THE EFFECTS OF RECOVERY GARMENT ON HEART RATE VARIABILITY FOLLOWING THE MAXIMAL AEROBIC EXERCISE TEST

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Part I

Introduction

Optimization of recovery from physical and mental fatigue is critical to maximize the training effects of exercise and improve subsequent performance (Chartard et al., 2004; Kellmann et al., 2010; Monedero et al., 2000). During exercise, the sympathetic nervous system is more active in order to prepare the body for activity. During the recovery period, the parasympathetic nervous system is responsible for returning the body to its resting state (Arai et al., 1989; Imai et al., 1994; Nunan et al., 2010). Disruption of the dynamic balance between sympathetic and parasympathetic function may prolong post-exercise fatigue (Freeman et al., 1997; Hautala et al., 2009; Hynynen et al., 2006; Leti et al., 2012). Autonomic recovery can be evaluated noninvasively using heart rate variability (HRV) in order to investigate autonomic nervous system function, which is related to cardiac regulation following exercise (Goldberger et al., 2006; Leti et al., 2012; Nunan et al., 2010; Task force 1996). Metabolic responses such as blood lactate and pH levels in working muscles have also been used as indicators of exercise-induced fatigue (Connolly et al., 2003; Juel et al., 1998; Richardson et al., 1998; Sahlin et al., 1998; Westerblad et al., 2002). However, the results of a previous study indicated that fatigue induced by supramaximal exercise was related to delayed parasympathetic reactivation rather than metabolic and ionic accumulation (Leprêtre et al., 2011). Thus, measurement of HRV appears to be a logical choice to examine the recovery status after exercise.

A number of methods have been proposed and implemented as post-exercise recovery protocols. Active recovery has been reported to be more effective to facilitate

blood lactate removal and heart rate recovery than passive recovery (Ali Rsooli et al., 2012; Bastos et al., 2012; Ferreira et al., 2011; Martin et al., 1998; Monedero et al., 2000; Rimaud et al., 2010; Toubekis et al., 2008). Active recovery is characterized as an implementation of low- to moderate-intensity aerobic exercise immediately after vigorous exercise. Exercising in such intensity increases blood circulation via vasodilation, which raises the rate of oxygen delivery to skeletal muscles (Bastos et al., 2012; Monedero et al., 2000).

Use of compression garments has also been proposed as a method to enhance post-exercise recovery (Chatard et al., 2004; Davies et al., 2009; Duffield et al., 2010; Lovell et al., 2011; Maton et al., 2006). Application of compression garments is believed to increase blood flow by increasing venous return (Ibegbuna et al., 2003; Watanuki et al., 1994), and thus helps the removal of waste products similar to the principle of active recovery (Davies et al., 2009). Previous research on such garments has utilized the compression garments during both active and passive recovery (Chatard et al., 2004; Davies et al., 2009; Duffield et al., 2010; Lovell et al., 2011; Maton et al., 2006). However, the additive effects from such garment for blood lactate removal and post-exercise recovery has been inconsistent (Davies et al., 2009; Duffield et al., 2010; Maton et al., 2006).

A new type of recovery garment (not a compression garment), made of a nano-platium and nano-diamond (DVP576) coated fabric, has recently been introduced. Unlike compression garments, the DVP576-coated recovery garment was designed to be worn only during passive recovery. The manufacturer claims that the application of such a garment can enhance the post-exercise recovery by increasing parasympathetic tone.

Although there is one unpublished study conducted with the DVP576-coated garment on HRV following a short bout of maximal anaerobic exercise (Gomyo, 2012), the effect of this material on autonomic function following a maximal aerobic exercise protocol has not been investigated.

Therefore the purpose of this study was to examine the effects of the DVP576-coated recovery garment on HRV, perceived recovery scale (PRS) (Laurent et al., 2011), fatigue rating scores (FRS) (Kim et al., 2010), and heart rate recovery during 30-minute passive recovery period following maximal aerobic running protocol designed to induce fatigue in physically active, healthy, untrained young male adults.

Methods

Research Design

A single-blind experimental protocol with randomized trials was designed to investigate the effects of the DVP576-coated recovery garment following fatigue induced by maximal aerobic exercise. The independent variables consisted of the experimental conditions (recovery garment and control garment), and data collection time periods. The dependent variables consisted of indices of HRV, PRS scores, FRS and heart rate recovery (time for resting values to plateau).

Participants

Fifteen (n=15) healthy males, ranging in age from 18 to 34 years old, volunteered as participants from University of Hawaii at Manoa and surrounding Honolulu community in this study. Exclusionary criteria included: neurological diseases, cardiopulmonary diseases, and exercise contraindications as outlined by American College of Sports Medicine (Appendix B). An informed consent form (Appendix A) approved by the University of Hawaii Human Studies Program was signed by all participants prior to the study.

Recovery and Control Garments

All garments used in this study were provided by Venex Co., Ltd. (Kanagawa, Japan). The participants were blinded as to which garments had the DPV576 materials. Experimental recovery garment (RG) shirt and full-length tights consisted of polyester (with DPV576 fiber materials) and polyurethane. The control garment (CG) consisted of

polyester and polyurethane without DPV576 materials. Both garments were similar in appearance and texture with the labeled tag inside the garments to indicate the control garment. Both garments were washed after each trial and used again for subsequent trials.

Experimental Procedure

The testing sessions were performed in the climate controlled Human Performance Laboratory at University of Hawaii at Manoa. Upon arrival the participants were given an informed consent form and Pre-Participation Medical History Form/ Physical Activity Readiness Questionnaire (Appendix F) to fill out. The American College of Sports Medicine (ACSM) guidelines for contraindications and termination of exercise testing were strictly followed (Whaley, 2001). An investigator walked through all testing procedures with each participant to familiarize them with the testing protocol.

The same Board of Certification Certified Athletic Trainer collected all data. Anthropometric data, including body mass, height and blood pressure, were collected and recorded prior to each testing session. Height (cm) was measured using the stadiometer, and body mass (kg) was measured using the Detecto Certifier scale (Detecto, Webb City, MO, USA). Following the anthropometric measurements, the participants were instructed to sit on a treatment table for electrode placement. The right and left arm electrodes were placed below the right and left clavicles, respectively. The right and left leg electrodes were attached to the right and left sides of the trunk, below the tenth rib on the anterior axillary line. The V_5 chest electrode was placed on the left side in the fifth intercostal space on the anterior axillary line. The investigator cleaned electrodes

placement sites with an alcohol prep. The participants were asked to lie supine on a treatment table and relax for 20 minutes prior to a maximal graded exercise testing (GXT). During this time, participants were asked to breathe at their normal self-determined pace while the investigator collected and monitored the ECG. The participants were supine and covered with a blanket for comfort during measurement of the ECG. The inter-beat intervals were recorded for last 5 minutes to determine indices of HRV. The HRV was evaluated twice (Pre- and Post-GXT) for each subject in each testing session (a total of four times). The ECG data were collected using CARDIO-CARD ver. 6.01ia software (Nasiff Associates, Inc., Brewerton, NY, USA), and HRV time and frequency domains data were obtained using Kubios Heart Rate Variability ver. 2.1 software (Biosignal Analysis and Medical Imaging Group, Dept. of Physics, University of Kuopio, Finland). The resting HR was measured prior to the GXT using the heart rate monitor (Polar Heart Rate Monitor FT1 Wrist Receiver/ T31 Transmitter, Oulu, Finland). Once the ECG was successfully recorded, the investigator removed the ECG leads prior to start GXT. Electrodes were kept in place for the duration of the data collection session.

A GXT was performed as maximal aerobic exercise test on the Quinton Medtrack T65 Treadmill (Cardiac Science, Corp., Bothell, WA) in a climate controlled laboratory setting to induce fatigue. The GXT, which was a modified version of Astrand Protocol (Stickley et al. 2008), consisted of two running bouts and 3-minute active recovery period. Standard instructions were given prior to each test as to the importance of maximal effort by the participant. Metabolic data were collected by a metabolic cart (TrueOne 2400 Metabolic Measurement System, ParvoMedics, Inc., Sandy, Utah, USA).

The metabolic cart was calibrated prior to each test with a commercially obtained calibration gas mixture (Airgas Specialty Gases, Inc., Lenexa, Kansas, USA). In the first running bout, the participants determined a running speed for the GXT between 5 and 8 miles per hour corresponding to a comfortable pace. Participants were blinded to the speed of the treadmill throughout the testing procedure. The subjects started at 0% grade and the grade was increased 2.5% every 3 minutes. The first running bout was stopped based at the point of volitional exhaustion for each participant. Upon completion of the first running bout, participants were given a three-minute active recovery at 1% grade on the treadmill at a self-selected walking pace. Following the active recovery period, subjects participated in the second running bout. Treadmill speed increased to a velocity predicted to elicit 80% of maximal oxygen consumption (VO_{2max}) at 1% grade as determined by ACSM equations for estimating oxygen consumption (Whaley, 2001). Participants continued running at the prescribed speed and the grade was increased 2.5% every 3 minutes until voluntary exhaustion. Heart rate and ratings of perceived exertion (RPE) scores (Borg. 1970) were collected at the end of each testing stage.

Immediately after a completion of the GXT, participants were instructed to change into either RG or CG as quickly as possible. Subsequently, participants laid down supine and rested for 30 minutes on a treatment table next to the treadmill. The investigator timed the length of time for changing into garments and measured HR immediately after garment application. After the GXT, the ECG leads were reconnected to the same electrodes by the investigator. The investigator recorded ECG data every 5 minutes until the end of the 30-minute recovery period. The perceived recovery status (PRS) scale (Laurent et al., 2011) and fatigue rating scores (FRS) (Kim et al., 2010) was

taken every 5 minutes after post-garment application. Post-GXT HR was measured immediately and every 5 minutes after post-garment application in order to determine the heart rate recovery response. If HR does not reach a plateau in the 30 minute recovery period, the participant continued to be monitored until HR plateaued.

In order to compare the two conditions (RG vs. CG), the participants performed a total of two testing sessions that were separated by at least 7 days and not more than 10 days. Garment application was assigned in a counter-balanced order and the participants were blinded as to which garment they would be wearing.

Statistical Analysis

Data were analyzed by using SPSS version 22 (IBM Inc., Chicago, IL). Descriptive statistics and correlations were generated. Paired t-tests were performed to determine if differences existed in $VO2_{max}$, exercise time, or RPE. Multiple two-way Analyses of Variance (ANOVA) with repeated measures were conducted with two within-subject factors (condition and time) for each dependent variable. Dependent variables included: HRV time domain and frequency domain measures, HR recovery, PRS scores, and FRS. Post hoc analyses were conducted when significant differences in main effects and interaction effects were detected. Statistical significance was determined at alpha level of $p \leq 0.05$.

RESULTS

Heart Rate and Heart Rate Variability

The demographic data of the 15 male subjects are presented in Table 1. Averaged HR and HRV data were collected before and after maximal aerobic exercise trial.

Table 1. Participant Demographics (Mean ± SD) and VO2max, Exercise Time, and RPE ($p \leq .05$)

Gender	Age (years)	Height (cm)	Weight (kg)	VO2max (kg/ml/min)			Exercise Time (min' sec")			RPE (Overall)		
				RG	CG	t-test	RG	CG	t-test	RG	CG	t-test
Male (n=15)	24.1 ±3.9	175.0 ±4.9	74.9 ±10.7	46.9 ±6.1	45.2 ±4.2	t=1.82 p=0.090	19'22" ±2'03"	20'02" ±2'01"	t=–1.34 p=0.199	16.3 ±2.6	16.6 ±2.4	t=–0.92 p=0.371

RG=Recovery Garment, CG=Control Garment, RPE=ratings of perceived exertion

The average HR during recovery periods for both conditions was presented in Table 2. Examination of post-exercise HR revealed a significant main effect only for time ($p \leq .05$). There was no interaction between condition and time in the HR values. Likewise, despite the significant main effect for time ($p \leq .05$), no interactions were found for either HRV time or HRV frequency domain variables between garments (Table 3 and 4).

Table 2. Summary Table for Averaged Data for HR (Mean ± SD) and Comparison between time, condition, and time by condition for HR ($p \leq .05$)

	Condition	Resting	Peak HR	5min Post	10min Post	15min Post	20min Post	25min Post	30min Post	F-value		
										Time	Condition	Time x Condition
HR (bmp)	RG	62.0 ±11.4	186.0 ±10.2	97.1 ±8.3	93.9 ±7.3	91.5 ±8.1	88.3 ±9.2	86.9 ±9.6	85.5 ±10.0	173.490 (.000*)	1.349 (.265)	1.376 (.234)
	CG	63.2 ±12.5	185.9 ±7.9	95.7 ±7.6	92.3 ±7.5	89.7 ±8.8	86.3 ±8.0	84.3 ±7.1	82.5 ±6.8			

RG=Recovery Garment, CG=Control Garment bmp=Beats per minute *P≤0.05: Statistically significant

Table 3. Summary Table for Averaged Data (Mean ± SD) and Comparison Between Time, Condition and Time by Condition for Time Domain HRV (p≤.05)

	Condition	Baseline	5min post	10min post	15min post	20min post	25min post	30min post	F-value		
									Time	Condition	Time x Condition
Mean RR (msec)	RG	1045.2 ±210.5	608.4 ±51.8	628.7 ±50.9	645.1 ±60.8	666.4 ±66.9	680.9 ±73.4	698.1 ±84.8	82.305 (.000*)	1.017 (.330)	.264 (.952)
	CG	1048.8 ±191.9	613.8 ±51.7	638.9 ±49.0	658.1 ±57.0	677.5 ±56.7	702.6 ±60.2	716.4 ±59.9			
SDNN (msec)	RG	54.5 ±17.0	14.2 ±9.6	10.7 ±4.7	12.1 ±5.7	14.4 ±6.3	16.3 ±7.3	18.1 ±7.2	87.627 (.000*)	.215 (.650)	.515 (.795)
	CG	57.9 ±17.0	13.3 ±7.0	12.2 ±6.6	12.7 ±8.1	15.8 ±8.4	16.2 ±6.8	19.4 ±5.7			
rMSSD (msec)	RG	61.8 ±25.7	15.8 ±13.6	10.6 ±8.3	13.4 ±10.3	13.2 ±8.4	15.5 ±6.5	15.6 ±7.6	60.967 (.000*)	.019 (.892)	.288 (.941)
	CG	63.5 ±25.0	13.7 ±10.6	12.4 ±9.5	12.2 ±11.0	14.6 ±11.8	15.5 ±10.1	16.8 ±8.3			
pNN50 (%)	RG	33.8 ±16.9	2.8 ±6.6	1.7 ±5.0	1.0 ±1.7	1.4 ±3.2	1.6 ±2.4	2.3 ±2.2	67.322 (.000*)	.385 (.545)	.321 (.925)
	CG	36.8 ±17.3	2.9 ±6.8	2.0 ±4.8	2.2 ±6.6	2.6 ±7.3	2.7 ±6.1	3.1 ±5.2			

RG= Recovery Garment, CG=Control Garment, MeanRR= mean inter-beat intervals, SDNN= standard deviation of inter-beat intervals, rMSSD= the square root of the mean of the sum of the squares of differences between adjacent NN intervals, pNN50= NN50 count divided by the total number of all NN intervals. *P≤0.05: Statistically significant

Table 4. Summary Table for Averaged Data (Mean ± SD) and Comparison Between Time, Condition, and Time by Condition for Frequency Domain HRV (p≤.05)

	Condition	Baseline	5min post	10min post	15min post	20min post	25min post	30min post	F value		
									Time	Condition	Time x Condition
LF Power (ms^2)	RG	1641.7 ±1176.9	63.9 ±59.2	51.5 ±42.8	106.9 ±118.8	113.1 ±79.1	172.6 ±156.3	199.9 ±189.1	44.899 (.000*)	.001 (.980)	.032 (1.000)
	CG	1626.5 ±988.8	80.2 ±120.9	76.7 ±75.4	90.9 ±94.2	135.0 ±121.3	135.9 ±119.8	214.7 ±168.0			
HF Power (ms^2)	RG	1372.0 ±873.3	48.7 ±61.6	21.9 ±30.1	33.1 ±43.4	35.6 ±41.8	45.5 ±41.8	95.3 ±141.3	31.934 (.000*)	.296 (.595)	.029 (1.000)
	CG	1418.7 ±1156.4	58.2 ±99.9	47.5 ±76.3	55.5 ±134.0	76.6 ±176.9	79.2 ±131.3	97.1 ±92.7			
LF Power (n.u.)	RG	53.7 ±12.6	67.7 ±19.5	71.2 ±17.3	71.7 ±22.0	78.7 ±12.5	72.7 ±17.7	71.4 ±18.1	4.710 (.000*)	.425 (.525)	.430 (.857)
	CG	56.0 ±16.3	66.2 ±24.6	70.1 ±22.2	74.3 ±23.6	70.7 ±21.3	68.5 ±18.0	69.8 ±18.9			
HF Power (n.u.)	RG	46.2 ±12.6	31.8 ±19.6	28.3 ±16.8	28.1 ±21.9	21.1 ±12.5	27.1 ±17.7	28.4 ±18.1	4.875 (.000*)	.442 (.517)	.446 (.846)
	CG	44.0 ±16.3	33.7 ±24.4	29.8 ±22.2	25.4 ±23.2	29.1 ±21.3	31.3 ±17.8	29.8 ±18.3			
LF/HF	RG	1.3 ±0.7	3.3 ±2.7	4.5 ±3.8	5.6 ±3.9	5.2 ±3.2	5.5 ±7.4	4.5 ±4.0	5.772 (.000*)	.179 (.678)	1.306 (.264)
	CG	1.5 ±0.8	4.4 ±3.6	5.2 ±4.7	7.8 ±7.0	5.7 ±4.9	3.4 ±2.8	4.0 ±3.3			

RG=Recovery Garment, CG=Control Garment, LF Power= power in low frequency range, HF Power= power in high frequency range, LF/HF= ratio LF (ms2)/HF (ms2). *P≤0.05: Statistically significant

Perceived Recovery Scale

The averaged scores of PRS are shown in Table 5. While the significant main effect for time was observed ($p \leq .05$), there was no main effect for condition or interaction between condition and time for PRS. The average scores in each time segment with RG were constantly slightly higher than the averaged scores with CG.

Table 5. Summary Table for Averaged PRS Scale Data (Mean ± SD) and Comparison Between Time, Condition, and Time by Condition for PRS ($p \leq .05$)

	Condition	5min post	10min post	15min post	20min post	25min post	30min post	F-value		
								Time	Condition	Time x Condition
PRS	RG	5.3± 1.9	7.0± 1.6	7.9± 1.3	8.5± 1.5	8.7± 1.4	9.0± 1.4	97.747 (.000*)	1.417 (.254)	.333 (.892)
	CG	4.8± 1.3	6.5± 1.6	7.3± 1.8	8.1± 1.6	8.2± 1.5	8.8± 1.1			

RG=Recovery Garment, CG=Control Garment, PRS=scores of perceived recovery status scale. *P≤0.05: Statistically significant

Fatigue Rating Score

A significant main effect for time ($p \leq .05$) was detected in the averaged score of FRS; however, there was no main effect for condition or interaction between condition and time, as presented in Table 6. Lastly, significant negative correlations were constantly observed between PRS and FRS over the course of recovery in both garments (Table 7).

Table 6. Summary Table for Averaged FRS Data (Mean ± SD) and Comparison between Time, Condition, and Time by Condition for FRS ($p \leq .05$)

	Condition	After exercise	5min post	10min post	15min post	20min post	25min post	30min post	F-value		
									Time	Condition	Time x Condition
FRS	RG	8.1 ±1.4	5.1 ±1.4	3.4 ±1.6	2.6 ±1.6	1.7 ±1.4	1.3 ±1.3	1.1 ±1.4	77.517 (.000*)	2.017 (.177)	.993 (.428)
	CG	8.1 ±1.2	5.6 ±1.3	4.1 ±1.4	3.2 ±1.6	2.5 ±1.7	2.0 ±1.4	1.3 ±1.2			

RG=Recovery Garment, CG=Control Garment, FRS=Fatigue rating score *P≤0.05: Statistically significant

Table 7. Summary Table of correlation between PRS and FRS ($p \leq .05$) during the recovery period

	5min	10min	15min	20min	25min	30min	Overall
RG	-0.277	-0.714*	-0.830*	-0.929*	-0.928*	-0.906*	-0.849*
CG	-0.425	-0.593*	-0.699*	-0.791*	-0.827*	-0.749*	-0.834*

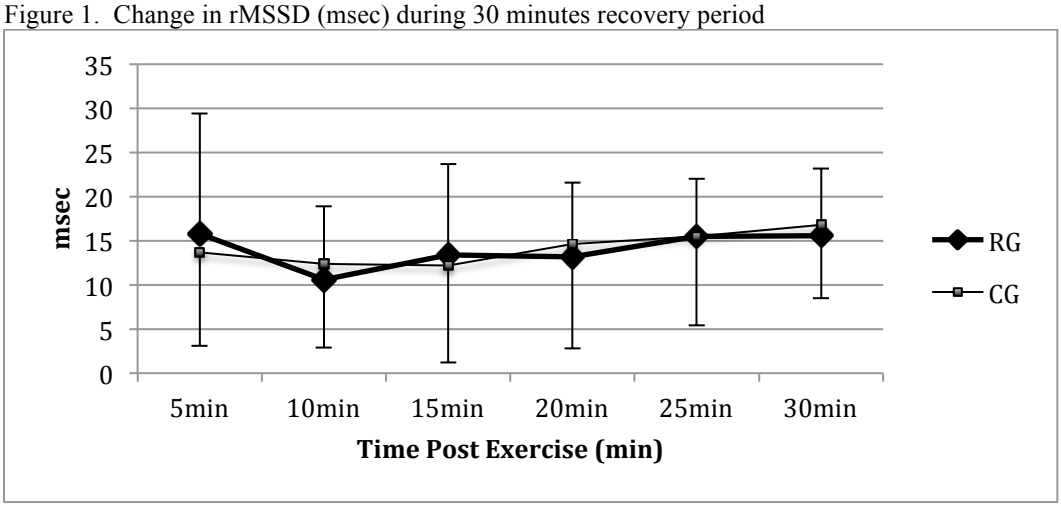
RG=Recovery Garment, CG=Control Garment *P≤0.05: Statistically significant

DISCUSSION

The manufacturer of the RG claims that wearing the RG should enhance the post-exercise recovery by increasing the parasympathetic activity. This theory may be supported by Leprêtre et al. (2011)[27], who reported that fatigue induced by supramaximal exercise results in delayed post-exercise parasympathetic reactivation. With the cessation of the exercise, increased HR drops immediately due to reactivation of parasympathetic nervous system[3,20,33]. During the recovery period HR gradually declined, however it did not reach resting levels by the end of the 30-minute recovery period. This trend has been previously reported by Javorka et al. (2002)[21] and Gomyo (2012)[16].

In the present study both time and frequency domain HRV parameters, especially rMSSD and HF power were investigated as indices for the post-exercise parasympathetic reactivation. The rMSSD was deemed to be an appropriate indicator of parasympathetic activation based on the study by Goldberger et al. (2006)[15], who reported that the rMSSD was effective parameter to assess parasympathetic reactivation. In the present study, time domain HRV indices are very similar between the previous studies in the magnitude and shape of the recovery curve (Figure1).

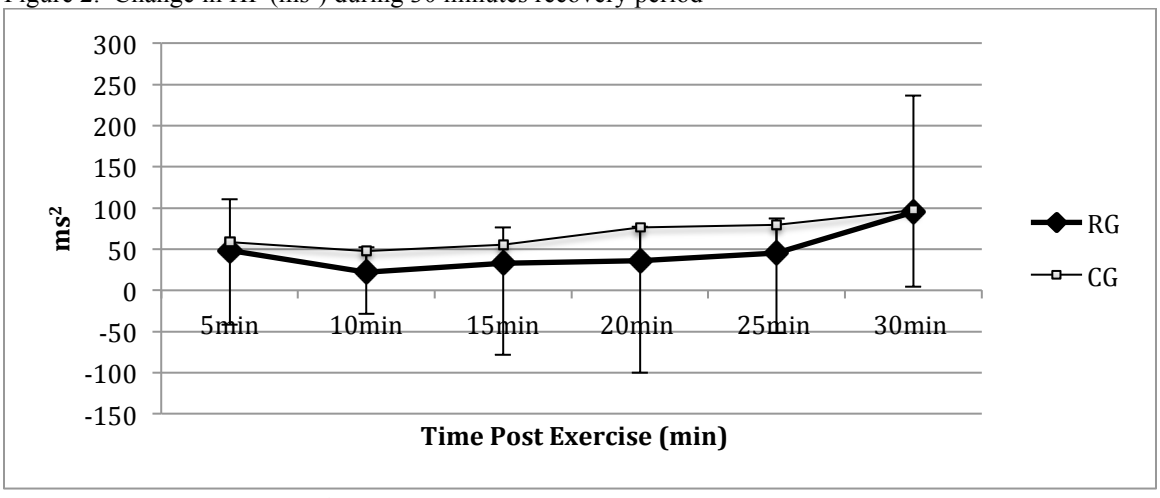
Figure 1. Change in rMSSD (msec) during 30 minutes recovery period



RG=Recovery Garment, CG=Control Garment

Additionally, HF power in the frequency domain has been related to vagal activity[1, 39] and represents parasympathetic modulation[39]. The tendency of HF power decreasing in the early of recovery period and gradually increasing (Figure2) is agreement with Gomyo's study[16]. Natural long transformations for LF and HF power in the present study resulted in the values that were similar in the magnitude and shape of the recovery curve to those reported by Javorka et al (2002)[21] and Gomyo (2012)[16].

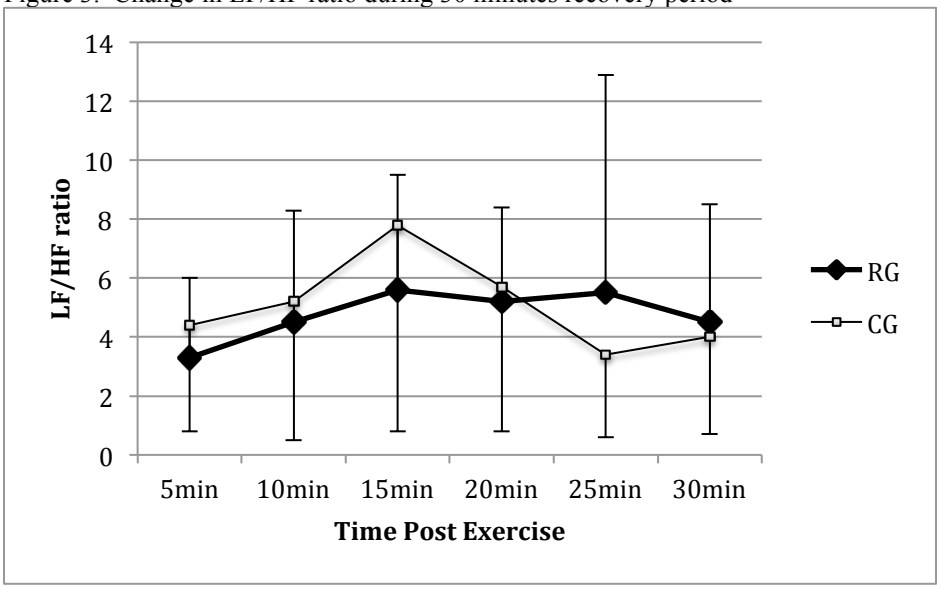
Figure 2. Change in HF (ms^2) during 30 minutes recovery period



RG=Recovery Garment, CG=Control Garment

The ratio of LF to HF (LF/HF) was also used as an index of balance between sympathetic and parasympathetic activity; the ratio less than 1 represents a parasympathetic dominance and the ratio above 1 indicates sympathetic dominance[25]. Although no difference was found between trials (p=0.678), an increase in sympathetic dominance was observed in the first 15 minutes of recovery, followed by a slight decrease indicating a shift toward parasympathetic dominance (Figure3). This trend was similar to the Gomyo's study[16]. Pierpoint et al. (2000)[34] reported a slower autonomic recovery after performing high intensive exercise than after low or moderate intense exercise, because sympathetic activation remained after exercise to contribute to tachycardia. Therefore, data from the present study were judged to be reasonable indices of HRV during recovery.

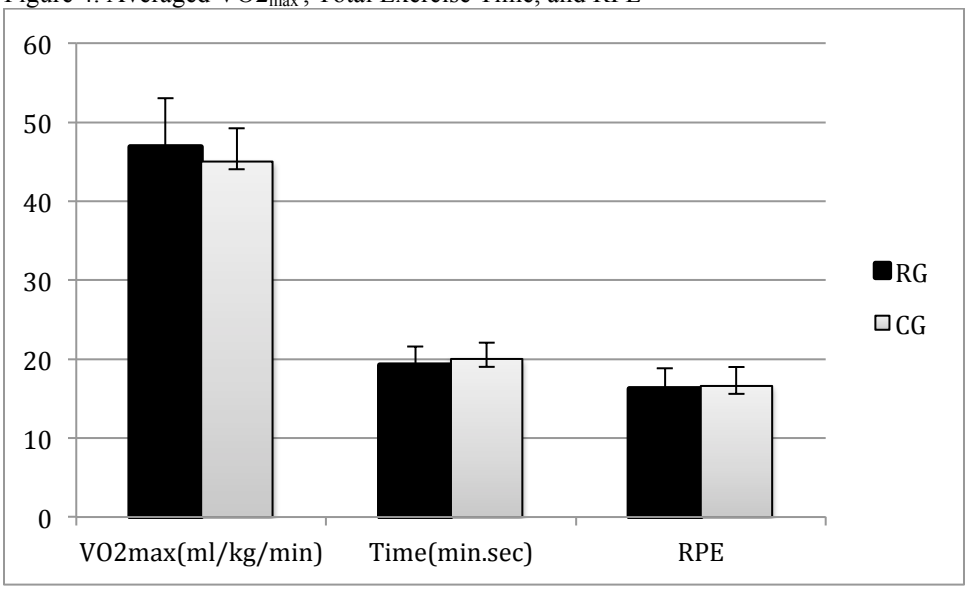
Figure 3. Change in LF/HF ratio during 30 minutes recovery period



RG=Recovery Garment, CG=Control Garment

While running at the same speed, there was no difference in $VO2_{max,}$ total exercise time, or RPE between the trials (Table1 and Figure4), indicating the subjects were able to maintain the comparable effort level during the fatigue protocol for both sessions. Additionally, even though the subjects did not record their daily activity level, subjects were instructed not to change their activity level throughout the duration of their participation. The mean interval between trials was 7.4 days (SD ± 0.9). Table 1 presents mean the VO2max, total exercise time, and overall RPE at the end of exercise on treadmill during modified Astrand test. There were no significant differences between trials ($p>.05$)

Figure 4. Averaged $VO2_{max}$, Total Exercise Time, and RPE

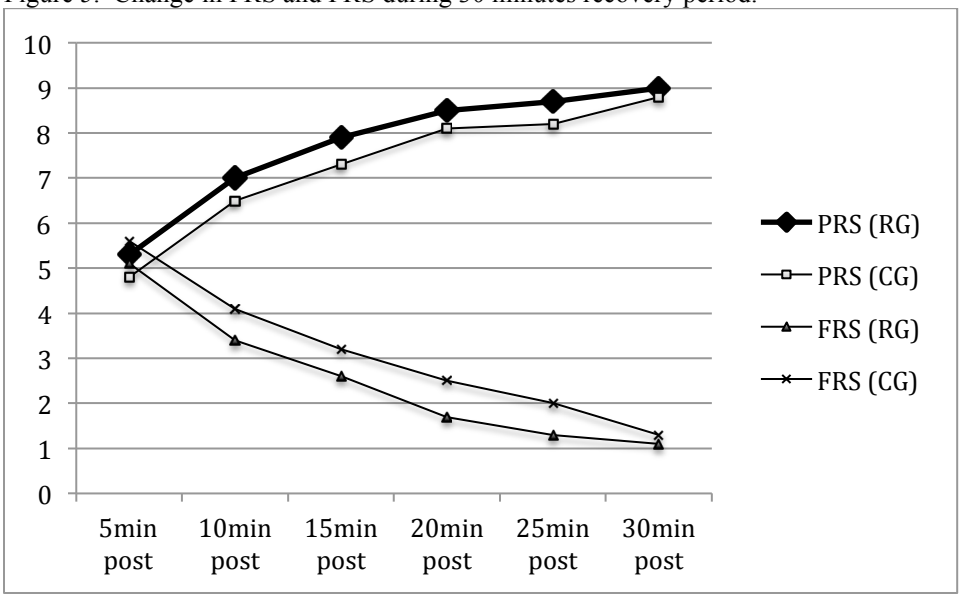


RG=Recovery Garment, CG=Control Garment, RPE=ratings of perceived exertion

In terms of assessment of fatigue status following exercise, Leti et al. (2012)[28] suggested that the use of the combination of the HRV analysis and a questionnaire was useful. The PRS scale was created by Laurent et al. (2011)[26] in order to measure the

individual's perceived recovery after high-intensity exercise. In their study, subjects were asked to rate their recovery level using PRS scale before repeated intermittent sprint trials. They found the negative correlation between the PRS and the sprint performance and concluded that PRS score may be useful to identify the individual's recovery status in terms of the prevention of the overtraining. Similarly, Gomyo (2012)[16] also recorded PRS scale during 30 minutes passive recovery period between two anaerobic exercise tests to determine how much subject had recovered from the previous test. In the present study, PRS scores gradually increased over the recovery period (Table 5). The average scores with RG were constantly slightly higher than the average scores with CG (Figure5). However, there was no significant difference between the garments (p=.254).

Figure 5. Change in PRS and FRS during 30 minutes recovery period.



RG=Recovery Garment, CG=Control Garment, PRS=Perceived Rating Scale, FRS=Fatigue rating score

The FRS was taken immediately after the exercise and at every 5 minutes of post-garment application. Kim et al. (2010)[24] created the real-time digital fatigue score and

compared its utility with the Fatigue Severity Scale and the Modified Fatigue Impact Scale which were used as the methods to retrospectively recall prior week or month fatigue status, respectively. They found that the real-time digital fatigue score proved to be an effective indicator of the subject's fatigue level. In the present study, the average FRS score immediately post exercise was 8.3 ± 1.1 on the 10 point scale and it dropped over the 30-minute recovery period in both groups (Table 6). However, there was no significant difference between groups (p=.177). The relationship between PRS scores and FRS resulted in high negative correlation between trials (Table 7 and Figure 5). These findings suggest the use of both indexes during recovery period will be beneficial to identify an individuals' recovery and fatigue status.

Limitations of the present study included the following; the subjects' health condition was assessed through the use of a questionnaire after signing the informed consent form. No attempt was made to determine if subjects suffered from chronic fatigue. Freeman et al. (1997)[12] investigated the relationship between chronic fatigue syndrome and autonomic nervous system, and they found the group with chronic fatigue syndrome showed alternations on autonomic nervous system function. However, student-athletes who regularly undergo strenuous training were excluded from the present study. Moreover, participants in the present study were not tested for hydration status before the trials, however Castro-Sepúlveda et al. (2015)[6] emphasized it was necessary to control hydration state before HRV assessment.

This was the first study that examined the effect of the DVP576-coated recovery garment on the autonomic function via HRV during 30-minute passive recovery following modified Astrand maximal oxygen uptake test designed to induce fatigue. The

most important finding of the present study was that there was no acute effect on autonomic nervous system function in both RG and CG during post-exercise recovery period. Additionally, there were no significant differences in perceived recovery scale and fatigue rating scale. It was concluded that the RG for increasing parasympathetic tone was no more effective than CG during recovery from strenuous exercise. It was further concluded that the RG did not significantly effect the subjects' perception of recovery or fatigue.

Part II

Review of Literature

Heart Rate Variability as a measurement of Autonomic function

The changes of heart rate (HR) during physical exercise are primarily due to alternations in autonomic nervous system (ANS) activity. During exercise, HR increases due to an activation of the sympathetic nervous system and an inhibition of vagus nerve. Upon the cessation of the exercise, increased HR drops immediately due to reactivation of parasympathetic nervous system[3,20,33]. The parasympathetic nervous system has a crucial role to recovery from exercise. Heart rate variability (HRV) is widely used as an index of ANS activity, especially parasympathetic activity[15,21,27,33,]. In order to analyze HRV, two domain methods have been used; time domain and frequency domain. In the time domain method, the simplest variable calculated from R-R interval of electrocardiographic (ECG) record is the standard deviation of the R-R interval (*SDNN*)[39]. And the most commonly used variables from R-R interval differences include the square root of the mean squared difference of successive R-R interval (*RMSDD or MSDD*), the number of interval difference of successive R-R interval greater than 50ms (*NN50*), proportion derived by dividing NN50 by the total number of R-R intervals (*pNN50*). Another one is frequency domain methods. There are three main spectral factors; very low frequency (VLF, <0.04 Hz), low frequency (LF, 0.04 Hz-0.15 Hz; which represents both parasympathetic and sympathetic modulation), and high frequency (HF, 0.15 Hz-0.40 Hz, which represents parasympathetic modulation)[39]. Both time domain and frequency parameters have been used in the previous literature as affective variables of HRV in examining post-exercise parasympathetic activity.

Goldberger et al. (2006) examined the effectiveness of measuring HRV as the indicator of parasympathetic reactivation after exercise in two subject groups. Group I, which consisted of 10 healthy volunteers (5 men and 5 women; age 33 ± 5 years), performed their maximum capacity. Group II, which consisted of 12 subjects (10 men and 2 women; age 61±10 years) with coronary artery disease, exercised for 16 minutes on two separate conditions. At *day* 2, atropine (0.04mg/kg) was administered in four divided doses (0.01mg/kg every 30 seconds) to both groups during exercise. The ECG data were obtained for 5 minutes immediately after exercise. The researchers determined parasympathetic activity via measuring the R-R interval and compared between the two conditions. The mean R-R interval in each of the segments was calculated and analyzed using multifactorial repeated measures analysis of variance with post hoc analysis. Researchers also used linear regression analysis in order to calculate the correlations of parasympathetic effects to the root mean square residual (RMS), the standard deviation (SD), and the MSSD. Statistical significant difference was determined at $P<0.05$. The findings in this study included that the R-R interval with atropine was significantly shorter than during the baseline recovery period in both group ($P<0.0001$). The HRV without atropine, as measured by the MSDD and RMS, significantly increased early in recovery from 4.1 ± 0.4 and 3.7 ± 0.4 milliseconds in the first 15 seconds to 7.2 ± 1.0 and 7.4 ± 0.9 milliseconds after 1 minute, respectively ($P<0.0001$) compared to those parameters with atropine. The most findings included that both RMS and MSSD were directly related ($r^2 = 0.47$ and 0.56, respectively; $p < 0.0001$) to parasympathetic effect. The authors concluded that RMS and MSSD as parameter of HRV analyze were effective to assess parasympathetic reactivation after physical exercise[15].

Nunan et al. (2010) studied the relationship between short-term resting measures of HRV and prognostic HR responses before, during and after GXT. A 10-minute R-R interval was measured in each of 33 healthy participants in supine position, followed by a GXT using Bruce protocol on treadmill until the point of volitional exhaustion. A peak value (VO_2peak) of maximal oxygen uptake (VO_2max) and HR were obtained during GXT. Upon completion of the GXT, the HR and R-R interval for 10 minutes were recorded in seated position. The post-GXT heart rate recovery (HRR) was also calculated from the difference between peak HR and HR of a post 1, 2, and 3-minute GXT analyzed to assess for associations with resting HRV. The frequency domain variables such as LF, HF, and ratio of LF to HF, and the time domain variables such as mean R-R interval and RMSSD were determined to assess HRV. Pearson correlation analysis was performed to evaluate the relationship between selected exercise test response and HRV measures. The analyses of difference between the different HR groups were used *t*-test, Wilcoxon's rank-sum test, and Chi-square test. Significant difference was set to $P<0.05$.

There were three major findings in this study. The first finding was that small associations were seen for the majority of resting HRV and GXT HR responses ($r<0.3$). The second finding was that strong relationship was consistently indicated between HRV and HRR ($P<0.05$), especially those representing modulations in vagally mediated measures of HRV such as RMSSD and HF. The third finding was that resting HRV could singularly and consistently distinguish between individuals when grouped according to cut-points and/or quintiles for prognostic resting and exercise HR response measures. Researchers concluded that those findings supported the resting HRV

measured to determine individuals likely to demonstrate a negative HRR following GXT, however, post-exercise HRV and heart rate recovery was strongly correlated[33].

Freeman et al. (1997) investigated that the characteristics of ANS in the patients with chronic fatigue syndrome (CFS). Subjects consisted of twenty-three patients with CFS (age 38.9±2.1 years) as an experimental group and twenty recruited participants (age 37.9±1.8 years) as a control group. All participants and control subjects performed the autonomic function tests, which consisted of the HRV with deep respiration; the blood pressure (BP) and HR response to a 5-minute passive upright tilt, active stranding, and a Valsalva maneuver; the BP response to isometric exercise. Subjects with CFS completed a questionnaire relating to autonomic and CFS symptoms, physical activity level, and premorbid and coexisting psychiatric disorders. Student's paired *t* test was used to compare between groups. Relationships between variables were analyzed using stepwise multiple linear regressions. Significance level was set at $P<0.05$. A significant increase in baseline HR ($P<0.01$) and maximum HR on standing and tilting (both $P<0.001$) was seen in subjects with CFS, while parasympathetic nervous system functioned significantly less in the CSF group. They concluded that CFS group indicated the alteration in functions of sympathetic and parasympathetic nervous[12].

Hynyne et al. (2006) examined the autonomic imbalance in overtrained athlete during sleep and after awakening with analysis of HRV. Subjects consisted of 12 overtrained (OA, 6 men and 6 women) and 12 control (CA, 6 men and 6 women) athletes, respectively. The HRV was recorded during sleep and after awakening and analyzed with time and frequency methods. Also nocturnal urinary stress hormones analysis with liquid chromatography was taken place to examine overtraining status. The significance

level was set at $P<0.05$. There were no differences in HRV or stress hormones during night sleep. However, in awakening, the standard deviation of R-R interval and low frequency were significantly lower ($P<0.05$) in OA group than in CA group. They concluded that the disturbance of cardiac autonomic modulation after awakening was seen in OA group, which suggested that parasympathetic cardiac modulation after awakening was slightly decreased in the condition of the overtraining[18].

Javorka et al. (2002) examined the relationship between heart rate recovery following exercise, HRV, and heart rate complexity. 17 healthy male subjects measured their heart rate during 30 min pre-exercise, during 8 min of the step test with 70% of individual maximal power output frequency, and during 30min of the recovery time. HRV was analyzed in both time and frequency domain. Repeated measures ANOVA with contrasts was performed to determined changes in the parameters. Logarithmic transformation on LF and HF spectral powers was used, and pearson correlations were performed on selected pairs of parameters. Statistical significant difference was set at $P<0.05$.

Major finding from this research were that time and frequency HRV indices increased during recovery period. On the other hand, heart rate gradually declined after exercise but did not reach the pre-exercise levels in 30 min recovery period. The rate of decline of heart rate was not correlated with the HRV parameters but positively correlated with HRV indices acquired from early phase (5 and 10 min following exercise) of recovery period. They concluded that cardiodeceleration due to parasympathetic activation after exercise was related to HRV indices of early phase of post-exercise recovery, while there were no relationships with HRV measures during resting time[19].

Leti et al. (2012) assessed the relationship between the post-exercise HRV and fatigue status in 10 senior long distance runners with competitive level (age 51±5 years). Participants took a 14-day rest without any physical activity before starting their training. At the end of resting period, each participant measured nocturnal HR to get HRV and completed 3 questionnaires to evaluate objectively each fatigue level. Three questionnaires are the questionnaire of fatigue (SFMS), profile mood states (POMS), and quality of sleep. Nocturnal HR of participants was monitored over 12 weeks in different conditions; after a resting period, after a training day, after a competition day, and after a rest day. Questionnaire of SFMS was measured at end of the resting period and then week 3, 8, and 12, while both questionnaires of POMS and quality of sleep were at week 12. The HRV was analyzed in the indices of both time domain and frequency domain including VLF, LF, and HF. They performed Friedman test as the data analyzed with a Kolmogorov-Smirnov test were not normally distributed. Wilcoxon tests were performed if Friedman test was significant. Qualitative variables were analyzed using Fisher's test, and relations between variables were explored with Spearman rank order correlations. The significant threshold was set at $P<0.05$.

The major findings from this study included that the HR, LF, HF, and ratio of LF and HF were significantly shifted toward sympathetic predominance with competitive impact. Also they found that there were positive correlation between fatigue and indices of frequency domain of HRV and fatigue and training impact. Researchers concluded that the relationship between ANS modulation and fatigue was significantly strong, and the combination use of both HRV and questionnaires to athletes was useful to assess athlete's fatigue status[28].

Measurements of metabolic responses such as blood lactate and muscle pH levels have been also originally utilized to assess the exercise-induced fatigue and recovery status following physical exercise[8,22,32,37,42]. However, a previous study has suggested that these metabolic parameters may not be indicative of physical fatigue. Leprêtre PM et al. (2011) conducted the study to investigate the effect of fatigue and metabolite accumulation on postexercise parasympathetic reactivation in 11 well-trained long-sprint runners. Participants performed an exhaustive 400m sprint and a 300m sprint with the same 400m pacing. Within 5 seconds after the end of sprint performances, participants sat passively for 7 minutes as recovery period. During exercises and passive recovery period, HR was measured beat-to beat using HR monitor. Blood (85μL) was collected from the ear lob before exercise and at 1, 4, and 7 minutes after exercise in order to measure biochemical parameter (blood lactate, pH, PO_2, PCO_2, SaO_2, and HCO_3^-). During a 7-minute passive recovery phase, time constant of HRR (HRRτ) and vagally mediated HRV indexes such as RMSSD, HF, and LF were assessed. A two-way repeated measures ANOVA was used to compare the time of the metabolic and HR variables, and paired *t*-tests were used to compare HRR kinetics responses. Scheffe post hoc tests were performed when appropriate. All significant differences were set at $P<0.05$.

Major findings in running performance was that the time of the intermediary 300m sprint was not significantly different between both exhaustive sprint trials. In terms of recovery, HRRτ was longer after the 400m sprint compared to the 300m running ($P<0.01$), and absolute power density in LF and HF was lower after 400m compared to the 300m running trial ($P<0.05$). On the other hand, there was no correlation between biochemical and cardiac recovery responses except for the PO_2 values which were

significant correlated with HF levels measured at 4 minutes after both 400m and 300m running bouts. Researchers concluded that fatigue induced by supramaximal exercise was caused by the delayed parasympathetic reactivation rather than stresses due to metabolic accumulation[27].

In conclusion, parasympathetic reactivation after exercise has been reported to be responsible for recovery from exercise-induced fatigue. Measuring HRV following exercise is a reasonable method to examine the recovery status via the assessment of parasympathetic reactivation, along with other commonly used methods such as measurements of blood lactate and pH level in working muscles.

Post-exercise recovery methods

A number of methods has been proposed and implemented as post-exercise recovery methods. Many research have been conducted to examine their effect after high intensity exercise on biochemical and cardiac recovery responses. As recovery interventions, active recovery, passive recovery, cold water immersion, massage, and compression garments have mainly been applied.

Monedero et al. (2000) compared four different recovery interventions； active and passive recovery, massage, and combination of active recovery and massage on blood lactate removal and subsequent cycling performance. Eighteen healthy male performed maximal incremental cycling test to determine their VO_2max. After then they performed two 5km maximal effort tests, which was separated by 15 minutes recovery period. During passive recovery participants remained seated on chair, while they kept cycling at intensity of 50% VO_2max during active recovery. Massage was applied to the

posterior lower legs in supine position by same certified masseur. Combined recovery intervention consisted of 3.75 minutes active recovery before and after 7.5 minutes massage. Researcher recorded the time of each maximal effort test, blood lactate during each test and every 3 minutes during each recovery, and heart rate during each recovery intervention and second cycling test. All participants underwent all four-recovery interventions, and the difference between four interventions was analyzed by repeated measures ANOVA. Statistical significance was set at $p<0.05$. Post hoc analysis was performed with the Scheffe F test. The most significant findings included that combined recovery intervention was better than passive ($P<0.01$), and either active or massage intervention ($P<0.05$) in terms of maintenance of performance. The active recovery was the most effective method to eliminate blood lactate at a 9-minute and 12-minute post exercise, however the combine intervention was better than passive at a 3-minute and significantly better than passive ($P<0.05$), massage ($P<0.05$), and active intervention ($P<0.01$) at a 15-minute post exercise. Researchers concluded that combined recovery was the most successful intervention. They theorized that active recovery increased the rate of blood lactate removal while massage portion facilitated glycogen restoration[32].

Ferreira et al. (2011) investigated the effect of active recovery on the blood lactate concentration (La) following maximal intensity exercise in 10 healthy cycling athletes. All subjects performed Anaerobic Threshold Test by HR on bicycle ergometer in order to determine HR corresponding to and Anaerobic Threshold Test by Subjective Effort Perception on aquatic bicycle ergometer in swimming pool. After performing maximal test, subjects were performed one of recovery procedures including passive recovery on land (PRL; supine position for 60 minutes), passive recovery in the water (PRW; supine

position with float in the pool for 60 minutes), and active recovery in the water (ARW; the 30-minute volunteer performed exercise on aquatic bicycle with intensity equivalent to 85% of intensity of LA and PRW for another 30 minutes). All subjects underwent all recovery methods in different day. Blood samples were collected to analysis lactate at 5, 15, 30, 60 minutes of post-maximal test. A repeated measure ANOVA with Tukey's post hoc analysis was performed to determine the between-group differences. Significant difference was set at $P<0.05$. The major findings included that there was no difference in La among three recovery procedures at 5 minutes. Significant difference between ARW and other passive recovery methods was shown from 15 minutes of recovery period ($P<0.05$), and the ARW showed lower values. No significant difference shown between the PRL and PRW. Researchers concluded combination of active recovery with water immersion was more effective in eliminating blood lactate compared to a single method of water immersion[11].

In conclusion, among several proposed recovery methods, active recovery following exercise has been shown to be effective in reducing blood lactate. A combined method of active recovery and water immersion or massage has also been reported in one study that suggested a greater effect on the elimination of blood lactate than an each individual intervention.

Recovery via Garment Application

Recovery method using garment application was given a separate section as it relates to the method of recovery used in the present study, recovery wear. Compression garments have been used among athletes to enhance exercise performance and accelerate

post-exercise recovery. However results of previous studies investigated the effects of compression garments have been equivocal. Chatard et al. (2004) examined the effects of elastic compression stockings (ECS) on recovery and leg pain following maximal exercise in 12 elderly trained cyclists. Participants performed cycloergometer exercises consisted of 2 sets of 5 minutes maximal exercise separated by 80 minutes passive recovery with elevated legs, and performed them 4 times in 2 weeks. In recovery period, participants were randomly assigned to either passive recovery with ECS or only passive recovery group. Blood sample for blood lactate concentration were collected at a 50- to 60-minute resting period, immediately after maximal exercises, and at every 20 minutes during 80 minutes post-exercise recovery period. Leg pain sensation was assessed with questionnaire. A two-way ANOVA with repeated measures was used to analysis the comparison of the 5-minute exercise, HR, ratings of perceived exertion (RPE), and blood samples at both conditions if wearing ECS or not during recovery period. The level of significant difference was set at $P<0.05$. The most significant findings included that blood lactate concentrations ($P<0.01$) and hematocrit ($P<0.01$) between two exercises decreased in passive recovery with ECS group. Participants in the ECS group stated that ECS had a positive effect on their leg pain sensation, although there was not significant relationship between exercise performance and leg pain sensation. Researchers concluded that wearing ECS during recovery period enhanced post-exercise blood lactate removal and subsequent performance[7].

Duffield et al. (2010) studied the effects of wearing compression garment (CG) on recovery following high-intensity sprint and plyometric exercises in 11 trained athletes. Participants performed both 20m sprint and 10 plyometric bounds every minute for 10

minutes with and without CG. Muscle activations were assessed using an isokinetic dynamometer and blood sample for metabolic responses were taken at before, 2h, and 24h post-exercise. Also HR, RPE, and lower extremity muscle soreness (MS) scale were measured before and after exercise. Each collected data was analyzed by repeated measures ANOVA ($p<0.05$). The most significant findings included that the CG had no effect on voluntary performance and no improvement on removal of anaerobic metabolites. However, small changes in aspartate transaminase and reduced MS were observed in CG. The researchers concluded that the effect of compression garment was minimal, however it might contribute to ease the perception of muscle soreness following exercise[10].

Similarly, Lovell et al. (2011) examined whether compression garments (CG) enhance the active recovery process after high-intensity running in 25 semiprofessional rugby players. Participants attended 3 testing session including one graded exercise test and two submaximal treadmill tests with CG and with normal shorts respectively. Submaximal treadmill test consisted of 6 sets of 5-minute stages at $6km \cdot h^{-1}$, $10km \cdot h^{-1}$, approximately 85% of VO_2max, $6km \cdot h^{-1}$ as recovery stage, and approximately 85% of VO_2max and $6km \cdot h^{-1}$. Maximal oxygen consumption (VO_2max) based on submaximal tests was measured in the graded exercise test. Heart rate (HR), VO_2max, respiratory exchange ration (RER), blood lactate concentration (La^-), and blood pH were measured as dependent variables to determine the effect of CG, and the differences between the conditions were analyzed using a paired *t*-test with the significant level set at $P \leq 0.05$. The major findings concluded that HR and La^- were lower ($P \leq 0.05$) during the first and second $6km \cdot h^{-1}$ recovery stage with CG compared to wearing normal shorts. Also the

compression garments lowered La^- at $10km \cdot h^{-1}$ ($P \leq 0.05$). No significant difference in blood pH was shown at any stage with both CG and running shorts. Researchers concluded that CG might enhance the active recovery process in lowering La^- and HR following high-intensity exercise and assist athletes to prepare for their subsequent performance[29].

Davies et al. (2009) examined the effect of compression garments on recovery following plyometric exercise. The purpose of the study was to investigate the whether wearing compression garments (CG) lower the indexes of muscle damage and decrease the performance in sprinting and jumping on 11 trained athletes. Participants consisted of 7 female and 4 male. As pre-exercise condition, participants undertook performance test including sprints (5m, 10m and 20m), a 5-0-5 agility test, and a countermovement jump test. After one week of performance test, participants completed plyometric drop-jump protocol, which consisted of 5 sets of 20 drop jumps (drop from a 60 centimeter platform immediately followed by a maximal vertical jump). Parents underwent treatment of either CG or passive recovery as control (CON) for 48 hours, after which the performance test was repeated. After the second bout of the performance test, each participant switched the recovery intervention to CG or CON. Blood sample for creatine kinase (CK) and lactate dehydrogenase (LDH), girth measurement of mid-thigh, and perceived muscle soreness (PMS) were collected before first performance test as baseline and after 24 hours and 48 hours recovery period, and each variable was analyzed by repeated measures ANOVA. The significant level was set at $P \leq 0.02$ in all data analysis. The most important findings from this study included that an increased CK values after 24-hour recovery ($P=0.02$) and a greater PMS after 48-hour recovery were observed in

the CON of female subjects (P=0.02), but not in the CG condition. The time of 10m (P=0.016 and P=0.004, respectively) and 20m (P=0.004 and P=0.001, respectively) sprints significantly increased in both CON and CG condition, and time of 5m-sprint was increased (P=0.014) in only CG condition. No significant change was shown in all other parameters. Authors concluded that there was no significant change on reducing muscle damage markers such as CK and LDH between CG and CON. Additionally, no benefit was indicated in wearing CG following plyometric exercise on improving performance. Authors noted that subjects with CG did express more comfort with less muscular pain after 48 hours of drop jump protocol indicated by lower value of PMS[9]. Compression garment has been theorized to increase venous return via application of external pressure, thus aiding in removing waste product and allowing blood gases to return to a normal state. However, from the abovementioned studies definitive conclusion of benefits and effectiveness of such method cannot be drawn.

In the present study, a new type of recovery garment, a mixture of Nano-platium and Nano-diamond (DVP576) coated garment was used during passive recovery period. This garment, introduced by Japan-native Venex Co., Ltd. is designed to increase parasympathetic reactivation via a direct contact with the specially prepared fabric without providing external compression. According to previous in-vivo studies, DVP576 coated material may be useful in improving immune function and T-cell proliferation[13,14]. In an unpublished study, Gomyo (2012) investigated the effect of DVP576 coated recovery wear on heart rate variability following maximal anaerobic exercise in 30 healthy individuals. Participants completed two 20-second Wingate test (WAnT) as maximal anaerobic exercises separated by 30 minutes passive recovery, and repeated

same procedure separated by at least 7 days. During 30 minutes passive recovery period, participants were assigned to wear either DVP576 coated recovery wear (RW) or sham wear (SW) and laid supine on a treatment table. ECG was monitored throughout 30 minutes period in order to analyze HRV. RPE was collected pre- and post-exercise, and HR and the perceived recovery status (PRS) scale were taken at every 5 minutes during recovery period. Analyses of Covariance (ANCOVAs) with repeated measure were used to analyze HRV time domain and frequency, and ANOVAs with repeated measures were used to analyze the PRS, HRR, and the performance of the WAnT. Statistical significant was set at $P<0.05$. The most important findings included that there was no significant differences between garments in post-exercise HR and HRV time and frequency domain. The PRS scores with RW were constantly higher than SW, although there was no significant differences between conditions. Researchers concluded that the DPV576 coated garment had no effect on HRV, HR, PRS and performance of WAnT, while the PRS scale provided valid recovery status data based on HRV[16]. Therefore, no studies have successfully shown the effect of the DPV575 coated recovery wear on autonomic function to date.

Appendix A:

Informed Consent Form **Participants ID_____**

INFORMED CONSENT TO PARTICIPATE IN A RESEARCH STUDY

Department of Kinesiology and Rehabilitation Science, University of Hawaii at Manoa

I. Investigator

Kohhei Ohnishi, ATC: Iris F. Kimura, PhD, ATC, PT. Christopher Stickley, PhD, ATC, CSCS. Yukiya Oba, MS, ATC, CSCS. Kazuhiko Yanagi, MA, ATC, CSCS. Kinesiology and Rehabilitation Science Department. University of Hawaii at Manoa. 1337 Lower Campus Rd, Honolulu Hawaii 96822. Phone: (808) 956-7606.

II. Title

Effects of the Recovery Garment on Heart Rate Variability Following a Maximal Aerobic Exercise

III. Informed Consent

I am being asked to participate in a study conducted through the University of Hawaii at Manoa. The purpose of this consent form is to provide me with information about this research to help me decide if I would like to participate in this study. This form is called an informed consent form. If there are any words or sections in this consent form that I do not understand or want to clarify, I will ask the research staff to explain them. I will review this consent form and discuss any questions I may have with the research staff. If I understand the study and agree to take part in this study, I will be asked to sign this consent form.

It is important that I understand that taking part in this study is of my own free will. I may decide not to participate, or I may decide to drop out of the study at any time.

IV. Purpose of the study

The purpose of this study is to examine the effects of a Recovery Garment after a strenuous aerobic exercise on heart rate rhythm. The RG was introduced from Venex Co., Ltd. (Kanagawa, Japan). The garments contain DPV576 material fibers, which are made from the mixtures of Nano-platinum and Nano-diamond. The company claims that it facilitates recovery when it is worn after exercise by affecting parasympathetic nervous activity of autonomic nervous system (ANS). In order to compare the effects of the RG and control garment, a total of two testing sessions will be conducted. I will perform a maximal graded exercise testing (GXT) to increase heart rate to voluntary exhaustion in a short period. The electrocardiogram will be used to determine the heart rate variability (HRV), which is a measure of how heart rate increases or decrease as I breathe in or out by the effect of ANS function.

V. Procedure

If I take part in this study, I will have the following tests and procedures.

All testing sessions will be performed in the climate controlled Human Performance Laboratory at University of Hawaii at Manoa.

- I will be asked to read and sign an informed consent form and complete a medical health history questionnaire upon a first visit.
- I will need to meet the health screening eligibility requirements in order to participate in the study.
- At the first visit, an investigator will walk through all testing protocols with me to make me feel comfortable performing the tests.
- I will be measured for height, body weight, and resting blood pressure.
- I will be escorted to a treatment table next and lie on my back on a treatment table for a **baseline 20 minute rest period**. A heart rate monitor with five electrodes will be applied on the bare chest after cleaning my skin with alcohol pad and scrub gel as needed. The electrocardiogram (ECG) will monitor my heart rate throughout the 20-minute period to determine baseline heart activity.
- After the baseline rest period, I will then **perform the GXT on a treadmill to voluntary exhaustion.** I will wear a mouthpiece and headgear during the exercise to obtain metabolic data.
- After a three minute walking cool down I will **perform a run with increasing treadmill grade (slope) until voluntary exhaustion.**
- Immediately after the GXT, I will be instructed to change in a private area into either Venex recovery garment or a control garment, and lie on my back on a treatment table and rest again for another 30 min. My heart rate, ECG activity, subjective rating of recovery will be monitored during this period.
- If my heart rate does not return to resting heart rate in the 30 minutes recovery period, monitoring will continue until HR returns to baseline.
- After the recovery period, the investigator will remove the recovery garment and I will change back into my own clothing.

In order to compare the two conditions, I will participate in a total of two testing sessions, which will be separated by at least 7 days and not more than 10 days. The two data collection sessions are identical, except the type of garment. The order of the garment application will be assigned in a counter-balanced order and I will not be informed which garment I am wearing. The investigator may decide to remove me from this study if I:

1) decide not to participate in this study;
2) cannot perform the GXT;
3) cannot continue the procedures due to side effects from the GXT, or
4) get injured during the test.

I may stop participating in this study at any time. The total session time for each visit is approximately 1 hour and 45 minutes.

VI. Risks

There are slight risks associated with the GXT. I may experience nausea, vomiting, dizziness, fainting, discomfort, and soreness after the GXT. There is a very remote chance of a cardiac arrest and/or death as result of exercise testing. The risks from taking

ECG are quite low. However, I may have temporally skin reactions such as itch, redness, and slight bruise where the electrodes are placed.

VII. Research Related Injury

In case of any physical injury during this study, immediate medical treatment including first aid, CPR and, an automated external defibrillator (AED) is available on site. If I am injured as a result of being in this study, immediate on-site care is available for my injuries. University of Hawaii does not possess any policy designed to cover the medical treatment required as a result of injuries incurred in this study. I will utilize my personal medical insurance for my research related injuries. ***I understand that I may be responsible for the costs of procedures that are solely part of the research project.***

VIII. Benefits

I will learn my maximal aerobic power output (maximal oxygen uptake) through the results of the GXT. The results of this study may help athletes and others recover from exercise more quickly and safely.

IX. Safeguard

I will be monitored closely by allied-health care providers (Board Certified Athletic Trainers) while I am in this study.

X. Confidentiality

All my research information will be kept confidential to the extent allowed by law. My personal information will not be given to anyone without my written permission. However, the University of Hawaii Committee on Human Studies has the right to review research records.

A code, which will be known only to research personnel, will be used instead of my name on medical records in this study. Research records that may be identifiable to me will be kept in a secure locked file in the Department of Kinesiology and Rehabilitation Science at the University of Hawaii at Manoa.

XI. Compensation

I will receive no compensation (direct or implied) for completing this study.

XII. Biological Specimens

I will not be asked to provide my biological specimens such as blood, saliva, and urine in this study.

XIII. Certification

Participation is voluntary; refusal to participate will involve no penalty to me. There are no alternatives to the procedures in this study. I may withdraw my consent and discontinue participation in this research project at any time without negative consequences. I have the right to ask questions concerning the procedures at any time and have any questions answered to my satisfaction. If any new findings are developed during the time that I am in this research project which may affect my willingness to continue to be in the study, I will be informed as soon as possible. All testing will be scheduled at my convenience when I am on campus. No reimbursement for parking is

available and I will not be compensated for my time. If I desire further information about this research project, I may contact Dr. Iris Kimura at (808) - 956-3797. If I would like to talk with someone about my rights of being a subject in this study I may contact the Human Studies Program at (808)-956-5007, or by email: uhirb@hawaii.edu

Informed Consent Form **Participants**
ID_____

INFORMED CONSENT TO PARTICIPATE IN A RESEARCH STUDY

Department of Kinesiology and Rehabilitation Science, University of Hawaii at Manoa

I understand that if I am injured in the course of this research procedure, I alone may be responsible for the costs of treating my injuries.

By signing below, you certify that you have read and understand this informed consent form and all your questions have been answered to your satisfaction. You are aware of your rights and you choose to participate in this research project.

_____ _____
Printed Name of individual participant Date

_____ _____
Signature of individual participant Date

I have explained and defined in detail the research procedure in which the participant has agreed to participate and have offered him a copy of this informed consent form.

_____ _____
Printed Name of investigator Date

_____ _____
Signature of investigator Date

Appendix B:
American College of Sports Medicine's Guidelines for Exercise Testing and Prescription, 7th Edition Contraindications to Exercise

Absolute

- A recent significant change in the resting ECG suggesting significant ischemia, recent myocardial infarction (within 2 days), or other acute cardiac event
- Unstable angina
- Uncontrolled cardiac disrhythmias causing symptoms or hemodynamic compromise
- Symptomatic severe aortic stenosis
- Uncontrolled symptomatic heart failure
- Acute pulmonary embolus or pulmonary infarction
- Acute myocarditis or pericarditis
- Suspected or known dissecting aneurysm
- Acute systemic infection, accompanied by fever, body aches, or swollen lymph glands

Relative

- Left main coronary stenosis
- Moderate stenotic valvular heart disease
- Electrolyte abnormalities (e.g., hypokalemia, hypomagnesemia)
- Severe arterial hypertension (i.e., systolic BP of >200 mm Hg and/or a diastolic BP of >110 mm Hg at rest)
- Tachydysrhythmia or bradydysrhythmia
- Hypertrophic cardiomyopathy and other forms of outflow tract obstruction
- Neuromuscular, musculoskeletal, or rheumatoid disorders that are exacerbated by exercise
- High-degree atrioventricular block
- Ventricular aneurysm
- Uncontrolled metabolic disease (e.g., diabetes, thyrotoxicosis, or myxedema)
- Chronic infectious disease (e.g., mononucleosis, hepatitis, AIDS)
- Mental or physical impairment leading to inability to exercise adequately

1. Relative contraindications can be superseded if benefits outweigh risks of exercise. In some instances, these individuals can be exercised with caution and/or using low-level end points, especially if they are asymptomatic at rest.

Appendix C
Perceived Recovery Status (PRS) Scale

At every 5 min (5,10,15,20,25, and 30) of post-garment application, we will ask you to rate your recovery status, according to the PRS scale. You will be asked to choose a number to describe how much you have recovered from the previous maximum aerobic exercise test. A rating of "8-10" would correspond to those feelings and sensations that you are well recovered and can expect better performance on subsequent exercise test. A rating of "4-6" corresponds to the feelings and sensations that you are moderately recovered and would expect similar performance on the subsequent exercise test. A rating of "0-2" would correspond to those feelings and sensations that you are not recovered at all and would expect declined performance on subsequent exercise test.

Please tell the number that you feel is appropriate.

10	Very well recovered/ Highly energetic	Expect Improved Performance
9		
8	Well recovered/ Somewhat energetic	
7		
6	Moderately recovered	Expect Similar Performance
5	Adequately recovered	
4	Somewhat recovered	
3		
2	Not well recovered/ Somewhat tired	Expect Declined Performance
1		
0	Very poorly recovered/ Extremely tired	

Appendix D
Fatigue Rating Score (FRS)

Like PRS scale, at every 5 min (5,10,15,20,25, and 30) of post-garment application, we will ask you to rate your fatigue status, according to the FRS. You will be asked to choose a number to describe how much you still feel tired from the previous maximum aerobic exercise test. A rating of "0" would correspond to none fatigue. A rating of "2" and "5" corresponds to the mild and moderate fatigue, respectively. A rating of "8" and "10" would correspond to the severe and worst possible fatigue, respectively.

Please tell the number that you feel is appropriate.

Fatigue Rating Score

0	Energetic no fatigue/ None fatigue
1	
2	Mild Fatigue
3	
4	
5	Moderate Fatigue
6	
7	
8	Severe Fatigue
9	
10	Worst Possible Fatigue

Appendix E:
Ratings of Perceived Exertion (RPE) Scale
RPE (modified Borg RPE Scale, Borg, 1998)

At every stage of a 1st running bout, the end of a 3-minute active recovery period, and the end of a 2nd running bout, we will ask you to rate the work, according to the RPE scale. You will be asked to choose a number to describe how hard the work is for you. A rating of "6" would correspond to those feelings and sensations you have during the easiest work you can imagine, similar to sitting in a chair. A rating of "20" corresponds to the feelings and sensations you would have during the most difficult work you could imagine yourself doing, so exhaustive that you cannot continue.

We will ask you to give local muscular ratings for perceived exertion and feelings of strain in the legs and joints; central readings which are sensations involving the chest and breathing; and overall readings, for which you may integrate the local and central sensations in the way you feel appropriate. Please point to the number that you feel is appropriate.

RPE Scale

6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

Appendix F:

Pre-Participation Medical History Form/ Physical Activity Readiness Questionnaire

Participant Information

ID number _____
Date of Birth:_____ Age (years) _____ Sex: M / F
Home Address:_____
City/State/Zip:_____ Email: _____
Home/Cell Phone (___) _____
Emergency Contact Person/Relationship/Phone Number:
_____(___)_____

Physical Activity Readiness Questionnaire (American College of Sports Medicine, 1997)

Please read the questions carefully and answer each one honestly.

YES NO

€ € 1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

€ € 2. Do you feel pain in your chest when you do physical activity?

€ € 3. In the past month, have you had chest pain when you were not doing physical activity?

€ € 4. Do you lose your balance because of dizziness or do you ever lose consciousness?

€ € 5. Do you have a bone or joint problem (ex. back, knee or hip) that could be made worse by a change in your physical activity?

€ € 6. Is your doctor currently prescribing drugs (ex. water pills) for your blood pressure or heart condition?

€ € 7. Do you know of any other reason why you should not do physical activity?

Medical History: the subsequent sections were obtained following guidelines for exercise testing (American College of Sports Medicine, 2005).

A. History: please check the box any condition you currently have or had in the past.

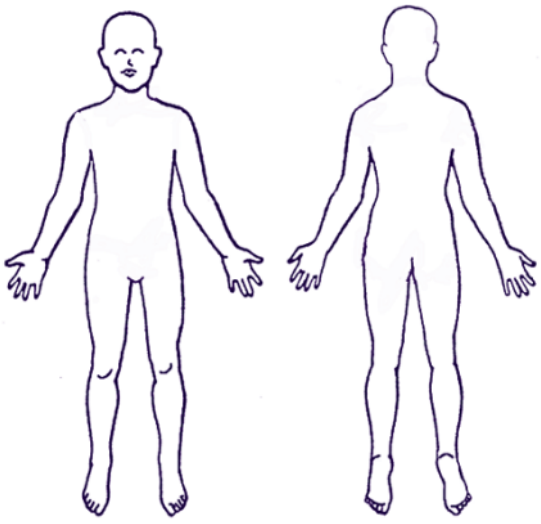
- ☐ Heart Attack
- ☐ Heart Surgery
- ☐ Cardiac Catheterization
- ☐ Coronary Angioplasty (PTCA)
- ☐ Pacemaker/implantable cardiac
- ☐ Defibrillator/rhythm disturbance
- ☐ Heart valve disease
- ☐ Heart failure
- ☐ Heart transplantation
- ☐ Congenital heart disease
- ☐ Diabetes
- ☐ Asthma
- ☐ Lung Disease
- ☐ Heart murmur
- ☐ Seizures
- ☐ Head injury or concussion
- ☐ Loss of consciousness or memory

B. Symptoms: please check the box for any symptoms you have or had experienced at rest, during or following exercise.

- ☐ Chest discomfort
- ☐ Cough or wheezing
- ☐ Dizziness, fainting, or blackouts
- ☐ Difficulty breathing
- ☐ Abnormal heart beats

Musculoskeletal Symptoms: please check the box for any symptoms you have or had experienced, locate and label the occurrence of each symptom on the figure below.

- ☐ Numbness
- ☐ Tingling
- ☐ Pain
- ☐ Swelling
- ☐ Burning
- ☐ Cramping



APPENDIX G:
Data Collection Sheet

Subject ID:_____ Gender:_____ Testing Session: 1 2

Body mass (kg)_____ Height (cm)_____ BP_____/_____

Room temp_____ Date/Time_____am____pm___

HR	**GXT**					**Speed**	
Resting HR	HR and RPE					1st bout	
		HR	legs/joint	chest/breathing	overall	VO2 max	
	0min					2nd bout	
	3min						
	5min						
	7min						
	9min						
	11min						
	13min						
	15min						
	17min						
	19min						
	21min						
	End of Active recovery					**FRS**	
	End of 3rd Stage						

Subject ID:_____ Testing Session: 1 2

Garment: RG / CG Size

Time from GXT	
Till changing into garments	
Till recording ECG	

Post-Garment application HRV			
	HR	**PRS**	**FRS**
Immediate			
5min			
10min			
15min			
18min			
20min			
23min			
25min			
28min			
30min			
33min			
35min			
38min			
40min			

Length of Time untill HR reach plateau	

APPENDIX H:
HRV Raw Data

Appendix: H-1 Raw Data for Mean RR with RG (ms)

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	1345.8	655.6	657.4	726.2	770.9	832.6	877.0
2	880.6	559.2	574.9	586.8	586.3	598.4	611.6
3	983.6	607.8	640.0	656.1	661.3	677.2	682.6
4	1072.1	574.7	606.3	626.4	647.3	661.2	667.9
5	812.8	521.0	543.4	543.4	577.9	589.3	589.9
6	991.3	628.2	658.9	678.8	701.9	712.6	765.7
7	1302.7	570.9	597.5	613.2	643.9	655.4	692.4
8	697.9	564.2	573.5	585.8	586.8	593.3	590.4
9	1253	634.1	641.2	627.6	643.8	643.6	663.1
10	871.6	559.6	586.1	600.0	616.7	637.7	643.5
11	1314.4	619.4	624.0	638.2	660.0	666.2	675.2
14	1036.1	601.7	627.1	631.2	657.0	662.2	673.3
15	1268.7	722.6	740.2	781.4	811.3	814.9	847.0
16	1043.4	658.7	681.8	693.8	724.4	738.6	753.0
23	803.3	648.2	678.3	687.9	705.9	730.1	739.5

Appendix: H-2 Raw Data for Mean RR with CG (ms)

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	1541.9	701.2	717.8	799.8	814.6	858.9	861.8
2	888.5	595.9	605.1	632.9	664.7	666.5	691.1
3	1079.0	614.8	638.7	651.8	677.3	701.2	714.2
4	1092.1	655.5	694.3	703.1	720.3	748.1	764.3
5	963.3	498.2	545.4	565.6	582.9	613.9	625.8
6	947.6	598.5	611.2	642.9	677.6	707.8	710.7
7	995.8	567.9	610.4	616.8	628.2	651.5	660.2
8	862.4	568.7	586.5	600.9	619.5	644.9	666.7
9	1270.5	662.7	670.4	681.3	700.0	707.0	758.5
10	864.3	590.0	605.7	623.4	644.7	689.9	693.1
11	1310.7	582.2	602.9	616.8	629.3	637.3	650.2
14	962.7	610.7	646.2	646.2	667.2	709.9	739.7
15	1087.1	670.4	700.8	710.1	736.5	763.5	786.8
16	959.8	625.6	660.4	671.6	676.3	706.5	709.7
23	905.9	665.0	687.6	707.7	722.8	731.6	713.8

Appendix: H-3 Raw Data for SNDD with RG (ms)

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	62.4	12.7	12.8	20.7	18.6	27.9	30.9
2	41.3	10.6	8.4	6.3	7.2	8.6	9.1
3	46.0	4.5	7.4	7.3	8.4	15.3	15.9
4	59.5	15.6	8.5	10.1	16.3	23.9	16.6
5	37.9	4.3	4.2	4.2	6.2	8.2	9.3
6	40.7	11.2	10.0	12.2	18.9	26.2	29.5
7	70.9	8.7	12.2	11.5	11.1	20.3	25.4
8	46.8	22.9	13.9	21.5	21.4	8.4	14.6
9	75.9	15.5	12.9	13.0	16.4	14.1	16.0
10	61.9	6.8	7.6	10.2	11.8	15.3	14.8
11	65.7	38.7	11.1	8.1	23.4	8.7	11.5
14	72.0	6.5	6.3	7.0	9.1	10.7	16.3
15	77.7	25.4	24.1	21.0	25.7	26.4	26.1
16	40.1	7.4	7.9	10.5	6.9	10.3	11.4
23	19.4	22.5	13.7	18.1	15.0	20.6	24.2

Appendix: H-4 Raw Data for SNDD with CG (ms)

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	42.6	15.6	17.1	23.0	25.3	22.8	23.4
2	38.9	22.0	17.0	11.6	17.1	16.9	21.0
3	61.2	6.9	8.7	8.8	14.7	18.1	18.3
4	44.3	15.9	13.1	8.4	13.0	16.4	19.6
5	49.3	5.5	3.7	4.3	11.0	7.6	9.2
6	54.2	10.0	7.7	11.7	10.5	13.6	15.2
7	73.7	7.6	9.2	11.5	13.7	16.6	16.3
8	59.1	11.7	9.5	10.5	7.8	10.9	14.8
9	92.2	22.3	13.6	14.3	13.9	13.2	18.8
10	59.8	16.2	6.8	9.5	11.9	16.6	29.0
11	78.5	11.5	12.8	5.9	8.5	7.2	11.8
14	63.3	7.6	7.7	9.6	14.3	18.9	22.9
15	56.0	9.4	14.4	17.2	18.2	18.8	20.8
16	71.0	29.7	31.5	36.9	42.0	35.0	30.0
23	24.5	7.1	9.6	8.0	14.6	10.4	19.7

Appendix: H-5 Raw Data for rMSSD with RG (ms)

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	77.3	8.6	8.0	11.0	11.6	17.3	23.9
2	42.8	8.7	6.0	4.6	5.0	8.6	6.0
3	45.3	4.6	5.6	43.8	6.0	15.3	8.4
4	64.9	12.0	6.4	8.6	11.5	23.9	14.5
5	37.4	4.2	4.2	4.2	4.7	8.2	6.0
6	47.8	8.5	7.9	9.7	12.4	26.2	25.8
7	96.5	11.2	16.9	14.8	12.3	20.3	25.3
8	36.0	25.2	10.8	16.9	19.5	8.4	7.6
9	97.8	20.4	17.3	19.8	20.8	14.1	23.3
10	56.8	5.0	5.4	6.8	7.3	15.3	9.0
11	81.4	48.3	10.4	6.7	30.8	8.7	10.1
14	88.6	6.3	6.1	6.3	8.0	10.7	16.7
15	92.8	41.0	37.0	25.6	29.8	26.4	21.9
16	45.5	8.4	8.3	9.8	7.7	10.3	12.3
23	16.1	25.3	9.3	12.6	10.0	18.9	23.0

Appendix: H-6 Raw Data for rMSSD with CG (ms)

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	54.4	15.2	15.4	18.1	18.9	22.8	22.3
2	40.1	26.4	18.3	13.0	17.2	22.6	22.7
3	65.7	5.4	5.2	6.3	8.1	11.2	9.8
4	48.8	12.7	14.0	10.4	10.9	16.3	20.9
5	43.7	5.1	3.9	4.3	15.7	6.7	6.3
6	61.9	7.2	5.4	7.1	8.8	12.0	14.6
7	73.3	10.8	13.2	16.5	15.3	14.4	14.5
8	54.6	6.3	7.5	8.2	4.9	11.3	9.9
9	110.7	24.7	18.6	21.2	20.4	18.6	19.3
10	54.7	16.00	6.7	6.9	8.4	12.4	19.0
11	121.2	14.5	16.9	4.1	5.7	5.0	6.7
14	63.8	6.6	5.6	5.9	8.5	12.7	21.8
15	63.8	6.4	7.8	8.3	13.2	11.3	14.1
16	73.3	42.8	41.2	47.1	53.6	47.1	39.0
23	23.2	5.2	6.5	6.2	10.0	8.8	10.9

Appendix: H-7 Raw Data for pNN50 with RG (%)

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	38.3	0.4	0.2	0.0	0.0	0.8	5.6
2	22.6	0.6	0.0	0.0	0.0	0.4	0.0
3	30.3	0.0	0.0	0.0	0.0	0.0	0.0
4	42.7	1.9	0.2	0.6	0.9	2.7	1.6
5	17.7	0.0	0.0	0.0	0.0	0.0	0.0
6	30.5	0.0	0.0	0.0	0.2	2.4	5.1
7	52.0	0.0	1.8	1.2	0.2	2.4	4.4
8	14.2	2.6	1.0	2.9	2.2	0.0	0.2
9	56.7	1.5	0.4	1.5	1.9	2.6	4.0
10	27.7	0.0	0.0	0.0	0.0	0.2	0.2
11	37.0	6.0	1.2	0.4	2.9	0.4	1.4
14	49.0	0.0	0.0	0.0	0.0	0.0	3.4
15	61.9	25.8	19.6	6.5	12.5	9.3	3.7
16	26.2	0.2	0.2	0.5	0.0	0.2	0.3
23	0.0	3.7	0.5	0.7	0.2	2.0	5.2

Appendix: H-8 Raw Data for pNN50 with CG (%)

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	26.9	1.4	1.4	1.9	3.3	5.5	6.1
2	20.2	7.4	3.6	0.4	0.9	4.2	3.9
3	51.3	0.0	0.0	0.0	0.0	0.5	0.2
4	28.9	2.2	2.1	0.9	0.2	1.8	4.1
5	28.4	0.3	0.0	0.0	0.6	0.2	0.0
6	44.4	0.2	0.0	0.0	0.0	0.2	0.7
7	42.9	0.0	0.2	2.3	1.1	0.9	1.1
8	26.6	0.0	0.6	0.4	0.0	0.6	0.9
9	57.4	4.0	1.3	1.8	2.8	1.2	1.8
10	32.9	0.2	0.0	0.0	0.0	0.2	2.3
11	75.0	0.8	1.4	0.0	0.0	0.0	0.2
14	28.7	0.0	0.0	0.0	0.0	0.7	4.2
15	50.2	0.0	0.0	0.0	1.2	0.3	0.3
16	34.6	26.4	19.0	25.8	28.9	23.9	20.6
23	3.6	0.0	0.0	0.0	0.2	0.0	0.0

Appendix: H-9 Raw Data for LF Power with RG (ms)

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	1129	96	145	364	216	462	568
2	1059	69	15	29	38	20	78
3	670	10	21	53	45	324	234
4	2392	80	45	51	136	367	98
5	879	10	15	15	36	29	56
6	398	55	42	76	224	335	567
7	1762	15	78	36	56	116	278
8	2453	36	109	377	134	38	68
9	2336	100	44	26	121	80	28
10	2033	34	31	75	112	73	91
11	1443	193	10	24	106	13	40
14	2477	10	18	38	62	78	111
15	4801	46	67	137	293	312	357
16	513	19	15	89	18	41	39
23	280	185	117	214	99	301	385

Appendix: H-10 Raw Data for LF Power with CG (ms)

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	565	36	161	332	316	359	256
2	801	124	148	46	83	91	133
3	1529	15	59	57	207	323	276
4	784	177	95	32	107	105	177
5	1506	13	7	9	21	21	72
6	1626	57	22	81	31	45	56
7	2514	7	14	25	82	162	205
8	1742	77	21	128	40	35	79
9	2438	478	67	22	65	33	68
10	1842	17	31	93	79	73	730
11	712	6	22	41	42	27	90
14	4048	30	32	80	303	132	308
15	1446	27	285	123	116	325	274
16	2610	111	112	274	423	249	266
23	234	28	75	20	110	59	230

Appendix: H-11 Raw Data for HF Power with RG (ms)

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	1929	14	13	32	25	94	181
2	629	38	6	4	4	12	16
3	830	5	6	5	6	10	22
4	1301	71	13	7	27	131	53
5	717	2	1	1	3	5	5
6	647	7	16	26	60	96	527
7	2345	19	22	39	17	63	282
8	1087	6	29	173	149	4	5
9	3408	216	23	33	35	40	60
10	1049	6	3	14	15	18	21
11	1931	116	5	3	26	6	22
14	2026	2	3	6	15	18	37
15	1973	125	116	47	113	98	57
16	588	37	12	39	14	30	33
23	120	67	61	67	25	58	108

Appendix: H-12 Raw Data for HF Power with CG (ms)

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	698	19	98	104	118	196	186
2	356	196	106	43	56	62	91
3	2033	4	5	6	21	30	34
4	842	51	55	18	24	94	223
5	594	3	1	1	2	6	11
6	1546	5	5	10	45	69	94
7	1252	18	17	37	26	43	69
8	564	8	42	10	3	13	22
9	3426	267	48	45	42	30	41
10	749	2	3	11	29	19	112
11	4359	8	5	2	5	4	8
14	1831	4	4	4	19	29	118
15	1299	5	22	7	26	50	70
16	1569	278	294	530	708	521	346
23	162	5	7	5	25	22	32

Appendix: H-13 Raw Data for LF Power with RG (n.u.)

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	36.9	87.1	91.7	91.8	89.5	83.1	75.8
2	62.6	64.1	72.7	88.2	89.4	61.9	83.0
3	44.6	66.5	40.2	79.9	89.0	96.9	91.5
4	64.8	52.8	77.9	87.4	83.3	73.6	64.7
5	55.1	87.0	92.8	92.8	92.6	84.4	91.9
6	38.0	88.3	72.8	74.8	78.9	22.3	51.8
7	42.9	44.2	77.8	47.8	76.9	64.7	49.5
8	69.3	84.6	79.1	68.5	47.3	90.0	92.5
9	40.7	31.6	65.6	43.3	77.1	66.3	32.0
10	65.9	85.6	89.9	84.2	88.3	80.3	81.2
11	42.8	62.3	63.5	11.8	80.1	68.9	64.5
14	55.0	84.5	86.9	85.6	79.4	80.4	74.7
15	70.9	69.9	35.6	74.3	72.0	76.0	86.1
16	46.5	34.1	56.5	69.7	56.1	58.2	54.1
23	70.0	73.2	65.6	76.0	79.9	83.9	78.0

Appendix: H-14 Raw Data for LF Power with CG (n.u.)

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	44.7	65.4	62.0	76.1	72.7	64.6	57.9
2	69.2	38.7	58.1	51.7	59.2	59.2	59.4
3	42.9	35.7	92.1	91.0	27.3	91.5	89.1
4	48.2	77.7	62.7	64.4	81.7	52.7	44.3
5	71.7	83.0	82.7	89.6	92.0	77.1	86.7
6	51.3	91.7	80.8	89.0	40.8	39.3	32.7
7	66.7	28.2	45.4	39.5	75.8	79.0	74.8
8	75.3	91.0	33.3	92.7	92.7	73.2	78.3
9	41.6	64.1	58.0	32.3	60.7	52.1	61.8
10	71.0	88.9	92.2	89.5	73.1	79.5	86.7
11	14.0	42.4	82.4	95.0	89.8	86.4	91.8
14	68.8	87.6	89.1	95.3	94.1	81.9	72.1
15	52.7	85.7	92.9	94.6	81.8	86.6	79.4
16	62.3	28.4	27.5	34.0	37.3	32.2	43.5
23	59.1	84.2	91.6	79.7	81.4	72.7	87.9

Appendix: H-15 Raw Data for HF Power with RG (n.u.)

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	63.0	12.9	8.3	8.2	10.4	16.9	24.1
2	37.2	35.3	27.3	11.7	10.5	37.7	17.0
3	55.3	32.6	59.6	20.1	10.3	3.1	8.5
4	35.2	47.1	22.0	12.54	16.6	26.3	35.0
5	44.9	13.0	7.1	7.1	7.3	15.5	7.8
6	61.9	11.6	27.1	25.2	21.0	77.7	48.1
7	57.1	55.5	21.8	51.8	23.1	35.2	50.1
8	30.7	15.0	20.9	31.5	52.5	10.0	7.5
9	59.3	68.2	33.9	56.4	22.6	33.5	67.9
10	34.0	14.4	10.1	15.8	11.7	19.7	18.7
11	57.2	37.6	35.6	87.8	19.8	31.1	35.2
14	45.0	15.4	12.8	14.3	19.7	18.7	24.7
15	29.1	25.7	61.2	25.5	27.7	23.9	13.8
16	53.3	65.7	43.2	30.1	43.8	41.8	45.9
23	30.0	26.6	34.3	23.8	20.1	16.1	21.9

Appendix: H-16 Raw Data for HF Power with CG (n.u.)

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	55.2	34.2	37.9	23.8	27.0	35.3	42.0
2	30.8	61.2	41.6	48.2	40.1	40.5	40.5
3	57.0	63.8	7.8	8.9	72.5	8.4	10.9
4	51.7	22.2	36.8	35.4	18.3	47.1	55.7
5	28.3	16.9	16.8	10.3	7.8	22.7	13.1
6	48.7	8.2	19.0	11.0	59.1	60.6	62.7
7	33.2	70.9	54.3	59.7	24.0	20.8	25.2
8	24.6	9.0	66.7	7.1	7.3	26.6	21.7
9	58.4	35.8	41.5	65.0	38.8	47.9	37.9
10	28.9	11.0	7.8	10.4	26.9	20.5	13.3
11	85.9	57.0	17.4	5.0	10.1	13.5	8.0
14	31.1	12.1	10.8	4.7	5.8	18.0	27.7
15	47.3	14.3	7.1	5.4	18.0	13.4	20.3
16	37.5	71.3	72.5	65.9	62.5	67.2	56.5
23	40.9	15.6	8.4	20.3	18.6	27.2	12.1

Appendix: H-17 Raw Data for LF/HF Power with RG (n.u.)

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	0.585	6.735	11.007	11.215	8.594	4.907	3.139
2	1.684	1.818	2.664	7.559	8.475	1.643	4.889
3	0.807	2.044	3.229	11.144	8.085	31.267	10.788
4	1.838	1.121	3.538	6.976	5.018	2.801	1.847
5	1.227	6.701	13.117	13.117	12.700	5.429	11.737
6	0.615	7.647	2.685	2.972	3.759	3.476	1.076
7	0.751	0.795	3.572	0.921	3.332	1.839	0.988
8	2.257	5.627	3.788	2.175	0.901	9.029	12.397
9	0.685	0.463	1.937	0.768	3.411	1.982	0.471
10	1.939	5.955	8.941	5.315	7.547	4.083	4.341
11	0.748	1.658	1.783	7.426	4.041	2.281	1.832
14	1.222	5.486	6.768	5.982	4.029	4.289	3.025
15	2.433	0.368	0.582	2.915	2.594	3.185	6.237
16	0.873	0.519	1.307	2.314	1.278	1.394	1.179
23	2.331	2.752	1.915	3.189	3.978	5.225	3.567

Appendix: H-18 Raw Data for LF/HF Power with CG (n.u.)

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	0.810	1.909	1.634	3.190	2.688	1.830	1.378
2	2.248	0.633	1.396	1.073	1.489	1.462	1.469
3	0.752	3.466	11.805	10.263	9.998	10.833	8.141
4	0.931	3.493	1.705	1.819	4.474	1.120	0.795
5	2.534	4.901	4.923	8.695	11.758	3.401	6.624
6	1.052	11.123	4.240	8.104	0.690	0.648	0.594
7	2.008	0.397	0.836	0.661	3.160	3.802	2.968
8	3.058	10.103	0.499	13.038	12.780	2.750	3.609
9	0.711	1.790	1.396	0.497	1.565	1.088	1.632
10	2.460	8.114	11.841	8.586	2.720	3.888	6.529
11	0.163	0.744	4.737	19.122	8.870	6.407	11.452
14	2.211	7.228	8.274	20.356	16.186	4.557	2.603
15	1.113	5.987	13.176	17.585	4.537	6.488	3.907
16	1.664	0.398	0.38	0.516	0.597	0.479	0.769
23	1.442	5.392	10.921	3.934	4.377	2.671	7.286

APPENDIX I:
Raw Data for HR

Appendix: I-1 Raw Data for HR with RG

Subject ID	Baseline	Peak	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	47	180	83	83	80	71	68	69
2	70	177	110	100	100	98	100	98
3	62	188	94	92	89	87	86	86
4	58	202	102	96	94	87	87	87
5	74	190	111	107	104	102	98	98
6	61	187	93	90	84	84	79	73
7	60	198	99	99	95	91	87	85
8	84	195	101	101	100	102	100	101
9	46	190	98	92	94	94	93	88
10	68	195	105	102	99	95	96	94
11	67	185	97	96	94	88	88	87
14	55	191	98	94	93	88	88	89
15	46	168	83	81	76	74	73	70
16	55	172	90	87	85	82	81	78
23	77	172	93	89	85	81	80	80

Appendix: I-2 Raw Data for HR with CG

Subject ID	Baseline	Peak	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	47	172	85	75	66	69	67	68
2	65	171	98	96	94	89	86	83
3	54	188	96	91	88	84	84	83
4	54	188	92	88	85	81	78	77
5	98	194	113	106	104	98	96	94
6	67	189	98	97	90	83	85	83
7	61	190	102	95	95	94	88	90
8	69	189	102	100	96	92	92	88
9	47	185	89	87	85	85	81	75
10	68	196	99	96	95	94	85	84
11	68	196	103	99	98	98	94	91
14	60	191	94	93	94	84	84	79
15	57	177	85	87	82	79	78	77
16	59	181	92	90	87	86	85	86
23	74	181	88	85	86	79	82	80

APPENDIX J:
Raw Data for PRS Scores

Appendix: J-1 Raw Data for PRS with RG

Subject ID	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	2	5	7	8	9	9
2	3	5	6	6	7	8
3	7	9	10	10	10	10
4	7	8	9	10	10	10
5	4	4	5	5	5	5
6	5	8	9	10	10	10
7	6	8	8	9	9	9
8	4	7	8	9	9	10
9	4	7	7	8	8	8
10	6	8	9	10	10	10
11	5	8	8	9	9	9
14	8	8	8	9	9	10
15	3	4	7	7	7	8
16	8	8	9	9	10	10
23	7	8	9	9	9	9

Appendix: J-2 Raw Data for PRS with CG

Subject ID	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	3	6	7	8	8	9
2	4	4	4	5	5	7
3	5	8	10	10	10	10
4	5	7	8	8	8	9
5	5	7	8	8	8	8
6	2	3	4	5	6	8
7	7	7	7	7	8	9
8	4	7	8	9	9	10
9	5	5	6	8	9	9
10	6	8	9	10	10	10
11	6	8	9	9	10	10
14	6	8	9	10	10	10
15	4	6	7	8	7	7
16	6	8	8	9	8	8
23	4	6	6	7	7	8

APPENDIX K:
Raw Data for FRS

Appendix: K-1 Raw Data for FRS with RG

Subject ID	Post Exercise	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	10	8	7	5	3	1	1
2	10	5	5	5	4	3	3
3	10	6	3	2	1	1	0
4	6	2	2	1	0	0	0
5	8	6	6	6	5	5	5
6	8	5	2	1	0	0	0
7	9	4	3	3	2	1	1
8	8	4	2	1	1	1	0
9	8	5	3	3	2	2	2
10	9	5	2	1	0	0	0
11	8	5	2	1	1	0	0
14	9	7	5	3	2	1	1
15	6	5	4	3	2	2	1
16	7	5	3	2	1	1	1
23	6	4	2	2	1	1	1

Appendix: K-2 Raw Data for FRS with CG

Subject ID	Baseline	5min post	10min Post	15min post	20min Post	25min Post	30min Post
1	10	8	5	4	3	2	1
2	10	6	6	6	6	5	4
3	9	6	4	2	1	1	0
4	7	5	4	5	4	4	3
5	7	5	3	2	2	2	2
6	9	7	6	5	4	3	1
7	9	5	5	4	3	2	1
8	8	6	2	2	1	1	1
9	8	4	4	3	3	2	1
10	7	5	3	1	0	0	0
11	8	5	2	1	0	0	0
14	8	4	2	2	1	1	0
15	7	6	5	3	2	2	2
16	9	8	6	5	4	3	2
23	6	4	4	3	3	2	1

APPENDIX L:
Raw Data for VO2max and Exercise Time

Subject ID	1st visit		2nd visit	
	VO2max	Total exercise time	VO2max	Total exercise time
1	44.7	22'51"	51.2	23'47"
2	43.2	18'12"	42.7	19'42"
3	45.2	21'05"	45.0	19'50"
4	51.9	18'41"	43.7	18'36"
5	38.2	18'02"	42.1	18'24"
6	46.7	21'45"	48.9	22'08"
7	41.7	19'05"	44.8	19'25"
8	46.5	19'34"	45.0	20'12"
9	50.7	19'52"	58.2	17'42"
10	59.1	16'00"	54.2	17'01"
11	40.8	20'15"	42.3	18'03"
14	46.3	22'11"	45.8	22'12"
15	35.1	20'45"	41.4	20'58"
16	45.5	17'17"	49.0	15'17"
23	45.9	19'56"	43.3	20'09"

APPENDIX M:
Raw Data for RPE

Appendix: M-1 Raw Data for RPE (RG trial)

Subject ID	End of 1st stage			End of Active recovery			End of 2nd stage		
	legs joints	chest breathing	overall	legs joints	chest breathing	overall	legs joints	chest breathing	overall
1	20	20	20	17	17	17	20	20	20
2	20	20	20	18	18	18	19	20	19
3	20	20	20	17	15	16	20	20	20
4	8	10	12	8	8	8	12	11	12
5	17	16	16	13	13	13	17	16	16
6	15	17	16	9	9	9	14	16	15
7	13	15	16	6	8	8	16	19	18
8	15	16	16	11	12	12	12	19	17
9	17	17	17	13	13	13	18	18	18
10	13	15	14	12	12	12	14	15	14
11	15	17	17	14	14	14	16	17	17
14	18	18	18	12	10	11	17	18	17
15	11	12	12	11	12	12	15	15	14
16	13	17	16	12	9	10	16	13	15
23	16	12	10	13	10	10	15	14	12

Appendix: M-2 Raw Data for RPE (CG trial)

Subject ID	End of 1st stage			End of Active recovery			End of 2nd stage		
	legs joints	chest breathing	overall	legs joints	chest breathing	overall	legs joints	chest breathing	overall
1	20	19	20	10	9	10	19	20	20
2	19	19	19	12	12	12	20	20	20
3	17	18	18	11	10	11	18	18	18
4	12	14	13	10	8	10	16	10	12
5	17	17	17	12	12	12	16	16	16
6	15	17	15	9	9	9	17	17	17
7	16	18	18	6	7	6	16	18	17
8	13	17	17	14	16	15	15	19	17
9	17	17	17	10	10	10	18	18	18
10	14	15	14	12	12	13	15	16	15
11	15	15	15	16	16	16	17	19	19
14	18	15	17	10	8	9	16	14	15
15	13	13	13	12	12	12	14	14	14
16	17	17	19	17	14	16	17	16	18
23	14	13	12	15	13	12	16	12	13

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