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The influence of exercise intensity on post-exercise baroreflex sensitivity

Abstract

Purpose: To investigate the influence of exercise intensity on post-exercise supine and tilt baroreflex sensitivity (BRS). Method: Nine healthy, active men performed two conditions of interval cycling of 40% WR_{max} and 75% WR_{max} of matched work done and a control condition of no exercise in a counterbalanced order. BRS outcome measures were determined pre and post exercise up to + 24 hr in supine and tilt positions. R-R interval and BP data was collected over consecutive 10 min periods and analyzed by Fast Fourier transformation analysis. Results: A fully repeated ANOVA revealed a significant interaction ($p < .05$) between time and condition in supine for $BRS_{\alpha LF}$ $F(3,134) = 5.19$, $p < .05$, ES = .39 and BRS_{TFTG} $F(3,134) = 5.65$, $p < .05$, ES = .41 and, in tilt for BRS_{UpUp} $F(3,134) = 3.54$, $p < .05$, ES = .31, $BRS_{DownDown}$ $F(3,134) = 5.94$, $p < .05$, ES = .43, $BRS_{\alpha LF}$ $F(4,134) = 6.23$, $p < .05$, ES = .44 and BRS_{TFTG} $F(4,134) = 9.22$, $p < .05$, ES = .54. There were significant differences ($p < .05$) between condition comparisons at + 15 min and between control and 75% WR_{max} and between 40% WR_{max} and 75% WR_{max} conditions at + 60 min. At + 15 min BRS was lower in the 75% WR_{max} condition compared to the 40% WR_{max} condition and the control condition, and the 40% WR_{max} condition was lower than the control condition. Conclusion: The findings demonstrate an intensity-dependent relationship in the BRS response following exercise.

Key words: Cardiovascular response, exercise testing, physical activity

The influence of exercise intensity on post-exercise baroreflex sensitivity

Previous research suggests that regular physical activity and increased fitness is associated with a reduction in the risk for hypertension and cardiovascular diseases, and an improvement in blood pressure (BP) control (Pescatello et al., 2004; Wannamethee & Shaper, 2001). Autonomic influences are implicated in the causation and progression of disease (Somers & Narkiewicz, 2002). Improved autonomic regulation following regular physical activity may enhance vagal tone and reduce sympathetic influence (Buch et al., 2002) having a positive effect on cardiac autonomic status (Billman, 2002). Greater elucidation for the autonomic response following exercise may help to define the acute physiological response post-exercise and provide further evidence for the risks and benefits of exercise for health. The determination of baroreflex sensitivity (BRS) is one method which can be employed to assess the cardiac autonomic influence post-exercise.

Whether BRS is acutely manipulated following exercise is an important question given the influence of BRS on cardiovascular control. Currently, there is little research that has investigated the effect of a single bout of exercise on post-exercise BRS (Convertino & Adams, 1991; Halliwill, Taylor, Hartwig, & Eckberg, 1996; Niemelä et al., 2008; Piepoli et al., 1993; Ploutz, Tatro, Dudley, & Convertino, 1993; Raczak et al., 2005; Somers, Conway, LeWinter, & Sleight, 1985; Stuckey et al., 2012; Terziotti, Schena, Gulli, & Cevese, 2001) and, in particular, none have investigated the influence of multiple exercise intensities on BRS. Intensity of exercise is considered to be a key component in the response to an exercise dose because it has a vital role in producing either favorable adaptations or detrimental health consequences via increased exercise load (Haskell, 2001). The variety of findings across previous studies investigating the acute BRS post-exercise response may be related to differences in exercise bouts and methodological procedures, making comparison difficult. Previous studies have reported both an enhancement in BRS (Convertino & Adams, 1991; Halliwill et al., 1996; Raczak et al., 2005; Somers et al., 1985), reflecting increased parasympathetic influence and, no augmentation in BRS following exercise (Niemelä et al., 2008; Piepoli et al., 1993; Stuckey et al., 2012), suggesting a prevailing influence of sympathetic activity (Billman, 2002). Thus, it is unclear how the components of a single bout of exercise, and particularly intensity of exercise, influence BRS post-exercise (Parekh & Lee, 2005).

The assessment of the cardiovascular autonomic influence may be more pronounced through head-up tilt testing; a commonly used procedure to assess the cardiovascular response to orthostatic stress, including autonomic dysfunction (Mathias & Bannister, 2002). The orthostatic stress through the tilt procedure induces activation of the baroreflex to enable maintenance of homeostasis in BP. When assessing subtle changes in BRS following exercise, the orthostatic stress may highlight changes that are difficult to reveal in a supine position (Bernardi, Passino, Robergs, & Appenzeller, 1997; Radaelli et al., 1994). Furthermore, the reproducibility of BRS has been found to be markedly improved in procedures incorporating an orthostatic maneuver resulting in a reduction in the measurement error, and an enhanced ability to detect modest BRS changes in studies incorporating limited sample sizes (Herpin & Ragot, 1997; Reynolds, De Ste Croix, & James, 2016)

Therefore, the aim of the present study was to investigate the post-exercise effect, up to + 24 hr, of the intensity of a single bout of exercise on BRS outcomes assessed in supine and tilt.

Methods

Participants

Nine healthy non-smoking male participants (mean ± SD) (age 26 ±5 years; stature 1.79 ± 0.05 m; mass 77.9 ± 11.4 kg; resting HR 63 ± 9 $b\cdot min^{-1}$; resting BP systolic 129 ± 11, diastolic 71 ± 11 mmHg; $\dot{V}O_{2peak}$ 52.3 ± 7.5 $ml\cdot kg^{-1}\cdot min^{-1}$; HR_{peak} 185 ± 7 $b\cdot min^{-1}$) who were undertaking regular exercise (moderate exercise 5 ± 2 $hr\cdot wk^{-1}$) volunteered to participate. All participants completed health screening and subsequently provided informed consent. All procedures conformed to those approved and cleared by the University Research Ethics Committee.

Study Design

The study design was within subjects repeated measures with two separate exercise conditions and a control condition (no exercise) administered in a counterbalanced order. Each participant was required to visit the laboratory on seven separate occasions (figure 1). Visit one included completion of health questionnaire and consent form, determination of resting HR and BP, and familiarization with equipment. Participants were also required to undertake a progressive exercise test for peak oxygen uptake ($\dot{V}O_{2peak}$) assessment to determine their individual fitness level, peak heart rate (HR_{peak}), and maximal work rate (WR_{max}). Visit one was scheduled > 72 hr before the first exercise condition to ensure adequate recovery (James & Doust, 1998). Visits 2, 4, and

6 were separated by 3 - 6 days but scheduled at the same time of day to avoid circadian variation. Visits 3, 5, and 7 were the following day after the second, fourth, and sixth visit respectively. During visits 2, 4, and 6, data collection was undertaken at baseline, + 15 min, + 60 min, + 120 min, + 180 min, and during visits 3, 5, and 7 data collection was undertaken + 24 hr respectively. Participants were requested not to exercise 48 hr before each test beyond normal daily activities.

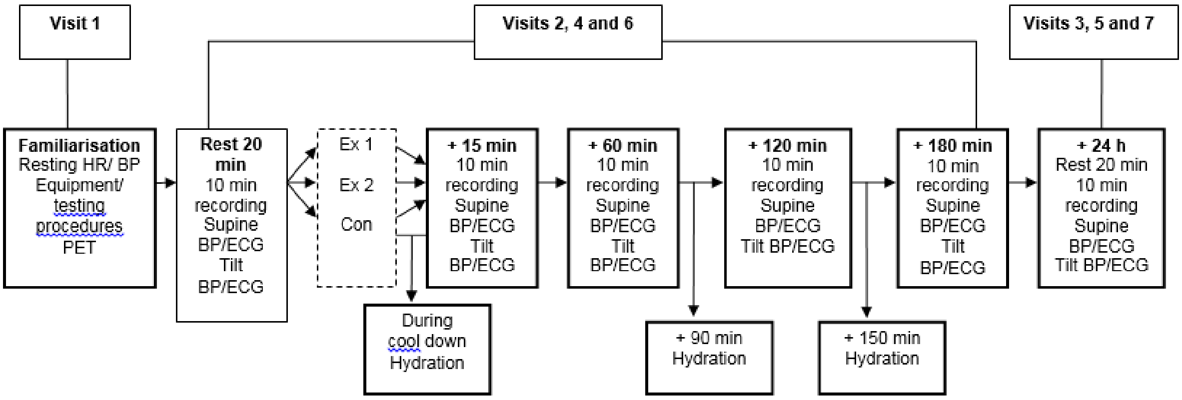

Figure 1. Order of testing procedures for determination of BRS
Note: BP is blood pressure; BRS is baroreflex sensitivity; Con is control (no exercise); ECG is electrocardiogram; Ex 1 is 40% WR_{max} exercise; Ex 2 is 75% WR_{max} exercise; HR is heart rate; min is minute; PET is progressive exercise test; WR is work rate. The order for the control condition and exercise conditions was randomized.

Procedures

The progressive exercise test and interval exercise conditions were undertaken on a cycle ergometer (Lode Excalibur Sport, Lode BV Groningen, The Netherlands). The progressive exercise test commenced at 25 W with increments of 25 W every min which was achieved via a progressive ramp protocol to the limit of tolerance. The starting level and increments were chosen to enable participants to reach their peak/ maximal level within 10 ± 2 min as recommended in exercise testing guidelines (ACSM, 2006) with participants encouraged to keep a cycle cadence of 60 – 80 $rev.min^{-1}$. During the progressive exercise test, expired gases were collected continuously via Douglas bag technique. Throughout the test participants wore a chest strap and HR was measured by short range telemetry (Vantage, Polar, Electro Oy, Kempele, Finland). Expired gas was collected at 1 min intervals for the first 7 min and every 30 s thereafter with procedures described previously (James & Doust, 1998).

The determination of $\dot{V}O_{2peak}$ was taken as the highest value recorded in any full 30 s prior to the participant's volitional termination of the progressive exercise test, or at the point of test termination by the assessor due to a large drop in cadence below 60 $rev.min^{-1}$, and the inability of the participant to cycle proficiently. The fulfillment of a maximum effort was based on other assessment criteria, including the rate of perceived exertion (RPE) ≥ 19 (Borg, 1998), 220 – age (± 10 beats) (ACSM, 2006), and the respiratory exchange ratio (RER) > 1.1 (Issekutz, Birkhead, & Rodahl, 1962). The determination of HR_{peak} was taken as the maximal HR (5 s average) recorded immediately prior to the termination of the progressive exercise test. The determination of WR_{max} was taken as the maximal work rate achieved immediately prior to the termination of the progressive exercise test.

The % of WR_{max} for each individual was determined by quantifying the % from each participant's WR_{max} achieved during the progressive exercise test. Work done was equivalent across exercise conditions, and resulted in the length of each individual exercise bout for the 75% WR_{max} exercise condition being 138 s while the length of each individual exercise bout for the 40% WR_{max} exercise condition was 258 s. A 5 min warm up and cool down was undertaken at 60 W at a cadence of 60 – 80 $rev.min^{-1}$ pre and post the exercise condition. Seven bouts at % of WR_{max} were undertaken interspersed with active recovery of 3 min at 60 W between each bout. The WR was controlled independently of cadence and participants were encouraged to keep a cadence of 60 – 80 $rev.min^{-1}$ throughout the testing. The RPE data (Borg, 1998) was recorded at the end of each exercise bout and stored for later analysis. The total duration was 44 min 06 s for the 75% WR_{max} exercise condition and 58 min 06 s for the 40% WR_{max} exercise condition. During the control condition the participants sat quietly reading. Following the two exercise conditions and control condition, 100 ml water was provided at set intervals to ensure gastric emptying had occurred prior to the measurement of outcomes.

During supine condition, participants lay on a tilt bed (Model 501, Plinth 2000, Stowmarket, Suffolk, UK) in a horizontal position and rested for 20 min before data collection. The tilt maneuver was undertaken at a 60º upright tilt following reinstatement of signal acquisition with data collected on achievement of tilt position. All tilt procedures were undertaken with consideration for the accepted guidelines for tilt table testing (Benditt et al., 1996; Parry et al., 2009). The tilt maneuvers were undertaken following supine data collection to ensure cardiovascular outcomes were not influenced prior to supine conditions.

Data collection

Continuous 10 min collections of R-R interval data and beat by beat BP data were undertaken while participants were in supine and tilt positions. A three lead ECG chest attachment (Absolute Aliens Oy, Turku, Finland) was attached to the participants' chest and R-R interval measures were attained from the recorded ECG. The collection of beat-by-beat non-invasive BP signal data was determined via the volume-clamp method (Portapres Model-2, FMS, Finapres Medical Systems BV, Amsterdam, The Netherlands). Following the application of an appropriate finger cuff size to the left hand middle phalanx of the middle finger, BP was determined with the hand kept at heart level throughout the measurement process.

Data analysis

The signal data were fed into an acquisition system (WinAcq, Absolute Aliens Oy, Turku, Finland) where the signals were interpolated and relayed to a laptop computer (Tecra S1, Toshiba, Finland) using a sampling rate of 800 Hz and stored for later analysis. The data were processed with dedicated software (WinCPRS, Absolute Aliens Oy, Turku, Finland) and both time (BRS_{UpUp} and $BRS_{DownDown}$) and spectral ($BRS_{\alpha LF}$ and BRS_{TFTG}) analyzes of BRS were undertaken. The software calculated the moving average of the signal over the data range (.05 s) for the BP data. The ECG data was filtered using a Butterworth low pass filter at 45 Hz to reduce noise and minimize any measurement error. R-R intervals were calculated from the ECG signals and the data was visually inspected to identify and correct any irregular or missing R-R intervals. BP data signals were generated and the R-R interval signal data and SBP signal data was utilized to produce BRS measures. Three analysis techniques for BRS determination were employed and have been described previously (Bertinieri et al., 1988; De Boer, Karemaker, & Strackee, 1987; Pagani et al., 1988; Parati, Di Rienzo, & Mancia, 2000; Robbe et al., 1987). The software detected and identified spontaneously occurring sequences in the time domain in which SBP and R-R interval concurrently increased or decreased over three or more consecutive beats. Sequences were calculated from increasing SBP and lengthening of R-R interval indices (BRS_{UpUp}) and decreasing SBP and shortening of R-R interval indices ($BRS_{DownDown}$) with minimal sequence specificity for accepted change of 1 mmHg for SBP and 5 ms for R-R interval and a correlation of > .85. The software calculated the square root of the ratio of RRI and SBP powers in LF region ($BRS_{\alpha LF}$) and the mean transfer gain (BRS_{TFTG}) in SBP and RRI signals following a specific change in SBP where the coherence value was ≥ .05.

Statistical analysis

Following initial assessment of the ratio data, Kolmogorov-Smirnov tests were undertaken to test for normal distribution. All statistics were $p > .05$ indicating the data could be considered normally distributed and therefore could be analyzed using parametric statistics.

Using SPSS version 16.01, the interaction between time and condition was examined using a 3 (condition: no exercise, 40% WR_{max} and 75% WR_{max} exercise) x 6 (time: baseline, +15, +60, +120, +180 min and +24 h in supine and tilt) factor fully repeated measures ANOVA. A correction factor was applied to produce a valid *F* ratio and multicollinearity was assessed and found to be acceptable. The main effect of time and condition was examined with one-way repeated measures ANOVA. Statistically significant effects ($p < .05$) were explored with post-hoc t-tests (with Bonferoni adjustment) to locate where differences lay.

Results

Exercise bout HR response

Heart rate data was captured every 5 s and averaged over each exercise bout. The 40% WR_{max} exercise condition evoked mean heart rates of 61 - 69% of HR_{peak} (moderate intensity exercise) and the 75% WR_{max} exercise evoked mean heart rates of 73 - 88% of HR_{peak} (high intensity exercise).

BRS response following exercise

The BRS outcomes and statistical outcomes (p values) are summarized in table 1 and table 2 respectively. A significant interaction between time and condition in supine was found for $BRS_{\alpha LF}$ $F(3, 134) = 5.19$, $p < .05$, ES = .39 and BRS_{TFTG} $F(3, 134) = 5.65$, $p < .05$, ES = .41 (table 2). In tilt, a significant interaction between time and condition was found for BRS_{UpUp} $F(3, 134) = 3.54$, $p < .05$, ES = .31, $BRS_{DownDown}$ $F(3, 134) = 5.94$, $p < .05$, ES = .43, $BRS_{\alpha LF}$ $F(4, 134) = 6.23$, $p < .05$, ES = .44 and BRS_{TFTG} $F(4, 134) = 9.22$, $p < .05$, ES = .54 (table 2). Post-hoc analysis indicated there were significant differences between all conditions (with the exception of $BRS_{DownDown}$) at + 15 min, and between control and 75% WR_{max} and between 40% WR_{max} and 75% WR_{max} conditions at + 60 min following exercise (table 2). At + 15 min, BRS was lower in the 75% WR_{max} condition compared with the 40% WR_{max} and the control condition, and the 40% WR_{max} condition was lower than the control condition (table 1). No clear pattern of change was found between exercise conditions at baseline, + 120 min, + 180 min, and + 24 h.

Table 1

BRS Parameters prior to and at 15, 60, 120, 180 min and 24 h following the three conditions of Control (no exercise), 40% WR_{max} and 75% WR_{max}

BRS (ms/mmHg) (± SD)									
	Baseline			15 min			60 min		
	C/Condition	*40% WR max*	*75% WR max*	*C/Condition*	*40% WR max*	*75% WR max*	*C/Condition*	*40% WR max*	*75% WR max*
$BRS_{Up/Up}$ (S)	32.18 (14.45)	25.23 (11.44)	25.50 (10.37)	33.97 (13.35)	21.49 (7.69)	11.50 (9.74)	30.71 (20.27)	25.86 (12.42)	21.09 (14.24)
$BRS_{Up/Up}$ (T)	9.83 (2.53)	10.24 (2.05)	10.33 (3.00)	11.53 (3.90)	10.74 (4.71)	7.60 (2.69)	12.10 (3.99)	10.57 (3.53)	8.73 (2.58)
$BRS_{DownDown}$ (S)	27.30 (10.33)	23.08 (10.64)	24.01 (9.79)	30.93 (17.60)	20.41 (7.60)	11.38 (10.01)	24.64 (5.94)	23.51 (7.77)	18.91 (7.40)
$BRS_{DownDown}$ (T)	8.13 (2.76)	9.11 (4.10)	7.97 (2.69)	10.00 (3.56)	7.62 (4.29)	4.90 (3.16)	9.08 (3.74)	7.14 (3.11)	5.44 (1.81)
$BRS_{\alpha LF}$ (S)	13.88 (6.42)	15.09 (5.96)	16.34 (8.92)	23.10 (8.49)	15.82 (6.11)	7.37 (6.42)	21.04 (4.01)	13.90 (5.51)	12.05 (5.09)
$BRS_{\alpha LF}$ (T)	8.86 (2.17)	9.49 (2.45)	8.78 (2.21)	10.17 (2.60)	8.63 (2.56)	5.28 (2.62)	9.91 (2.69)	8.97 (3.01)	6.81 (2.05)
BRS_{TFTG} (S)	15.07 (5.48)	16.00 (5.82)	17.26 (6.51)	24.65 (8.67)	14.43 (5.73)	6.96 (5.38)	20.7 (5.73)	17.66 (7.66)	12.12 (6.06)
BRS_{TFTG} (T)	7.92 (2.06)	8.36 (2.30)	8.09 (2.02)	10.14 (2.42)	8.25 (3.46)	4.92 (2.67)	9.58 (2.58)	8.15 (3.16)	6.23 (1.69)
	120 min			180 min			24 h		
	C/Condition	*40% WR max*	*75% WR max*	*C/Condition*	*40% WR max*	*75% WR max*	*C/Condition*	*40% WR max*	*75% WR max*
$BRS_{Up/Up}$ (S)	34.54 (13.32)	24.71 (14.56)	23.44 (12.20)	34.66 (11.95)	25.04 (9.72)	24.50 (8.10)	23.30 (9.28)	30.17 (14.53)	28.89 (13.52)
$BRS_{Up/Up}$ (T)	10.46 (3.57)	10.16 (2.83)	9.81 (3.21)	10.12 (2.09)	10.90 (4.62)	10.62 (3.72)	9.61 (2.66)	11.14 (4.23)	11.04 (3.51)
$BRS_{DownDown}$ (S)	23.22 (7.31)	22.57 (8.04)	21.98 (14.24)	25.53 (9.34)	21.09 (7.12)	21.38 (7.92)	20.33 (6.36)	23.21 (8.14)	23.78 (6.55)
$BRS_{DownDown}$ (T)	8.91 (2.37)	7.90 (3.13)	6.80 (2.21)	8.49 (1.84)	8.22 (3.43)	7.59 (2.76)	7.30 (2.09)	9.08 (3.38)	8.37 (2.47)
$BRS_{\alpha LF}$ (S)	19.32 (7.84)	18.18 (8.70)	16.94 (6.04)	19.71 (4.76)	18.81 (7.14)	18.10 (7.99)	16.23 (6.93)	15.97 (6.11)	17.99 (8.77)
$BRS_{\alpha LF}$ (T)	10.04 (2.58)	9.04 (2.09)	8.54 (2.67)	9.93 (2.44)	9.68 (3.11)	9.43 (5.01)	8.23 (2.34)	10.01 (3.18)	9.39 (2.29)
BRS_{TFTG} (S)	19.10 (6.42)	16.30 (7.04)	16.29 (5.95)	19.36 (5.07)	17.96 (7.04)	16.88 (7.22)	15.23 (5.98)	17.67 (5.71)	16.80 (6.53)
BRS_{TFTG} (T)	9.51 (2.25)	8.41 (2.28)	7.82 (2.45)	9.15 (1.91)	9.23 (3.48)	9.19 (4.52)	7.29 (2.00)	9.26 (3.00)	8.94 (2.59)

Note: Parameters are group mean. SD is standard deviation; Seq is sequence; LF is low frequency; TFTG is transfer function transfer gain; (S) is supine (T) is tilt

Table 2

Supine and Tilt BRS Statistical Outcomes (p values) for Interaction, Main Effects and Condition Comparisons prior to and at 15, 60, 120, 180 min and 24 h following three conditions of Control (no exercise), 40% WR_{max} and 75% WR_{max}

Variable	Interaction	Main Effect		Condition Comparison							
SUPINE	Condition x Time	Condition	Time	Control vs 40%	Control vs 75%	40% vs 75%	Control vs 40%	Control vs 75%	40% vs 75%	Control vs 40%	Control vs 75%
					Baseline			+ 15 min			+ 60 min
BRS_{UpUp}	.082	*.032*	.327	.125	.148	.946	*.025*	*.006*	*.012*	.587	.338
$BRS_{DownDown}$	.058	.084	.491	.148	.335	.714	.175	*.019*	*.025*	.729	.104
$BRS_{\alpha LF}$	*.006*	*.032*	.136	.608	.344	.667	.054	*.007*	*.023*	*.013*	*.004*
BRS_{TFTG}	*.004*	.078	.291	.671	.373	.619	*.010*	*.003*	*.027*	.530	.066
					+ 120 min			+180 min			+ 24 h
BRS_{UpUp}				.106	.082	.667	*.048*	*.013*	.791	.087	.191
$BRS_{DownDown}$				.851	.839	.841	.169	.174	.904	*.027*	.137
$BRS_{\alpha LF}$				.675	.258	.492	.622	.493	.601	.879	.562
BRS_{TFTG}				.452	.472	.993	.443	.132	.613	.060	.396
TILT	Condition x Time	Condition	Time	Control vs 40%	Control vs 75%	40% vs 75%	Control vs 40%	Control vs 75%	40% vs 75%	Control vs 40%	Control vs 75%
					Baseline			+ 15 min			+ 60 min
BRS_{UpUp}	*.027*	.453	.602	.683	.682	.907	.637	*.031*	*.006*	.275	.051
$BRS_{DownDown}$	*.004*	.151	.192	.560	.877	.182	.202	*.008*	*.004*	.154	*.019*
$BRS_{\alpha LF}$	*.001*	.084	.119	.537	.912	.299	*.024*	*.001*	*.001*	.373	*.008*
BRS_{TFTG}	< *.001*	.070	.154	.645	.790	.679	*.046*	< *.001*	*.001*	.150	*.005*
					+ 120 min			+180 min			+ 24 h
BRS_{UpUp}				.787	.612	.525	.609	.737	.808	.095	.175
$BRS_{DownDown}$				.370	.050	.051	.828	.396	.173	.070	.148
$BRS_{\alpha LF}$				.280	.157	.263	.785	.751	.786	*.015*	.084
BRS_{TFTG}				.187	.078	.060	.933	.981	.944	*.006*	*.010*

Note: LF is low frequency; TFTG is transfer function transfer gain; WR_{max} is work rate maximum; *italics* denotes statistical significance ($p < 0.05$)

Discussion

The main finding in the present study was the influence of exercise and exercise intensity on the BRS response in the short term recovery period (+ 15 min and + 60 min). Baroreflex sensitivity was not immediately restored following exercise in either condition with differing magnitude of response between the moderate and high intensity conditions indicating an intensity-dependent autonomic influence. A longer recovery period (+ 60 min) with a greater reduction in the magnitude of the BRS outcome measures was observed following the high intensity exercise condition compared to the relatively short recovery period (< 60 min) and marginal reduction in the magnitude of BRS outcome measures following the moderate intensity exercise condition. This pattern of recovery was observed across the spectral BRS outcome measures in supine and across both the time and spectral indices in tilt. By + 120 min all BRS values for both exercise conditions had returned to near baseline levels. Previous research has shown that a single bout of exercise alters BRS temporarily (Convertino & Adams, 1991; Halliwill et al., 1996; Niemelä et al., 2008; Piepoli et al., 1993; Ploutz et al., 1993; Raczak et al., 2005; Somers et al., 1985; Stuckey et al., 2012; Terziotti et al., 2001) although the role of exercise intensity on autonomic dynamics is unclear. Although previous studies have included various intensities of exercise, testing procedures have not provided an explicit identification of intensity of exercise in the intervention procedure or incorporated a tilt maneuver and the methodological differences between studies have made comparison of findings difficult. However, previous studies have reported a decrease in BRS lasting ≤ 20 min (Halliwill et al., 1996; Somers et al., 1985) and > 2 hr (Stuckey et al., 2012) following exercise and provide supporting evidence that an altered autonomic influence may be dependent on the intensity or volume of exercise (Niemelä et al., 2008; Stuckey et al., 2012) with such change more apparent in measures incorporating an orthostatic maneuver (Stuckey et al., 2012).

In the present study, a greater sympathetic influence was suggested immediately following exercise in both exercise conditions which was more pronounced following the high intensity exercise condition. Evidence for a strong sympathetic influence following high intensity exercise was implied by the marked reduction in BRS across all BRS indices in tilt (table 1). In healthy individuals the active change from supine to upright during tilt increases HR and the autonomic balance changes from a parasympathetic predominance in supine to one of increased sympathetic influence when upright (Aubert, Seps, & Beckers, 2003) and is reflected by a relative decrease in HF and relative increase in LF of R-R interval and an increase in LF spectrum of BP (Bernardi et al., 1997; Radaelli et al., 1994). An increase in LF dominance post exercise compared to baseline measures may indicate increased sympathetic activity (Bernardi et al., 1997) which may only be revealed by employing an orthostatic maneuver (Mourot, Bouhaddi, Tordi, Rouillon, & Regnard, 2004). Indeed, findings from the present study suggest evidence provided under a stressor (i.e., tilt) furnished greater insight into autonomic reactivity following exercise than supine measures alone, indicating tilt testing may provide a more sensitive BRS outcome measure (Bernardi et al., 1997) and thus, a greater ability to detect genuine change following exercise.

The determination of BRS may be undertaken by various techniques which are characterized by distinct features (Parati et al., 2000). These features may provide variation in the magnitude of the BRS outcome measure which could reduce or improve the ability to observe genuine change in BRS. The present study employed the modern method and techniques for BRS determination which included both time and spectral indices (LF). The spectral BRS measures appear more robust (tables 1, 2) which may be due to a reduced influence of parasympathetic activity on BRS indices and the determination properties of the measure (Reynolds et al., 2016). These findings imply the employment of BRS spectral measures under supine and tilt testing conditions may provide a more effective method for the assessment of BRS following exercise.

A number of studies have reported an enhancement in BRS following exercise (Convertino & Adams, 1991; Halliwill et al., 1996; Raczak et al., 2005; Somers et al., 1985), while the present study and other previous studies found a general attenuation in BRS following exercise (Niemelä et al., 2008; Piepoli et al., 1993; Stuckey et al., 2012). Enhanced BRS is suggestive of a parasympathetic predominance while a reduction in BRS is associated with greater sympathetic influence. The findings in the present study suggest a greater disturbance in autonomic balance over a longer duration following high intensity exercise compared to moderate intensity exercise.

In order to attain equal work done across two exercise conditions, the duration of exercise differed. The influence of duration of exercise on post-exercise BRS has not been established although no significant difference in cardiac autonomic control assessed via HRV was observed following 20 min and 60 min bouts of moderate intensity exercise (James, Reynolds, & Maldonado-Martin, 2010). Thus it is considered unlikely that the observed BRS changes were significantly influenced by the variance in duration of exercise, although this cannot be discounted.

In conclusion, to our knowledge the present study is the first to explicitly investigate the effect of the intensity of exercise on the post-exercise BRS response. The findings indicate there is an intensity effect on post-exercise BRS with a greater magnitude in the reduction in BRS and longer recovery period following high intensity exercise compared to moderate intensity exercise. Future research should track the time course for change of BRS following exercise after a given exercise bout to establish the duration of such change and incorporate both supine and tilt BRS outcome measures to improve elucidation for the post-exercise BRS response.

What does this article add?

Previous research investigating the direction and magnitude of change in BRS following a single bout of exercise is inconclusive, particularly with regard to the recovery of BRS indices in the short and long term following exercise. The present study undertook an original approach with the assessment of BRS and included a tilt maneuver to achieve a more sensitive outcome measure. The present study also specifically delineated intensity of exercise as the cursor for change because intensity of exercise is considered to be a possible factor for alterations in autonomic influences of the heart. The findings are important because they have provided a novel insight into the reactivity of BRS following exercise. Accordingly, more research is needed to ascertain the BRS response following exercise in diverse populations to ascertain differences in age, sex or training status.

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