blood flow in humans during exercise. The excellent time resolution of this method has afforded the opportunity to observe renal vascular responses within the initial first few seconds after the initiation of exercise. Using this method we have found that activation and sensitization of mechanosensitive muscle nerve afferents play a crucial role in evoking renal vasoconstriction during static exercise in healthy humans (25) as well as in those with heart failure (24).

However, it is not known whether gender and/or muscle mass influences renal vascular responses to exercise in humans.

Therefore in this report, we examined renal vasoconstrictor responses to static exercise in age and body mass index (BMI) matched healthy young men and women to address the following questions: 1) do men and women exhibit different renal vasoconstrictor responses during fatiguing handgrip (HG) and post-handgrip circulatory arrest (PHG-CA)?; 2) do men and women exhibit differences in renal vascular responses to short bouts (15 s) of static exercise?; and 3) does the size of the active muscle mass affect renal vascular responses to static exercise during short bouts (15 s) of exercise?

Our studies suggest that renal vasoconstrictor responses are similar in men and women during HG. Our results also reveal that the size of active muscle mass does not influence the renal vasoconstrictor response seen during short bouts of exercise.

METHODS

Study population

A total of ten healthy young men (age 28 ± 2 years, mean BMI 24 ± 1 Kg/m²) and 10 healthy young women (age 25 ± 2 years, mean BMI 22 ± 1 Kg/m²) were recruited for the protocols described below. The same 9 men and same 8 women participated in protocol 1 and 2. Not all

of these individuals participated in protocol 3. Each subject signed an informed written consent and had his/her physical examination done prior to conducting the study protocols that had been approved by the Institutional Review Board. Volunteers were nonsmokers, normotensive and on no medication.

Renal blood flow velocity (RBV)

All subjects were studied in the post absorptive state. Duplex ultrasound (HDI 5000, ATL Ultrasound, Bothell, WA, USA) was used to determine renal blood flow dynamics. The renal artery was scanned using the anterior abdominal approach while the subject was lying supine. A curved-array transducer (2–5 MHz) with a 2.5 MHz pulsed Doppler frequency was used. The probe insonation angle to the renal artery was $<60^\circ$. The focal zone was set at the depth of the renal artery. In order to obtain optimum velocity tracings, the transducer was held in a constant position and thus the data were obtained in the same phase of the respiratory cycle. Care was taken to ensure that the subject did not perform Valsalva maneuvers during the HG protocols. Each cardiac cycle Doppler tracing was analyzed using ATL machine's own software (HDI 5000) to obtain mean RBV. Velocity measurement was expressed as cm/sec.

It should be noted that blood flow (BF) is a function of mean blood flow velocity (MBV) and vessel cross sectional area ($BF = MBV * \pi r^2$, where r is the vessel radius). Therefore, accurate measurements of vessel diameter are required to determine renal blood flow. Due to the limited spatial resolution of the technique, accurate measurements of renal artery diameter are difficult to perform in humans. However, using renal angiography technique, Marraccini et al. (20) reported no significant changes in renal artery diameter despite large changes in flow velocity as pharmacological compounds were infused. Thus, RBV reflected the real time renal hemodynamic responses. Therefore, in our report, RBV is used as an index of renal blood flow, and the renal vascular resistance (RVR) index was in turn calculated by dividing mean arterial pressure by RBV. RVR is expressed in arbitrary units (AU).

Beat-by-beat recording of changes in RBV were obtained during different paradigms. Continuous recordings of HR (electrocardiogram) and blood pressure (Finapres; Ohmeda, Madison, WI) were also obtained during each protocol. Subjects rested for ~15 min between protocols. An automated sphygmomanometer (Dinamap; Critikon, Tampa, FL) was used to determine resting blood pressure. Each subject performed HG with a HG dynamometer (Stoelting, Wood Dove, IL). This device is adjustable for different hand spans.

Study Protocols

Protocol 1. Fatiguing static exercise followed by PHG-CA (n = 17; 9 male, 8 female)—In this protocol, we examined the effects of gender differences on renal vasoconstrictor mechanisms during fatiguing exercise. The effect of muscle metaboreflex engagement on renal vasoconstrictor responses were examined during PHG-CA. Maximum voluntary contraction (MVC) of the nondominant arm was determined in each subject prior to beginning the HG paradigm. Baseline HR, MAP and RBV data were obtained over a 5-min period at rest before beginning each protocol. Each subject began HG exercise at 40% MVC and continued until fatigue. At the end of exercise, all the subjects graded their perceived level of exertion as 20 (maximum effort) on the Borg scale (2). Immediately prior to stopping exercise, PHG-CA was initiated by inflating a previously placed blood pressure cuff around the arm at ~250 mmHg. This cuff was kept inflated for 2 min.

Protocol 2. Static handgrip exercise at graded intensity (n = 17; 9 male, 8 female)—This protocol was designed to examine the influence of gender on renal vascular responses within initial several seconds of the onset of HG exercise.

Five min of baseline HR, MAP and RBV data were collected. Each subject completed 15 s bouts of static HG exercise at 10%, 30%, 50%, and 70% of the respective subject's MVC. The same sequence was maintained in all subjects. Each bout of exercise was preceded by ~1 min period of rest. We attempted to perform quadriceps contraction until fatigue but were unsuccessful because of technical limitations. To obtain optimum renal artery velocity tracings, the Doppler probe needs to be placed in a constant position. During the sustained and fatiguing quadriceps contraction, the abdominal wall contracted and the transducer was no longer in the same position relative to the renal artery. Moreover, even if we could obtain a signal, the contracting abdominal muscles would likely make a varied and unquantifiable contribution to the reflex. This would make "QC reflex responses" impossible to quantify during a bout of fatiguing QC. Therefore, we performed only short bouts of QC in the subjects.

Protocol 3. Static quadriceps contraction (QC) at graded intensity (n = 15; 8 male, 7 female)—After protocol 1 and 2 were completed, protocol 3 was performed on a separate day. This protocol was designed to compare the renal vasoconstrictor responses during muscle contraction trials of a small and a large muscle mass. HG was used as the small muscle mass paradigm and QC was used as the large muscle mass paradigm. A custom-made device for quadriceps exercise was utilized for this paradigm. Subjects were placed in a supine position. The thigh was supported at an angle of 45° by an adjustable, padded, triangular wooden support. A recalibrated, universal, flat, load cell (Strainsert, West Conshohocken, PA) was mounted directly beneath and attached to the left ankle with nylon strapping. The device was calibrated before each study by using 22.7- and 45.5-kg weights.

Before initiating the studies, the MVC was determined for quadriceps muscle contractions.

Five min baseline data of HR, MAP and RBV were collected. Each subject completed 15 s bouts of static QC at 10%, 30%, 50%, and 70% of the respective subject's MVC. The subjects received visual feedback, via an analog meter, of the amount of tension generated. The same sequence was maintained in all subjects. Each bout of exercise was preceded by ~1 min period of rest.

Data analysis and statistics

Beat-by-beat sequential analysis of HR, MAP, RBV and RVR were performed for all subjects. Baseline values for each parameter were considered as the average data values obtained during 5-min rest period before each paradigm was begun.

In the fatiguing static HG protocol, each variable was measured around the time that represented 10%, 20%, 40%, 60%, 80% and 100% (peak) of the respective subject's time to exhaustion. Data from the last 15 s time period during circulatory arrest was used in the statistical analysis.

In the second and third protocols, data were analyzed in 5 s time periods. Statistical analyses were performed separately on each 5 s period (i.e. 1–5, 6–10 and 11–15 s).

Data are presented as mean $\pm$ SE. Comparisons of resting values were made using unpaired *t*-tests. Repeated-measures two-way ANOVA were applied to the data for each response variable (changes from the respective baseline) to assess the two main effects: gender (between male vs. female subjects) and the type of muscle contraction paradigm employed i.e. HG vs. QC. The possible interaction of these two factors was also assessed as a function of time (% time to fatigue in protocol 1 and each 5 s in protocol 2 and 3 during static exercise). Similarly, comparisons of each response during smaller (HG) and larger (QC) muscle contractions were made by 2-way ANOVA with muscle mass and exercise paradigms serving as the two main

effects. Respective time periods during contraction were compared using simple effects and Bonferroni corrections. P value < 0.05 was considered significant.

RESULTS

At rest, average of all baseline hemodynamic variables were similar in the two gender groups. No significant group differences were found with respect to age and BMI. HG and quadriceps muscle MVC were greater in the male than in female subjects ($P < .0001$).

Protocol 1: Fatiguing static exercise followed by PHG-CA

The time to fatigue was not significantly different in male and female subjects (male vs. female, 128 ± 21 vs. 90 ± 19 s; $P = .19$). Comparable changes in RVR and RBV from baseline to fatigue were noted in the two groups: baseline RVR values: male, $1.79 \pm .09$; female, $1.67 \pm .13$ RVR units. Values at fatigue: male, $2.73 \pm .26$; female, $2.48 \pm .21$ RVR unit. Baseline RBV values: male, 55.7 ± 3.8 ; female, 55.4 ± 4.8 cm/sec. Values at fatigue: male, 50.5 ± 5.8 ; female, 45.8 ± 3.7 cm/sec. No gender effect was seen during PHG-CA (Figure 1 A, B; Tables 1 and 2).

No significant group differences were observed for MAP (baseline values: male, 98 ± 5 ; female, 89 ± 3 mmHg. Values at fatigue: male, 129 ± 10 ; female, 110 ± 4 mmHg). However, the percent increase in MAP at fatigue tended to be less in the females than in the males (Table 1, Interaction $P < .04$). During PHG-CA, the percent increase in MAP also tended to be smaller in females than in male subjects although these did not reach statistical significance (gender effect, $P = .065$; Table 2).

Static handgrip exercise at graded intensity

RVR responses were similar in the men and women (Figure 2). RBV, HR and MAP values were also similar in men and women during this protocol (not shown).

Static QC at graded intensity

RVR rose with static QC (Figure 3) and the pattern of rise in RVR, RBV and HR were similar in the two groups. However, MAP rose more in men as compared with women during 11–15 s time period of quadriceps exercise ($P < .05$; Table 3).

Smaller (forearm) vs. larger (quadriceps) muscle mass contractions (n = 13)

HR, MAP, RBV and RVR responses were similar during short bouts of quadriceps and HG contractions (Table 4).

The values during 11–15 s of static contraction at 70% MVC for HG vs. QC are as follows: HR, 76 ± 4 vs. 79 ± 4 beat/min; MAP, 103 ± 7 vs. 101 ± 7 mmHg; RBV, 52.2 ± 3.6 vs. 52.2 ± 3.0 cm/sec and RVR, $2.03 \pm .13$ vs. $1.97 \pm .14$ RVR unit, respectively.

DISCUSSION

The objectives of this report were to evaluate the effects of gender and muscle mass on renal vascular responses to muscle contraction. The major new findings in this report are: 1) renal vasoconstrictor responses to HG are similar in males and females; and 2) renal vasoconstrictor responses during short bouts of exercise do not depend on the size of the contracting muscle mass.

Baseline RBV and RVR were similar in men and women. These findings are consistent with several previous animal and human studies (8,22,29). Resting MAP and HR were also not different in the groups. Some previous reports suggest that MAP may be higher in men than

in women (13,22), whereas other reports have also noted similar resting blood pressure in men and women (6,8,28). The exact reason for this inconsistency in resting blood pressure among men and women is not clear. However, the fitness level, family history or the environmental factors could play a role (15,18,26,30).

Fatiguing static HG followed by PHG-CA

In this study, no gender differences for RVR were observed during fatiguing HG. In a prior report, Ettinger et al. observed reduced MSNA responses in women as compared to men during the second min of HG. In addition, these authors noted an attenuated rise in MAP in women suggesting attenuated engagement of muscle metaboreflex in women (6). Jones et al. also observed reduced responses in blood pressure and MSNA during HG in women as compared to men when absolute values were examined. However, percent increases from baseline were similar in the two groups (13).

The RVR responses in women and men were similar during fatiguing HG even though the rise in blood pressure tended to be less in women than in men (Table 1). This suggests that sympathetic drive to the kidney during static exercise is similar in men and women. Moreover, similar RVR responses were also found between the groups during PHG-CA (isolates muscle metaboreflex) despite a tendency to have reduced blood pressure responses in women. These findings suggest that muscle metaboreflex mediated renal vasoconstriction was similar in men and women.

Static HG and quadriceps exercise at graded intensities

The data in the present report also suggests that differences in muscle mass do not contribute to RVR responses since the curves for RVR vs. % MVC for HG and QCs were superimposable. It needs to be mentioned that sympathoexcitatory responses during 15 s period of exercise could be due to either central command (36) and/or the muscle mechanoreflex (10). Engagement of muscle metaboreflexes is very unlikely since sufficient accumulation of metabolites is not present in the contracting skeletal muscle during 15 s period of exercise. An earlier report from this lab using involuntary biceps contractions suggested that central volitional influences are not necessary to evoke renal vasoconstriction (25). Thus we would argue that the similar renal vasoconstriction response for HG and QC in the present report suggests that the muscle mechanoreflex control of the renal bed are not influenced by muscle mass. It is unlikely that the lack of difference observed between men and women was due to a lack of statistical power. Specifically, to detect the differences in the changes in RVR index that are observed in our study, a sample size of 200 subjects (100 males and 100 females) would yield 80% statistical power to detect a standardized effect size of 0.4 between males and females at any % MVC level using a two-sided test having a significance level of 0.05.

A number of studies have been performed to examine the effect of muscle mass on cardiovascular responses. Consistent with our findings, a number of reports have demonstrated that exercise induced cardiovascular responses were not dependent on the size of exercising muscle mass (17,21,33,38). Contrary to these previous studies, studies examining pressor responses (23,31) and MSNA (31,32) to muscle contraction found that responses were muscle mass dependent. Interestingly, detailed analysis of these studies showed that magnitude of increases in pressor responses or MSNA did not vary among different muscle groups within the initial 30 or 40 sec of contraction. McCloskey and Streatfeild and Mitchell et al. observed an effect of muscle size on responses seen during post-exercise circulatory occlusion (isolates muscle metaboreflex). This suggests that muscle mass influences muscle metaboreflex mediated responses (21,23). Similarly, Iellamo and colleagues observed larger increases in HR and MAP responses with the larger muscle mass compared with the smaller muscle mass contraction and suggested that these greater responses are due to enhanced engagement of

muscle metaboreflexes (12). A prior work performed by Franke et al. documented greater sympathoexcitatory responses with quadriceps than with HG. In this report, 5-min bouts of supine isometric exercise were employed (7) and found that sympathoexcitatory responses were dependent on exercising muscle mass. The authors argued that the greater responses with leg contraction were due to greater engagement of central command.

When these data are viewed collectively with the data from our report, we would conclude that: 1) muscle mass may contribute to blood pressure control but not to renal vascular control; 2) muscle mechanoreflex mediated control of the renal vascular bed are not influenced by muscle mass. The present report does not allow us to draw inferences regarding the effect of muscle mass on central command and metaboreflex mediated control of the renal vascular bed; and 3) mechanoreflex control of the renal vascular bed is similar in men and women.

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Figure 1.

(A) % Change from baseline data in renal vascular resistance index (RVR; Y-axis) as a function of % time to fatigue (X-axis) during static handgrip at 40% of maximum voluntary contraction. Data presented as mean $\pm$ SEM. (B) Comparison between baseline and post-handgrip circulatory arrest (PHG-CA) renal vascular resistance (RVR) index in male and female subjects. P value reflects statistical analysis using two-way ANOVA comparing between male (closed circle, $n = 9$) and female subjects (open circle, $n = 8$).

Figure 2.

% Change from baseline data in renal vascular resistance (RVR; Y-axis) index during 15 s bouts of static handgrip at 10, 30, 50 and 70% of maximum voluntary contraction (MVC; X-axis) in male (closed circle, $n = 9$) and female (open circle, $n = 8$) subjects. Data presented as mean $\pm$ SEM. Data examined separately for 1–5, 6–10 and 11–15 s. P value reflects statistical analysis using two-way ANOVA comparing between male and female subjects.

Figure 3.

% Change from baseline data in renal vascular resistance (RVR; Y-axis) index during 15 s bouts of static quadriceps (Quad) exercise at 10, 30, 50 and 70% of maximum voluntary contraction (MVC; X-axis) in male (closed circle, $n=8$) and female (open circle, $n=7$) subjects. Data presented as mean $\pm$ SEM. Data examined separately for 1–5, 6–10 and 11–15 s. P value reflects statistical analysis using two-way ANOVA comparing between male and female subjects.

Table 1
Cardiovascular Including Renal Hemodynamic Changes during Fatiguing Static Handgrip – Smaller Muscle Mass (Protocol 1).

	Males						Females						P <
	10%	20%	40%	60%	80%	100%	10%	20%	40%	60%	80%	100%	
<i>Δ</i> % HR	16.9 ±4.5	22.9 ±4.8	32.3 ±7.2	38.9 ±7.4	42.0 ±8.2	48.3 ±7.8	12.8 ±4.7	21.1 ±4.4	24.4 ±5.4	29.0 ±4.3	34.6 ±5.6	36.5 ±4.8	ns .001 ns
<i>Δ</i> % MAP	5.2 ±1.5	8.1 ±1.8	14.6 ±2.6	20.7 ±4.2	29.6 ±5.0	31.5 ±5.5	8.3 ±2.0	9.5 ±2.1	13.0 ±2.6	20.5 ±2.7	18.9 ±2.8	23.5 ±3.0	ns .001 .044
<i>Δ</i> % RBF	-9.9 ±2.4	-13.0 ±2.6	-15.7 ±4.6	-13.7 ±4.9	-6.7 ±8.7	-10.0 ±7.8	-8.0 ±1.9	-11.4 ±2.2	-13.2 ±1.7	-13.3 ±2.7	-15.3 ±1.6	-16.8 ±2.0	ns ns ns

Fatiguing static handgrip protocol data expressed as percent change from baseline for heart rate (%HR, beats/min), mean arterial pressure (%MAP, mmHg) and renal blood flow velocity (%RBF, cm/sec). Two-way ANOVA's were performed and results are listed in the statistics column on the far right of the table.

Table 2

Minute 2 of PHG-CA during Protocol 1

	Males	Females	P <
Heart rate (bpm)	63.1 ± 5.6	64.4 ± 2.6	ns
Mean Arterial Pressure (mmHg)	122.0 ± 8.2	102.3 ± 4.1	.065
Renal Blood Flow Velocity (cm/sec)	55.0 ± 5.9	51.1 ± 4.0	ns

Two-way analysis of variance (ANOVA) were performed between males and females at baseline and minute 2 of PHG-CA. P value expressed above reflects the gender main effect.

Table 3
Cardiovascular Including Renal Hemodynamic Changes during Short Bouts of Static Quadriceps Contractions – Larger Muscle Mass (Protocol 3).

%MVC	Males					Females					Statistics	P <
	10%	30%	50%	70%	10%	30%	50%	70%				
0–5 seconds												
Δ %HR	3.4±2.5	9.3±2.6	13.6±3.0	13.3±3.3	8.7±3.2	12.0±3.2	14.2±3.6	21.5±3.4	Gender Paradigm Interaction	ns 0.004		
Δ %MAP	3.4±2.0	7.7±3.9	17.2±2.7	21.9±4.5	1.3±1.5	9.1±2.1	10.1±3.1	17.9±2.4	Gender Paradigm Interaction	ns 0.001		
Δ %RBV	-1.1±4.2	-1.5±4.4	2.9±4.0	-2.6±7.7	-7.8±2.1	0.3±3.6	-1.9±1.8	-4.0±5.2	Gender Paradigm Interaction	ns ns ns		
6–10 seconds												
Δ %HR	3.2±2.5	5.4±2.5	15.6±3.0	25.0±3.9	9.2±4.3	4.6±3.6	10.6±2.9	20.3±4.6	Gender Paradigm Interaction	ns 0.001		
Δ %MAP	-3.3±1.1	5.8±2.4	12.8±3.2	19.6±4.9	-2.5±1.8	3.8±2.4	8.0±2.7	15.7±2.1	Gender Paradigm Interaction	ns 0.001		
Δ %RBV	-4.6±4.4	-4.4±5.0	-2.5±4.7	-8.6±8.1	-6.8±1.3	-5.2±2.3	-8.3±2.2	-14.6±5.3	Gender Paradigm Interaction	ns ns ns		
11–15 sec												
Δ %HR	7.2±2.0	14.7±2.6	25.0±3.5	37.6±4.7	8.7±2.6	12.3±4.4	17.8±3.7	27.5±5.5	Gender Paradigm Interaction	ns 0.001		
Δ %MAP	-0.8±1.8	6.2±2.2	15.4±2.9	17.2±4.8	-2.2±1.5	-0.4±3.1	5.4±1.6	10.0±2.2	Gender Paradigm Interaction	ns 0.051 0.001		
Δ %RBV	-3.9±4.3	-7.3±4.4	-3.2±5.4	-4.2±6.4	-6.1±1.5	-3.7±2.3	-5.5±2.3	-13.6±5.5	Gender Paradigm Interaction	ns ns ns		

Graded static quadriceps exercise data (% change from respective baseline value) for heart rate (HR), mean arterial pressure (MAP), and renal blood flow velocity (RBV). P value reflects statistical analysis using two-way ANOVA comparing between male (n=8) and female (n=7) subjects.

Table 4

Cardiovascular Including Renal Hemodynamic Changes during Short Bouts of Static Quadriceps Contractions (Larger Muscle Mass) and Static Handgrip (Smaller Muscle Mass).

%MVC	10%	30%	50%	70%	10%	30%	50%	70%	Statistics	P<
Quadriceps 0–5 seconds										
Δ %HR	4.5±1.9	10.5±2.1	12.6±2.4	16.9±2.9	9.1±4.1	5.5±1.8	13.6±2.0	22.1±3.5	Muscle Mass Paradigm	ns
Δ %MAP	2.3±1.5	7.6±2.5	14.2±2.4	19.2±2.6	1.6±1.8	3.7±1.8	11.4±1.7	13.7±1.8	Interaction Muscle Mass Paradigm	0.001
Δ %RBV	-3.9±2.9	0.0±3.2	1.7±2.5	-0.2±4.5	-2.3±2.8	-3.2±3.8	-3.0±3.7	1.6±5.7	Interaction Muscle Mass Paradigm	0.068
Δ %RVR	7.1±2.9	8.8±4.4	13.9±4.8	22.6±8.2	3.8±2.4	9.8±6.3	16.4±4.1	14.8±4.5	Interaction Muscle Mass Paradigm	0.001
6–10 seconds										
Δ %HR	4.8±2.7	6.1±2.2	13.8±2.3	22.9±3.1	4.0±2.7	5.9±2.2	13.6±3.0	22.8±4.4	Muscle Mass Paradigm	ns
Δ %MAP	-3.4±1.0	4.1±1.8	10.6±2.5	16.9±3.0	-0.6±1.9	3.5±1.9	8.1±1.9	17.4±2.7	Interaction Muscle Mass Paradigm	0.001
Δ %RBV	-5.7±2.7	-5.2±3.2	-3.7±3.0	-9.0±5.0	-3.9±2.7	-3.5±2.6	-6.3±3.6	-1.5±5.6	Interaction Muscle Mass Paradigm	ns
Δ %RVR	3.2±3.0	11.5±5.4	16.5±5.4	35.1±12.1	4.0±3.2	8.4±4.0	16.8±3.1	22.5±4.6	Interaction Muscle Mass Paradigm	ns
11–15 seconds										
Δ %HR	7.6±1.6	15.2±2.4	21.2±2.8	33.2±4.3	5.8±3.0	6.1±2.2	17.5±3.7	28.2±5.3	Muscle Mass Paradigm	0.083
Δ %MAP	-1.3±1.3	3.1±2.3	11.3±2.4	13.1±3.0	-0.8±1.6	3.1±1.6	7.8±2.1	15.3±2.9	Interaction Muscle Mass Paradigm	0.001
Δ %RBV	-4.2±2.6	-6.2±2.9	-4.3±3.4	-6.0±4.1	-4.6±2.9	-6.0±2.4	-8.3±3.5	-7.2±5.4	Interaction Muscle Mass Paradigm	ns
Δ %RVR	3.6±2.7	11.3±5.0	17.9±5.2	23.0±7.5	5.2±3.6	10.6±3.5	18.7±3.2	26.9±4.4	Interaction Muscle Mass Paradigm	ns
11–15 sec										
Δ %HR	7.6±1.6	15.2±2.4	21.2±2.8	33.2±4.3	5.8±3.0	6.1±2.2	17.5±3.7	28.2±5.3	Muscle Mass Paradigm	0.083
Δ %MAP	-1.3±1.3	3.1±2.3	11.3±2.4	13.1±3.0	-0.8±1.6	3.1±1.6	7.8±2.1	15.3±2.9	Interaction Muscle Mass Paradigm	0.001
Δ %RBV	-4.2±2.6	-6.2±2.9	-4.3±3.4	-6.0±4.1	-4.6±2.9	-6.0±2.4	-8.3±3.5	-7.2±5.4	Interaction Muscle Mass Paradigm	ns
Δ %RVR	3.6±2.7	11.3±5.0	17.9±5.2	23.0±7.5	5.2±3.6	10.6±3.5	18.7±3.2	26.9±4.4	Interaction Muscle Mass Paradigm	ns

Graded static quadriceps exercise and handgrip data (% change from respective baseline value) for heart rate (HR), mean arterial pressure (MAP), renal blood flow velocity (RBV) and renal vascular resistance index (RVR). P value reflects statistical analysis using two-way ANOVA comparing smaller (handgrip) and larger (quadriceps) muscle contraction.