



## Central Hemodynamics Measured During 5 Repetition Maximum Free Weight Resistance Exercise

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### ABSTRACT

*International Journal of Exercise Science* 11(2): 342-354, 2018. The PhysioFlow™ is a piece of equipment that uses bioimpedance cardiography to measure central hemodynamics. The purpose of this research was to explore the novel approach of monitoring central hemodynamics during free weight resistance exercise using bioimpedance cardiography throughout a 5 repetition maximum (5RM). Thirty participants ranging from beginner to advanced lifters (16 males and 14 females) completed a 5RM for back squat, seated push press, and bicep curl while connected to the PhysioFlow™ to assess the response of heart rate (HR), stroke volume (SV), cardiac output (Q), and ejection fraction (EF). Participants were cued for form and to breathe normally throughout the lifts. The PhysioFlow™ detected an increase in HR and Q for all lifts between rest and each repetition ( $p < 0.05$ ). There was also an increase in HR and Q from repetition 1 to repetition 5 for all lifts ( $p < 0.05$ ). No changes in EF or SV were detected between resting measurements and each repetition for all lifts ( $p > 0.05$ ) and no changes in EF or SV were detected when all repetitions were compared to each other for all lifts ( $p > 0.05$ ). In conclusion, the PhysioFlow™ was able to detect changes in HR and Q during dynamic free weight resistance exercise. This novel approach may provide a mechanism for monitoring central hemodynamics during free weight resistance training. However, more research needs to be conducted as the exercise protocol for this investigation did not allow for a comparison to a reference method.

KEY WORDS: PhysioFlow™, bioimpedance cardiography, weight lifting, cardiac output

### INTRODUCTION

Resistance exercise is an important component of exercise programming for all individuals including athletes, the general population and those with chronic diseases. Current guidelines suggest resistance training should be performed 2 to 3 days per week and incorporate all large muscle groups for general health purposes (1). There are many physical and physiological adaptations that occur with resistance exercise that are beneficial to all individuals. Those changes include but are not limited to an increase in muscle power, strength, endurance and size, increase in bone mineral density, reduced body fat, and elevated metabolism (16). Resistance exercise has also been shown to affect acute central hemodynamic variables such as heart rate, stroke volume, cardiac output, ejection fraction, and systolic and diastolic blood

pressure (8, 12-17, 22, 23, 26, 27, 31). However, the techniques and protocols for assessing these variables are not consistent throughout the literature as technology has changed and resistance training protocols include various modalities, sets, and repetitions.

In the past, central hemodynamic variables measured during resistance exercise have been assessed mainly by the direct Fick method or dye-dilution method which are invasive procedures that require catheters and skilled technicians (4-6, 10, 11, 18, 20, 21, 29). Using the direct Fick method or dye-dilution also limits the execution of resistance exercises due to movement restrictions imposed on participants. For example, past studies were often limited to single joint exercises, and by controlling the timing of each segment of the lift. Controlling the timing for a lift may affect hemodynamics if the participant is not accustomed to lifting in this manner or if an unnatural breathing pattern occurs. Echocardiogram is another method that has been used to obtain central hemodynamic variables (4-6, 10-12, 14, 18, 20, 21, 23, 29). While this technique is less invasive it requires the torso of the participant to be still during exercise or the measurements must be taken after exercise. Bioimpedance cardiography is another non-invasive way to determine hemodynamics. Bioimpedance uses a high frequency electrical current and measures the changes in the electrical current that occur in the torso during each beat of the heart to determine central hemodynamics. The bioimpedance cardiography method can be used to assess central hemodynamic variables during exercise without requiring a participant to refrain from moving certain portions of their body.

The PhysioFlow™ is a device that measures central hemodynamics using bioimpedance cardiography. The electrical current is obtained through electrodes placed on the neck, chest and back. Bioimpedance cardiography technology has been around for decades (19) however, there have been few investigations involving resistance exercise (4, 8, 10, 13, 17, 18, 20). The limited amount of research may be due to the fact that some research has indicated that bioimpedance cardiography may underestimate the values for hemodynamic variables (10, 11). Yet other research has indicated that the PhysioFlow™ is a valid and reliable way to measure hemodynamic variables under various conditions such as during rest, aerobic activity, or surgeries (2, 3, 9, 25, 30).

Assessing central hemodynamics during resistance exercise may allow for the development and monitoring of resistance training programs for clinical and healthy populations. Monitoring central hemodynamic variables during such programs would allow for more precise adjustments to be made in a program, which could greatly benefit clinical populations and may improve overall recovery and rehabilitation for many conditions. A better understanding of how the cardiovascular system responds to resistance exercise may also aid in adjusting exercise prescriptions which could delay and/or resolve issues that some individuals may have in regards to cardiovascular function. Additionally, knowing how the cardiovascular system responds to different resistance exercise protocols may give insight on who may have adverse effects when participating in certain types of resistance exercise. Properly prescribing resistance exercise to all populations will help to maximize results while minimizing risk. Therefore, the purpose of this research was to explore the novel approach of



monitoring central hemodynamics during free weight resistance exercise using bioimpedance cardiography throughout a 5 repetition maximum (5RM).

## METHODS

### *Participants*

A total of 30 (16 males and 14 females) healthy individuals volunteered for this study and gave written informed consent prior to participation. Participants were between the ages of 18-44 years who were stratified as low risk using a health history questionnaire according to the American College of Sports Medicine (1). Participants' resistance training status varied from beginner to advanced, as defined by the National Strength and Conditioning Association (NSCA) (7). Exclusion criteria included females who were pregnant, and anyone who had known cardiovascular, pulmonary or metabolic diseases, any known orthopedic limitations, those who had a pacemaker, and those who did not stratify into the low risk category. Table 1 displays the descriptive information for the participants.

**Table 1.** Descriptive data (Mean  $\pm$  SD).

| Variable                  | Total Sample (N=30) | Men (N=16)       | Women (N=14)    |
|---------------------------|---------------------|------------------|-----------------|
| Age (yrs)                 | 23.2 $\pm$ 2.4      | 23.5 $\pm$ 2.3   | 22.8 $\pm$ 2.5  |
| Weight (kg)*              | 75.6 $\pm$ 13.4     | 85.3 $\pm$ 8.6   | 64.5 $\pm$ 8.2  |
| Height (cm)*              | 172.4 $\pm$ 10.3    | 179.8 $\pm$ 7.3  | 163.9 $\pm$ 5.3 |
| Body Fat (%)*             | 23.7 $\pm$ 8.0      | 18.7 $\pm$ 5.7   | 29.5 $\pm$ 6.1  |
| Squat 5-RM max (kg)*      | 96.1 $\pm$ 32.1     | 119.3 $\pm$ 19.9 | 69.6 $\pm$ 20.7 |
| Push Press 5-RM max (kg)* | 37.7 $\pm$ 16.0     | 51.0 $\pm$ 8.1   | 22.4 $\pm$ 5.4  |
| Bicep Curl 5-RM max (kg)* | 28.2 $\pm$ 11.1     | 37.5 $\pm$ 5.4   | 17.7 $\pm$ 4.4  |

\* = Significant difference between men and women

### *Protocol*

All procedures used in this study were approved by the Institutional Review Board. Before testing, participants were instructed to abstain from exercising for 24 hours, drinking alcohol for 24 hours, and eating for 2 hours, and to abstain from medications and stimulants the day of the test and during the test. For this study all participants entered the lab on two separate occasions for approximately 1.5 hours of testing. Both visits were required to occur over no longer than a 1 week period and have at least 48 hours in between visits. All participants were also advised to wear athletic attire that was absent of metal.

**Familiarization Session:** All participants completed a demographic questionnaire that included questions about activity level, age, sex, and race and a health history questionnaire. After completion of questionnaires, resting blood pressure was taken with a sphygmomanometer and stethoscope after the participant had been seated for at least 5 minutes. Height and weight were taken using the Tanita WB-3000 (Arlington Heights, Illinois) electronic physician's scale and stadiometer. Body composition was assessed with Dual Energy X-ray Absorptiometry using the GE Lunar iDEXA (Madison, Wisconsin). The participants started with a standardized warm up (Table 2) using only their body weight. Following the warm up participants were guided in finding their 5-repetition maximum for the barbell back squat,

barbell seated push press, and barbell bicep curl. All 5-repetition maximums were determined by first performing 10 repetitions of each exercise at a light weight which was initially decided with input from each participant. To estimate this initial load, participants were instructed to choose a weight which they felt would coincide with being able to complete 10 repetitions with proper form, and where additional repetitions would not have been performed properly. With a minimum of 2 minutes of rest but not exceeding 4 minutes of rest, the weight was then progressively increased for each set until only 5 repetitions could be completed (7). A 5-repetition maximum was chosen because participants' level of training ranged from beginner to advanced. Hemodynamics were measured during a protocol associated with muscular strength which requires a repetition range of 1-6, however the NSCA does not recommend a 1 repetition max for non-advanced lifters (7, 28, 32). Back squat (Figure 1) was performed first followed by seated push press (Figure 2) with the back support in a vertical position. Last, participants performed bicep curls (Figure 3) with a standard barbell while standing with strict form (elbows fully extended to elbows completely flexed while not leaning back or moving elbows away from the body) (12).

**Table 2.** Standardized warm up.

| Exercise               | Description   | Reps                   |
|------------------------|---|------------------------|
| Cycling                | Stationary bike   | 5 min self-paced       |
| Good mornings          | Standing up with feet shoulder width apart and bending at the waist to approximately 90 degrees and then stand back up straight | 5                      |
| Wide leg good mornings | Standing up with a wide stance and bending at the waist to approximately 90 degrees and then stand back up straight             | 5                      |
| Sumo squats            | Squat to 90 degree bend in knees with feet placed wide and angled at 45 degrees   | 5                      |
| Inch worms             | Standing up with feet together and then bending over to touch the ground with your hands and walking them out and back in       | 3                      |
| Hip circles            | Lifting the leg off the ground and rotating in a circle motion  | 5 each leg             |
| Kick backs             | Laying prone and bending the knee of one leg at a time and touching the heel to the buttocks                                    | 5 each leg alternating |
| Glute bridges          | Laying supine with feet on the ground and lifting hips off the ground while keeping upper back on the ground                    | 10                     |
| Push-ups               | Laying prone with hands and toes in contact with the ground push upwards off the ground   | 10                     |
| Press-ups              | Similar to a push-up but instead of keeping the body aligned, push the hips up  | 10                     |
| Scorpion               | Laying prone with hands stretched out try to touch your hand with the opposite foot by reaching back across your body           | 5 each leg             |
| Squat                  | Feet shoulder width apart bend at the knees to 90 degrees and stand back up, keeping knees aligned with toes                    | 5                      |
| Jump squat             | Explosive move where a squat is executed and a vertical jump is performed on the way up   | 5                      |

Testing Session: Participants returned to the lab between 48 hours and 7 days after the familiarization session. They started by resting in a seated position for 5 minutes which was followed by obtaining resting blood pressure in the same manner as the first visit. Next participants were seated in a chair to have electrodes placed for the PhysioFlow™ (Bristol,

Pennsylvania). Areas that required electrode placement were first prepared by removing hair. Next, Nuprep (Aurora, Colorado), an abrasive gel, was applied to the area to remove dead skin. This was then cleaned using an alcohol swab and allowed to dry. Following preparation of the sites, six Skintact FS-TB (Inverness, Florida) electrodes were placed on the body. Two were placed on the left side of the neck (Figure 4). The first was in line with the beginning of the earlobe just below the jaw line and the second slightly inferior and medial to the first electrode. One was placed on the chest at the midpoint of the sternum (Figure 5). Another was placed in the same location of the V6 electrode for an electrocardiogram (Figure 5). The final two electrodes were placed on the back, with one at the height of the xiphoid process just to the left of the spine, and the other was placed slightly inferior and lateral to the first electrode (Figure 6). Once all electrodes were attached a chest strap was secured around the participant. The chest strap was used to hold the junction box, where all the PhysioFlow™ wires joined together into one wire, to the body. Resting measurements for heart rate, stroke volume, cardiac output and ejection fraction were taken for one minute. Measurements taken by the PhysioFlow™ started with entering each participant's information into the PhysioFlow™ software. Once this was done the PhysioFlow™ calibrated to each person using 30 of their own heartbeats. While calibrating, participants were asked to sit still and refrain from talking. Upon completion of the calibration, measurements were recorded. After resting data were collected participants progressed through the standardized warm up. After the warm up, the same protocol from the familiarization session to determine the 5-repetition maximum was repeated for barbell back squat, barbell seated push press, and standing barbell bicep curl. The familiarization session information on 5 repetition maximums was utilized to insure that participants could work up to their maximums but not overly fatigue their muscles trying to find their true 5 repetition maximum. Measurements from the PhysioFlow™ were recorded once attempts for a 5-repetition maximum were started. The data collected for the highest weight achieved for each lift was used for statistical analysis.



**Figure 1.** Back Squat



**Figure 2.** Push Press

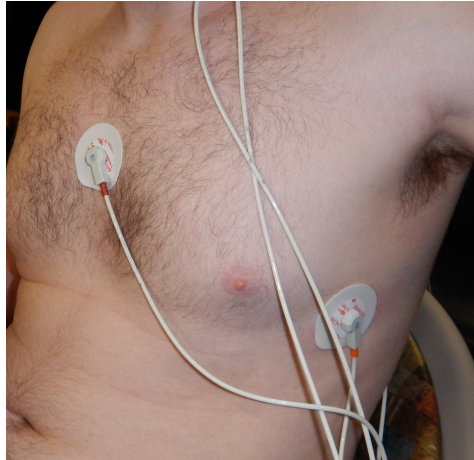


**Figure 3.** Bicep Curl

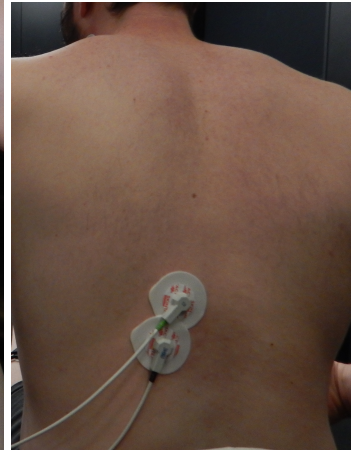




**Figure 4.** Electrodes on neck



**Figure 5.** Electrodes on Chest



**Figure 6.** Electrodes on back

### *Statistical Analysis*

All statistical analyses were performed using SPSS version 20 (Armonk, New York) for Microsoft Windows. Descriptive information was determined for age, sex, weight, height, body fat percentage, and maximal five repetition weight for each lift. A repeated measures ANOVA was used to compare heart rate, stroke volume, cardiac output and ejection fraction during each repetition of a lift to all other repetitions of that lift and against resting measurements. A multi-variate repeated measures ANOVA was run by sex to determine if there were any differences in the responses of hemodynamic variables between males and females. Significance level was set at  $p < 0.05$ .

## **RESULTS**

**Sex Differences in Hemodynamics:** There were no differences between males and females for all measurements for any lift or repetition ( $p > 0.05$ ).

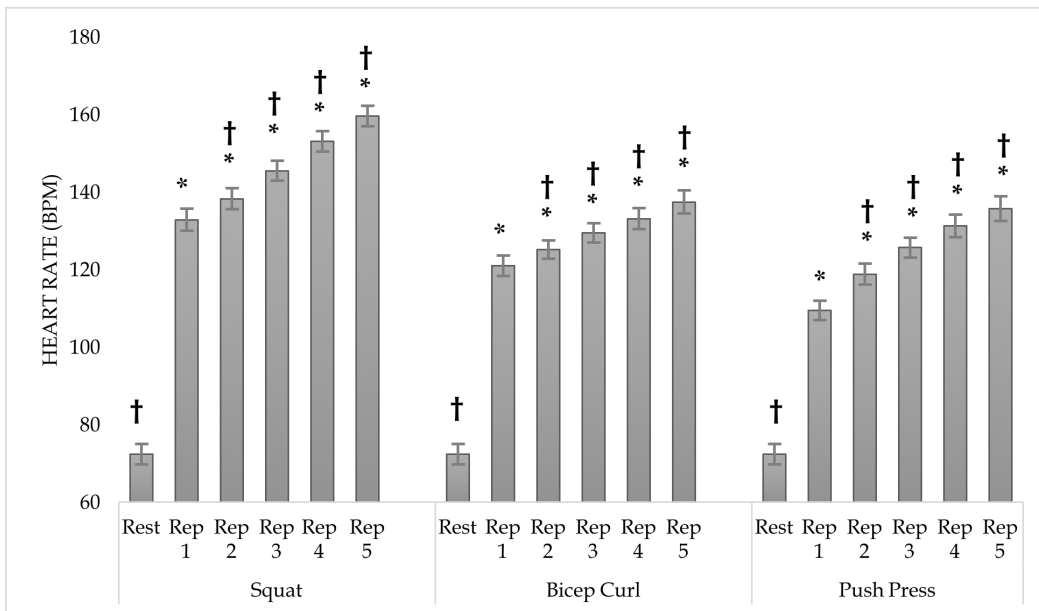
**Heart Rate Response to Resistance Exercise:** Heart rate was shown to increase significantly during each lift. Heart rate response during back squat exercise more than doubled from rest to the 5<sup>th</sup> repetition ( $p < 0.05$ ). During push press and bicep curl heart rate nearly doubled from rest through the 5<sup>th</sup> repetition ( $p < 0.05$ ). All exercises showed an increase in heart rate of at least 10 bpm from the first repetition to the 5<sup>th</sup> repetition of exercise ( $p < 0.05$ ). Figure 7 displays heart rate results for all lifts and repetitions where heart rate increased with every repetition for all exercises ( $p < 0.05$ ).

**Stroke Volume Response to Resistance Exercise:** There were no differences observed during any of the lifts between rest and all repetitions for any of the lifts ( $p > 0.05$ ). Figure 8 displays results for stroke volume for all lifts and repetitions.

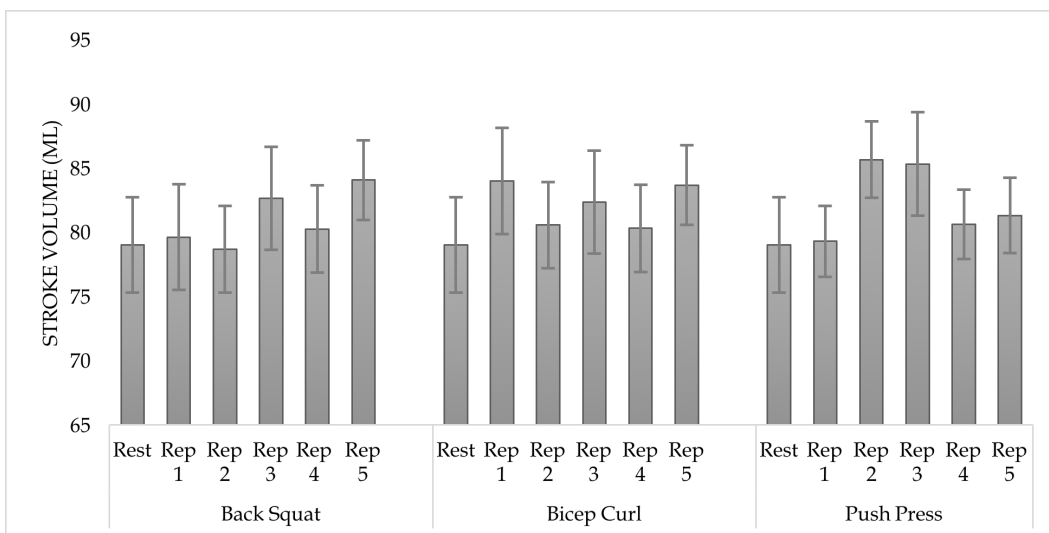
**Cardiac Output Response to Resistance Exercise:** Overall, cardiac output increased during each resistance exercise. Similar to HR there was an increase between rest and all repetitions for all lifts. However for the squat, only the 4<sup>th</sup> and 5<sup>th</sup> reps were different from the 1<sup>st</sup> rep ( $p <$

0.05). For the bicep curl only the 5<sup>th</sup> rep was different from the 1<sup>st</sup> rep ( $p < 0.05$ ). For the push press all reps were different compared to the 1<sup>st</sup> rep ( $p < 0.05$ ). Figure 9 displays cardiac output results for all lifts and repetitions where cardiac output increased from rest during all exercises ( $p < 0.05$ ).

Ejection Fraction Response to Resistance Exercise: There were no differences observed during any of the lifts between rest and exercise when looking at ejection fraction ( $p < 0.05$ ). Ejection fraction did not change when comparing any of the repetitions for an exercise to any other repetitions of that exercise ( $p < 0.05$ ). Figure 10 displays results for ejection fraction for all lifts and repetitions.

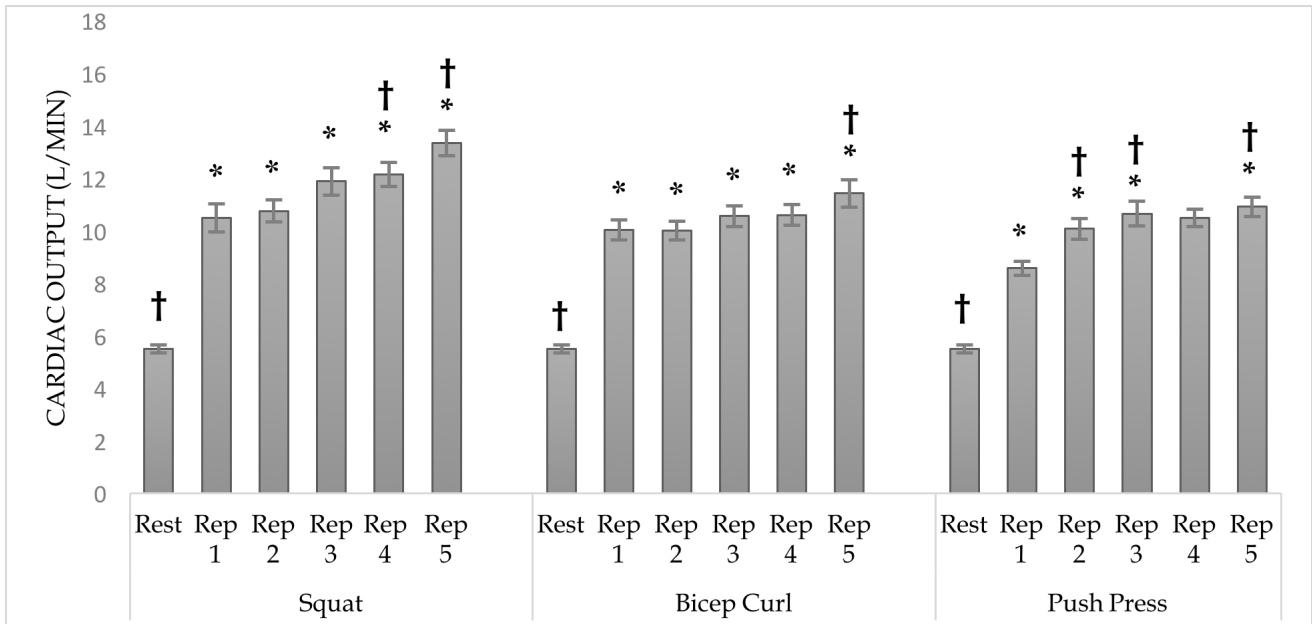


**Figure 7.** Heart rate response to resistance exercise (mean  $\pm$  SE). \* = Significantly different from rest ( $p < 0.05$ ), † = Significantly different from rep 1 ( $p < 0.05$ ).

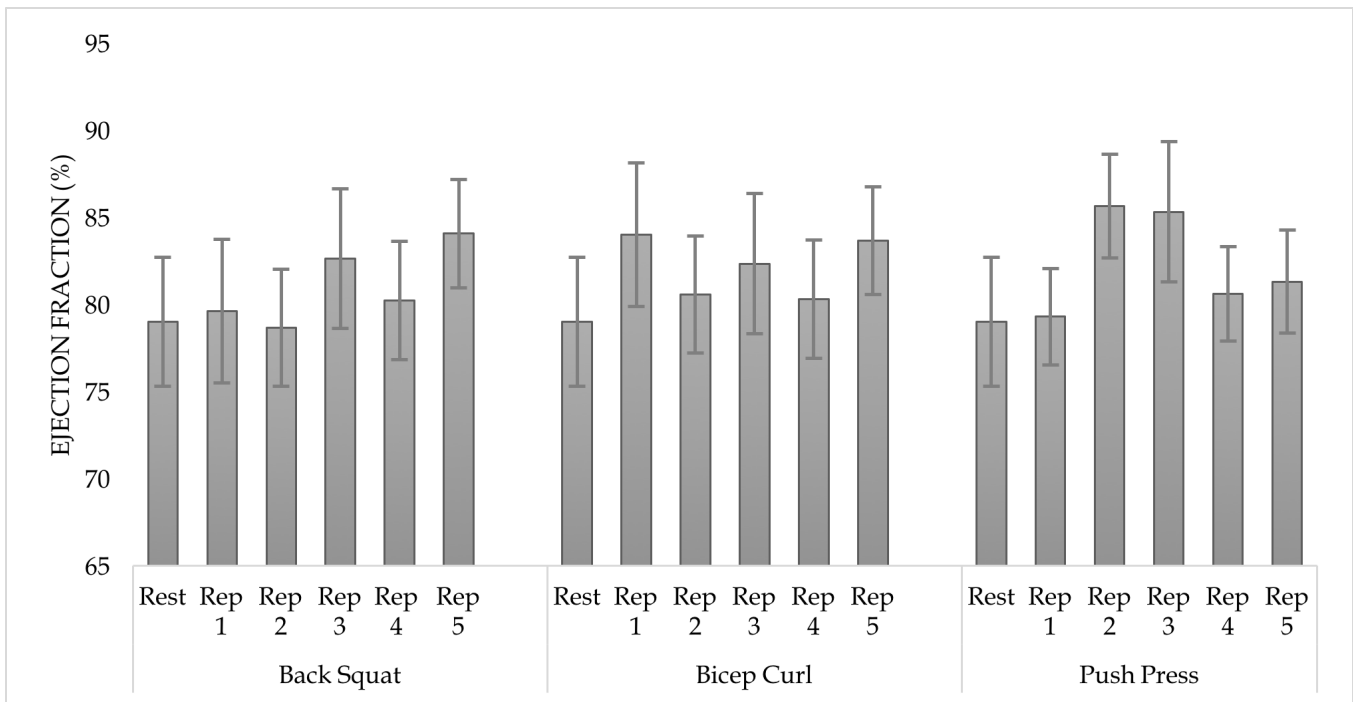


**Figure 8.** Stroke volume response to resistance exercise (mean  $\pm$  SE). No measurements were significantly different from each other ( $p > 0.05$ ).





**Figure 9.** Cardiac Output Response to Resistance Exercise (mean ± SE). \* = Significantly different from rest ( $p < 0.05$ ), † = Significantly different from rep 1 ( $p < 0.05$ ).



**Figure 10.** Ejection Fraction Response to Resistance Exercise (mean ± SE). No measurements were significantly different from each other ( $p > 0.05$ ).

## DISCUSSION

The purpose of this research was to explore the novel approach of monitoring central hemodynamics during free weight resistance exercise using bioimpedance cardiography throughout a 5 repetition maximum. It was determined that heart rate during all lifts and

repetitions was higher than during rest. This was expected as heart rate increases with increasing intensity for all forms of exercise. Heart rate also increased consistently from repetition 1 to 5 of each lift. This was expected as heart rate takes time to reach steady state with the onset of exercise. Most 5 repetition sets of exercise in this study took between 10 and 30 seconds to complete. Heart rate can take between two to three minutes to reach steady state from the onset of exercise, especially for high intensity bouts. This study had similar results regarding an increase in heart rate compared to past research that has also examined heart rate during resistance exercise (12-14, 17, 22, 26, 27).

In this investigation stroke volume had no significant changes from rest. These results are different from past investigations that measured stroke volume during isometric deadlifts, isometric leg extensions, machine leg extensions and during isometric squatting using various methods for measurements (8, 17, 26, 27). However, our results were similar to an investigation of hemodynamic variables that utilized bioimpedance cardiography and isokinetic exercise (13). The failure to see stroke volume increase during resistance exercise may be attributed to the relatively short period of time that each lift was performed. Exercises in this investigation had a maximum time of about 30 seconds, while in previous studies exercise duration ranged from 90 seconds to 4 minutes (17, 23, 26, 27). The upright body position of each lift could have contributed to the failure to see stroke volume increase as well. This may be due to blood pooling in the lower body due to gravity and during the lift the strong contraction of the muscle may impede blood flow back to the heart by occluding vessels. This would diminish the expected increase in blood flow to the heart that is normally seen with aerobic exercise and in response there would not be an increase in stroke volume.

Cardiac output was higher for all lifts and repetitions compared to resting values. Only the push press demonstrated a consistent increase in cardiac output from repetition 1 to repetition 5. However, during the squat only the 4<sup>th</sup> and 5<sup>th</sup> repetitions differed from the first, and for the bicep curl cardiac output did increase during the lift but a change in cardiac output from repetition 1 was not seen until repetition 5. This may be due to the smaller and fewer muscles that are recruited in order to perform the bicep curl. The muscles used for this single-joint movement compared to a multi-joint movement put less of a demand on the cardiovascular system and thus attenuates the rise of cardiac output that was seen in other exercises. This indicates as resistance exercise continues cardiac output increases to meet the demand of muscle tissue for these exercises. This increase of cardiac output during resistance exercise is similar to past research that measured cardiac output in special populations and during isokinetic and isotonic exercises (8, 13, 14, 26, 27). All cardiac output increases were driven by heart rate increases as stroke volume did not significantly increase during resistance exercise in this investigation.

Ejection fraction demonstrated no change from rest. Overall, these results do not match previous research which has shown both an increase and decrease in ejection fraction with isometric exercise (26, 27). Ejection fraction not changing may be explained by stroke volume not increasing during resistance exercise. This result may be attributed to a potential direct relationship between stroke volume and ejection fraction. (12). Since stroke volume did not increase, myocardial tissue did not experience Frank Starling's Law of the Heart (24) which

could have increased ejection fraction due to tissue stretching. An increase in stroke volume may have indicated that more blood was returning to the heart than at rest. This would have led to a stretching of the ventricular chamber in order to hold more blood. This stretching, in addition to allowing more blood into the heart, would have caused a stronger heart contraction because of the increased resting potential of myocardial fibers. The result would be that a larger fraction of the blood going into the heart would be ejected during each heartbeat.

The PhysioFlow™ was able to detect changes in hemodynamic variables during resistance exercise. Results from this study that differed from past investigations may be explained by a few factors (8, 12, 17, 26, 27). First, this study is different from past investigations in that central hemodynamics were determined during non-restrictive resistance exercise that was not limited by non-healthy individuals, invasive requirements for obtaining measurements, and included movements that translate into activities of daily living. Participants performed exercises with free weights and not selectorized equipment, and performed both single and multi-joint, exercises. Using free weights may change the demand put on the cardiovascular system because they require more activity from stabilizing muscles to perform the movement. Additionally, individuals may not be accustomed to selectorized equipment causing the body to respond differently to the exercise. Next, in order to replicate how these exercises would be performed outside of a research setting participants were allowed to lift in a manner that was comfortable to them without controlling for torso movement, or extremity movement that occurs due to the use of certain resistance training equipment, however participants were cued for proper form per NSCA guidelines (7). The timing of each phase of the lift was also not controlled. Most lifts were completed between 10 and 30 seconds. This is a short period of time for all cardiovascular variables to change. These factors may have influenced hemodynamics; however participants did not have to exercise in a way that they were unaccustomed to during the assessments. Lifting in a way that a participant is accustomed to may put less stress on the body because the motor pathways can work more autonomously allowing the body to work more efficiently. Finally, the PhysioFlow™ may not have detected some changes in hemodynamic variables during resistance exercise because of the duration of the lifts during this investigation were less than or equal to 30 seconds and it may underestimate changes in hemodynamics (10, 11).

The PhysioFlow™ has demonstrated the ability to measure and monitor hemodynamic variables during resistance exercise. The accuracy of heart rate measurements were supported by other studies (12-14, 17, 22, 26, 27). Stroke volume, cardiac output and ejection fraction results differed from previous studies (8, 17, 26, 27). While results in this investigation may differ from past investigations, a direct comparison cannot be made. This is due to the differences such as exercise protocols, the use of clinical populations, and restricted movement of non-exercising body parts. The current study indicates that there are different central hemodynamic responses to different types and styles of resistance exercise. The PhysioFlow™ may be a good way to monitor central hemodynamics during traditional free weight resistance exercise. The accuracy of PhysioFlow™ measurements for this study are difficult to compare to past investigations as exercise protocols are very different. Additionally, the chosen protocol

is unrealistic if using the direct Fick method, dye-dilution or echocardiogram to measure cardiovascular function and compare to the PhysioFlow™.

This study had several strengths. Participants had a familiarization session with the protocol used to determine the 5-repetition maximum which allowed for a better estimate of the 5-repetition maximum during the testing session. There was a fairly equal distribution of males and females which allowed for the comparison between sexes, which had not previously been studied. This study also sought to replicate an authentic resistance training experience by investigating both upper and lower body exercises. Additionally, the utilization of free weights is a common modality for resistance exercise and most research on hemodynamic variables has used more restrictive modes of resistance training. Finally, measurements were taken during multi-joint and single-joint exercises, which imitate a practical and realistic application of resistance training. A few limitations need to be noted. Although the implications of these results may be applicable to clinical populations, these data were collected on a fairly young healthy population of mostly (80%) Caucasian participants. While participants were instructed to breathe and not to perform the Valsalva maneuver, this study did not control for breathing such as instructing participants to exhale during concentric movements. Controlling for this may have allowed for more consistent measurements during each repetition. Future research should investigate how accurate the PhysioFlow™ is at monitoring blood pressure during resistance exercise to determine real time myocardial demand. Additionally, investigating the PhysioFlow™ with clinical populations during resistance exercise may yield different results. Those who have congestive heart failure, suffered from heart attacks, or those at a high risk for a cardiac event during exercise could benefit from knowing myocardial demand and cardiovascular function to prevent cardiac events during resistance exercise (12).

In summary, the PhysioFlow™ was able to measure hemodynamic variables, but the results of this study varied when compared to results of other studies. This study demonstrated an increase in heart rate and cardiac output and no changes in stroke volume and ejection fraction during 5-repetition maximum free weight resistance exercise. There were no differences between males and females when measuring central hemodynamics. In conclusion, the PhysioFlow™ was able to measure hemodynamic variables during dynamic free weight resistance exercise. However, more research needs to be performed as this was a novel approach to monitoring hemodynamic variables and the protocol for this investigation did not allow for a comparison to a reference method.

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