

**The influence of two-way breathing valves on determining physiological responses
during a graded exercise test in recreationally active and endurance trained males**

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Abstract

The determination of an individual's physiological responses to a graded exercise test (GXT) is a fundamental tool in the field of exercise physiology utilized in clinical, applied and/or research settings. A GXT often requires the use of a two-way breathing valve, which directs inspiratory and expiratory airflow. Although the two-way breathing valve allows for the collection and measurement of expired air, it also imposes resistances to airflow. Airflow resistances are different between the commonly used Hans Rudolph 2700 and the Daniels' two-way breathing valves. The differences in airflow resistance may increase the work of breathing, which may alter an individual's physiological responses to a GXT. Thus, the purpose of this study was to examine differences in physiological responses during a GXT when using a Hans Rudolph 2700 versus a Daniels' breathing valve. Fourteen healthy male subjects (7 recreationally active and 7 endurance trained) aged 18-35 years old volunteered to participate in this study. On two separate occasions, subjects performed identical GXTs. One GXT used the Hans Rudolph 2700 breathing valve and the other utilized the Daniels' breathing valve. The GXTs were completed on a treadmill and consisted of a submaximal and a maximal phase. During the submaximal phase, speed was increased one mph every four minutes. Running economy (RE), expired ventilation (V_E), heart rate (HR) and arterial oxygen saturation (S_aO_2) were measured during this phase. The maximal phase increased grade 1% every minute until volitional exhaustion. Peak oxygen consumption (VO_{2peak}), V_E , HR and S_aO_2 were measured during the maximal phase. Endurance trained subjects had significantly better RE ($p < 0.02$), lower V_E ($p < 0.01$) and higher S_aO_2 ($p < 0.01$) when using the Daniels' valve. There was no difference between valves in endurance trained subjects for peak VO_2 , V_E , HR, or S_aO_2 . Recreationally active subjects had no significant differences in any of the measured parameters between valves. These findings indicate that the assessments of an endurance trained individual's RE, V_E , and S_aO_2 are altered between the Hans Rudolph and Daniels' two-way breathing valves during submaximal exercise. Caution should be used when using the Hans Rudolph 2700 to determine physiological responses during submaximal exercise and when comparing research results that use two-way breathing valves with different airflow resistances at submaximal exercise.

Introduction

The determination of an individual's peak aerobic capacity, i.e. their VO_{2peak} , is a fundamental tool in the field of exercise physiology utilized in clinical, applied, and/or research settings. This is commonly determined during a graded exercise test (GXT) where work is progressively increased until volitional exhaustion. In addition to VO_{2peak} , GXTs allow researchers to analyze additional physiological parameters related to health and endurance performance such as running economy (RE), heart rate (HR), expired ventilation (V_E), and arterial oxygen saturation (S_aO_2). During a GXT, oxygen consumption (VO_2) and carbon dioxide production (VCO_2) are measured using an indirect calorimetric system. Key to this system is a two-way breathing valve that directs inspiratory and expiratory airflow. Even in controlled research settings, equipment like the two-way breathing valve may influence the assessment of the physiological responses to a GXT. These responses are used to prescribe exercise, predict performance and/or diagnose heart disease (Powers et al., 2014). Therefore, minimizing the influence that equipment may have on the assessment of physiological responses during a GXT is important.

There are a variety of breathing valves used for exercise testing, which include the Daniels' valve and the commonly used Hans Rudolph 2700 (Wagner et al., 2011). However, there is a clear distinction in airflow resistance between the Hans Rudolph 2700 and the Daniels' two-way breathing valves (Figure 1). The Hans Rudolph 2700 has resistance values of approximately 0.8 and 1.8 cm H_2O at flow rates of 100 and 200 L/min, respectively (Hans Rudolph Inc., 2015). In contrast, the Daniels' has 0.0 and ~ 0.1 cm H_2O of resistance at these same flow rates of 100 and 200 L/min, respectively (Daniels, 1971). Both two-way breathing valves demonstrate exponential increases in airflow resistance as V_E increases. However, the airflow resistances at all flow rates are greater with the Hans Rudolph 2700. Thus, individuals will experience the greatest airflow resistance at their maximal V_E while using the Hans Rudolph 2700.

Importantly, endurance-trained athletes are at a greater risk, compared to recreationally active individuals, to experience VO_{2peak} changes when using these breathing valves. Endurance-trained athletes are able to achieve higher V_E compared to recreationally active individuals. Studies show that highly trained individuals achieve maximal V_E that are approximately 35% greater than those who are untrained (183 vs. 136 L/min, respectively) (Folinsbee et al., 1982). This means trained athletes are more likely to experience higher airflow resistances that recreationally active individuals may not achieve during a GXT. For example, trained athletes would experience a resistance of ~ 0.1 cm H_2O at a V_E of 183 L/min and untrained individuals would have 0.0 cm H_2O resistance at a V_E of 136 L/min when using the Daniels' valve (Daniels, 1971). At the same V_E , trained athletes would experience a $\sim 50\%$ greater resistance compared to untrained individuals (~ 1.5 vs. ~ 1 cm H_2O , respectively) when using the Hans Rudolph 2700 valve (Hans Rudolph Inc., 2016). Due to higher V_E rates, endurance-trained athletes should experience higher resistances to airflow compared to recreationally active individuals.

In order to overcome the greater airflow resistance, there is an increase in respiratory muscle work. This increased work of breathing (WOB) will increase the oxygen requirement of the muscles involved with respiration. This could influence an individual's VO_{2peak} by diverting blood flow from the locomotor muscles to the respiratory muscles (Harms et al., 2000). If the reduction in VO_2 at the locomotor muscles is greater than the increase at the respiratory muscles, then VO_{2peak} may decrease. In contrast, if the reduction in VO_2 at the locomotor muscles is less than the increase in VO_2 at the respiratory muscles, then VO_{2peak} can increase. Finally, VO_{2peak} might not change if the VO_2 difference is equal and opposite. Therefore, the magnitude that VO_2 changes at the respiratory and locomotor muscles may determine if and how VO_{2peak} will change.

Also, disproportionate increases in WOB have been shown to develop at V_E above 120 L/min (Aaron et al., 1992). However, this exponential increase occurs earlier (~ 90 L/min) when

airflow resistances are added to a two-way breathing valve (Cerretelli et al., 1969). This would exacerbate the increases in WOB at lower V_E and might cause the respiratory system to experience physiological (Johnson et al., 1993) and mechanical (Dominelli et al., 2015) restraints that may prevent VO_{2peak} from being reached. This suggests that a two-way breathing valve with higher resistances to airflow will confound the interpretation of VO_{2peak} .

The influence of airflow resistance on VO_{2peak} is not just hypothetical. Studies have demonstrated changes to VO_{2peak} when resistance was added or removed from two-way breathing valves. These changes were explained by alterations in V_E and WOB (Dressendorfer et al., 1977; Babcock et al., 2002). However, the direction that VO_{2peak} changes is not clear (Figure 2). For example, Dressendorfer et al. (1997) found a 14% decrease in VO_{2peak} after adding inspiratory resistance. They also found a 60% reduction in V_E , which can partially explain the decrease in VO_{2peak} . This study demonstrates potential changes due to increases in airflow resistance. However, the difference in airflow resistances that this study reports were 45 times greater than the difference between the Hans Rudolph 2700 and Daniels' two-way breathing valves. In another study, researchers found no change in VO_{2peak} when they added airflow resistances to the inspiratory side (Harms et al., 1997). The differences in the airflow resistances were only four times greater, but the resistances to airflow for the control valve were still greater than the Daniels' valve. In addition, since expiratory airflow was unaltered, muscles involved in expiration during exercise are not experiencing the same increase in airflow resistance. The same study found an 8% decrease in VO_{2peak} when researchers used a ventilator to create a 6-fold reduction in the resistance to airflow. The ventilator reduced WOB, which explained the decrease in VO_{2peak} . Together, these studies demonstrate that different airflow resistances in two-way breathing valves can influence VO_{2peak} . However, neither study examined the physiological responses within the range of airflow resistances found between the Hans Rudolph 2700 and the Daniels' two-way breathing valves. Furthermore, unmodified two-way breathing valves have symmetrical expiratory and inspiratory resistances, which may elicit

a different response. Therefore, it is difficult to speculate how individuals will respond to the Hans Rudolph 2700 and the Daniels' two-way breathing valves during a GXT.

To our knowledge, no study has examined differences in VO_{2peak} between the Hans Rudolph 2700 and the Daniels' two-way breathing valves. If there were a difference between these two valves, then this would influence comparisons made between studies and the assessment of GXTs. Thus, research is needed to determine if these different two-way breathing valves alter physiological responses during exercise. The aim of this study is to use these different two-way breathing valves to determine how VO_{2peak} , RE, HR, V_E , and S_aO_2 are affected during a GXT in endurance trained and recreationally active populations.

Methods

Subjects

Fourteen healthy male subjects (seven recreationally active and seven endurance trained) aged 18-35 years old volunteered to participate in this project. Subjects were classified into recreationally active and endurance trained by weekly hours of aerobic training for at least four weeks. The recreationally active group exercised at least three times a week for a total of 2.5-5 hours per week. Endurance trained individuals trained a minimum of eight hours per week. All subjects resided at an elevation similar to the Boulder county area (~1600m) for a minimum of three weeks. Descriptive data for the subjects can be found in tables 1-3. The University of Colorado Boulder Institutional Review Board approved this project and all subjects gave their written informed consent prior to testing.

Protocol Overview

Subjects reported to the laboratory on two different occasions at similar times of day (± 1 hour). Each session was separated by at least 48 hours. Subjects were asked not to eat/drink anything (except water) or consume any stimulants two hours prior to each session. Subjects were also asked not to participate in vigorous exercise 24 hours prior to each test. Subjects reported having matched diet and exercise activity 24 hours prior to each test. This was done to

control for the effects of diet and exercise on energy expenditure during metabolic testing. The subjects wore the same footwear and style of running clothing during each visit.

Both sessions were identical in procedures, which included two pulmonary function tests (PFT) and a GXT. The PFTs were used to ensure normal pulmonary function. Subjects completed a PFT before and after each GXT. All subjects completed a GXT with the Hans Rudolph 2700 and the Daniels' two-way breathing valve. The valve order was randomly assigned for each visit. A cover (<5 grams) was placed over each two-way breathing valve to prevent subjects from identifying the valve.

Protocol Procedures

The PFTs were conducted according to the American Thoracic Society guidelines (Miller et al., 2005). Briefly, subjects performed breathing maneuvers that consisted of maximal inhalations and exhalations. Prior to data collection, subjects practiced the breathing maneuver until they were confident that maximum efforts would be given. Forced vital capacity (FVC), forced expiratory volume at 1 second (FEV1), and inspiratory vital capacity (IVC) were recorded (Parvomedics Truemax 2400, USA). The system was calibrated before each testing session. The volume was calibrated with a 3-L syringe at 10 distinct flow rates (five inspiratory and five expiratory) that were within the expected range of the study protocol.

The GXTs were performed on a treadmill (Trackmaster TM5, USA). Open circuit indirect calorimetry (Parvomedics TrueOne 2400, USA) was used to continuously measure 15-second averages of VO_2 , VCO_2 , and V_E . A heart rate chest strap (Polar T31, Finland) and a non-invasive forehead pulse oximeter (Nellcor N-595, USA) were attached to the subjects and then connected to the open circuit calorimetry system to continuously measure HR and S_aO_2 . Metabolic and cardiorespiratory data were averaged during the final minute of each stage. The open circuit indirect calorimetry system was calibrated before each testing session. Gas fractions were calibrated with room air and a primary standard gas mixture within a physiological range (16.06% O_2 and 4.139% CO_2). The volume was calibrated with a 3-L syringe at five

distinct expiratory flow rates within the expected range of the study protocol. Calibration was considered complete when gas fractions were within 0.02% of the primary standard gas mixture and within 3% of the calibration volume. A pulley system using Velcro straps was attached to the inspired and expired tubing to ensure proper balance of the mouthpiece system. A nose clip was used to prevent airflow in and out of the nose during the GXT. Subjects were connected to a lightweight safety harness while on the treadmill.

The GXT consisted of a submaximal and maximal phase. Subjects were allowed a 2-5 minute warm-up before the GXT. The submaximal phase started at 5.0 miles per hour (mph) at a 2% grade. A tachometer (Shimpo DT-107A, USA) was used to verify the treadmill speed during the first minute of each stage. Each stage lasted four minutes. The treadmill speed was then increased by 1.0 mph. During the 3rd minute of each stage, rating of perceived exertion (RPE) was recorded based on the Borg 6-20 scale. Subjects continued to run until they reached an RPE of 16 or higher. When a RPE of ≥ 16 was reached, the submaximal phase ended and subjects were given a 10-minute break. After the break, subjects started the maximal phase of the GXT. The treadmill speed was set at the last stage completed during the submaximal phase and remained at that speed for the remainder of the test. Subjects ran at this speed for the first two minutes, and then the grade was increased 1% every minute until volitional exhaustion. The highest 30-second VO_2 mean was used to determine $\text{VO}_{2\text{peak}}$. In addition, 30-second means at $\text{VO}_{2\text{peak}}$ were used to obtain peak V_E , HR, and $S_a\text{O}_2$. All subjects performed a PFT within two minutes of finishing the maximal portion of the GXT.

Statistics

Group differences were compared with an independent-sample t-test using Microsoft Office Excel 2010 (Microsoft Corporation, Redmond, WA). Additional statistical analysis was run using IBM SPSS Statistics version 21 (IBM Corporation, Armonk, New York). Main effects between the Hans Rudolph 2700 and Daniels' two way breathing valves in measured RE, V_E , HR and $S_a\text{O}_2$ were analyzed using an unstructured correlations linear mixed model. Pearson

correlation coefficients with 95% confidence intervals comparing the two valves in the measured parameters were used. Values are reported as mean and standard deviation (mean \pm SD). The level of significance is $p = 0.05$.

Results

Subject characteristics

The subject characteristics for each studied group are located in tables 1-3. There was no difference in height between the recreationally active and endurance trained groups (173.8 cm \pm 7.1 and 181.0 cm \pm 6.8, respectively). Mass was not significantly different between the recreationally active and endurance trained groups or between each testing session. The endurance trained group had a mass of 70.4 \pm 5.7 and 70.3 \pm 5.7 kg when using the Hans Rudolph 2700 and Daniels' two-way breathing valves, respectively. The recreationally active group had a mass of 70.9 \pm 10.9 and 71.0 \pm 10.8 kg when using the Hans Rudolph 2700 and Daniels' two-way breathing valves, respectively.

Pulmonary function tests

All subjects had normal pulmonary function. PFT data for all subjects can be found in Table 2. Recreationally active subjects had similar mean FVC, FEV1, and IVC values compared to the endurance trained. In both groups, there were no significant differences in FVC, FEV1, and IVC measurements before and after each GXT with either valve.

Submaximal Phase

During the submaximal phase of the GXT, all recreationally active subjects completed stages up to 6 mph before reaching an RPE of 16. However, five subjects were able to complete another stage with a speed of 7 mph. All endurance trained subjects completed stages up to 8 mph, while six subjects were able to complete the 9 mph stage. Submaximal measurements can be found in figures 3-12. The recreationally active subjects were significantly less economical ($p < 0.03$) than the endurance trained athletes at speeds 5-7 mph. In addition,

recreationally active subjects had significantly higher V_E ($p < 0.04$), and HR ($p < 0.02$) at each speed. There was no difference in S_aO_2 at the compared speeds.

For the recreationally active subjects, no effect of valve was observed for RE, V_E , HR and S_aO_2 . In addition, tidal volume and respiration rate were not significantly different. However, S_aO_2 tended to be higher at all speeds when using the Daniels' compared to the Hans Rudolph 2700 ($p < 0.07$).

For the endurance trained athletes, a main effect was observed between the Hans Rudolph 2700 and Daniels' for RE ($p < 0.02$), V_E ($p < 0.01$) and S_aO_2 ($p < 0.01$). RE improved 4.52 ± 7.11 ml/kg/km, V_E decreased 3.30 ± 2.62 l/min, and S_aO_2 increased $2.11 \pm 1.77\%$ with the Daniels' valve. There was no effect of valve on HR. In addition, the interaction coefficients in the linear mixed model were not statistically significant, so only the main effects for these variables are reported. Although respiration rate and tidal volume were not significantly different between valves, respiration rate tended to be lower in the Daniels' condition ($p < 0.08$).

Maximal Phase

Due to equipment problems, peak S_aO_2 was not recorded in two recreationally active and two endurance trained subjects. In addition, peak HR was not measured in one endurance trained subject. Peak data from the maximal phase can be found in table 2 and in figures 3-12.

During the maximal phase of the GXT, there was no difference in peak V_E , HR, and S_aO_2 between the two groups. Recreationally active subjects had ~19% lower VO_{2peak} ($p < 0.01$) compared to the endurance trained athletes. In both recreationally active and endurance trained populations, there was no difference in peak VO_2 , V_E , HR, S_aO_2 and duration between the two valves.

Discussion

Submaximal

Our findings demonstrate that in endurance trained males during submaximal exercise, altering airflow resistance by changing between the Hans Rudolph 2700 and the Daniels' valves

has a significant effect on RE, V_E , and S_aO_2 . In this group, we observed that the Daniels' valve consistently led to significantly better RE, lower V_E and higher S_aO_2 (4.52 ± 7.11 ml/kg/km, 3.30 ± 2.62 l/min, and $2.11 \pm 1.77\%$, respectively). These findings demonstrate that the higher airflow resistances encountered while using the Hans Rudolph 2700 in endurance trained men during submaximal exercise has a significant influence on physiological responses to exercise. We believe the reason for this effect is multifactorial and may include the direct and indirect effects of V_E and airflow resistance on the WOB.

Compared to the Daniels', using the Hans Rudolph 2700 resulted in the endurance trained individuals increasing their V_E during submaximal exercise. This increase in V_E against a higher airflow resistance resulted in a greater WOB that ultimately increased total body VO_2 at all speeds. Although we did not directly measure WOB, there is strong evidence that support our findings (Aaron et al., 1992; Aaron & Johnson et al., 1992; Harms et al., 1997; Harms et al., 2000; Wetter et al., 1999). In addition, we are confident that the observed changes in VO_2 are not due to deviations in substrate utilization, since the respiratory exchange ratio did not change significantly. All together, elevated V_E combined with higher airflow resistances resulted in a greater WOB that increased VO_2 when endurance trained individuals used the Hans Rudolph 2700.

The change in VO_2 has an essential role in determining changes in economy. Our research has demonstrated that when running speed is increased VO_2 also increased, which is in line with McArdle et al. (2012). However, we found that when endurance trained individuals were using the Hans Rudolph 2700, VO_2 was higher than the Daniel's valve across all speeds. In the current study, we define RE as the amount of VO_2 that is required to move a kg of body mass one km forward (ml/kg/km). If the body uses more oxygen to run the same distance, then RE is worse. This is important, because changes in RE are an important factor of running performance (Basset et al., 2000). Moreover, the effect that the Hans Rudolph 2700 had on WOB led to the impairment of RE in endurance trained individuals.

In order to analyze the S_aO_2 change more closely, we first directed our attention to additional factors that change V_E . Dead space volume is the air that remains in the upper parts of the trachea, mouth, nose, and the two-way breathing valve when breathing. Anatomical dead space in males is approximately 150 ml (Fowler et al., 1948). The dead space is 112 ml and 62 ml for the Hans Rudolph 2700 and the Daniels', respectively (Daniels, 1971; Hans Rudolph Inc., 2014), which we confirmed through water displacement. After taking into account the dead spaces of these two valves, we found that there was no significant difference in alveolar ventilation between the two valves.

$$\text{Alveolar ventilation} = [V_E - (\text{respiratory rate} * \text{total dead space})] \text{ (McArdle et al., 2010).}$$

This indicates that endurance trained individuals were able to maintain similar alveolar ventilations by elevating overall V_E when using the Hans Rudolph 2700. Similarly, previous studies reported that individuals counteract increases in external dead space by increasing their V_E (Fowler, 1948; Ward et al., 1980). Further, if alveolar ventilation is the same, oxygen pressure at the alveoli is also the same (McArdle et al., 2010). This line of reasoning indicates that the changes we observed in S_aO_2 were not due to differences in alveolar ventilation or oxygen diffusion gradient. If the oxygen diffusion gradients are the same, then the changes in S_aO_2 must be due to other factors. Previous studies have shown that increases in V_E change the intrathoracic pressure, which enhances the venous return into the heart and leads to increases in stroke volume (Anholm et al., 1987). In addition, stroke volume has been shown to decrease with lower resistances to airflow (Harms et al., 1998). An increase in stroke volume without changes in HR would result in an increase in cardiac output. This could increase the velocity that blood flows through the pulmonary capillaries, and therefore reduce the time that blood can absorb oxygen. This could potentially explain the decreased S_aO_2 during the Hans Rudolph 2700 condition. However, we do not have any mechanistic data to support this

conclusion. Therefore, the finding that S_aO_2 was different between conditions despite no difference in alveolar ventilation requires further study to fully understand how these valves influence S_aO_2 .

Although there was no effect of valve in the recreationally active group for any of the measured parameters, there was an interaction between RE and speed ($p < 0.05$). We investigated this interaction and found no significant difference in RE at 5 mph. However, when we analyzed speeds 6 and 7 mph separately, RE was significantly worse with the Hans Rudolph 2700 ($p < 0.05$). This follows a similar pattern that was found with the endurance trained individuals. This means airflow resistances are much higher and WOB should be greater with the Hans Rudolph 2700. Due to these reasons, we believe that the Hans Rudolph 2700 changed RE at speeds 6 and 7 mph in recreationally active individuals. Additional research is needed to investigate the interaction between RE and speed when recreationally active subjects use the Hans Rudolph 2700 and the Daniels' two-way breathing valves. Finally, we observed that the recreationally active group was significantly less economical than the endurance trained. The overall elevation in V_E and subsequent increase in the WOB contributed to the deterioration of RE in the recreationally active group.

Maximal

During the maximal phase of the GXT, we observed no significant changes in peak VO_2 , V_E , HR, or S_aO_2 in both recreationally active and endurance trained individuals. Due to changes in VO_2 during submaximal exercise, we can speculate that our subjects experienced equal and opposite shifts in VO_2 for the skeletal muscles used for respiration and locomotion during maximal exercise. These results are consistent with previous research that reported increasing airflow resistance in a two-way breathing valve did not change VO_{2peak} , but lowered VO_2 in the leg muscles due to a greater WOB (Harms et al., 1997). Future studies would benefit from measuring changes in VO_2 for locomotor muscles when recreationally active and endurance trained individuals use the Hans Rudolph 2700 and the Daniels' valves during maximal

exercise. However, the differences in airflow resistances between the Hans Rudolph 2700 and Daniels' two-way breathing valves do not significantly change peak $\dot{V}O_2$, V_E , HR and S_aO_2 .

Limitations

In order to avoid invasive instrumentation, we were only able to measure systemic changes in $\dot{V}O_2$. This prevented us from measuring $\dot{V}O_2$ fluctuations within respiratory and locomotor muscles. Nonetheless, our research allowed us to observe systemic responses that allowed us to compare the Hans Rudolph 2700 to the Daniels' valves during a GXT. Moreover, we were able to use our findings with previous literature to speculate beyond systemic $\dot{V}O_2$ measures.

We designed the GXT to compare the effects of each valve on physiological responses between recreationally active and endurance trained groups. In order to compare submaximal responses between these groups, subjects were expected to run at similar treadmill speeds. Unfortunately, increases in 1 mph resulted in the completion of only 2-3 stages with the recreationally active group. This combined with a low sample size ($n=7$) made it difficult to fully understand how these valves influence physiological responses during submaximal exercise in recreationally active subjects. However, these limitations did not affect the analysis of peak changes during the maximal portion of the GXT.

Finally, women may respond differently to increases in airflow resistance (Guenette et al., 2007; Dominelli et al., 2015). Future studies should investigate the physiological responses women have when using the Hans Rudolph 2700 and the Daniels' two-way breathing valves during a GXT.

Conclusion

In summary, we believe these findings are critical for those who use two-way breathing valves to measure physiological responses during a GXT. During maximal exercise, peak $\dot{V}O_2$, V_E , HR and S_aO_2 are not significantly different between the Hans Rudolph 2700 and the Daniels' two-way breathing valves in recreationally active and endurance trained individuals. However,

during submaximal exercise, we have demonstrated a consistent significant effect of the Hans Rudolph 2700 on RE, V_E and S_aO_2 in endurance trained individuals when compared to the Daniels' valve. We speculate that the major underlying factor between RE and two-way breathing valves are the influences of V_E and airflow resistance on an individual's WOB. Furthermore, the influences of valve on S_aO_2 were also significant, but it is not clear as to why these changes occurred. Also, additional investigation of how these valves alter RE in recreationally active individuals is needed. Caution should be used when measuring physiological responses to submaximal exercise with the Hans Rudolph 2700. In addition, when comparing results from studies that utilize GXT's, consideration of airflow resistances created by a two-way breathing valve is prudent.

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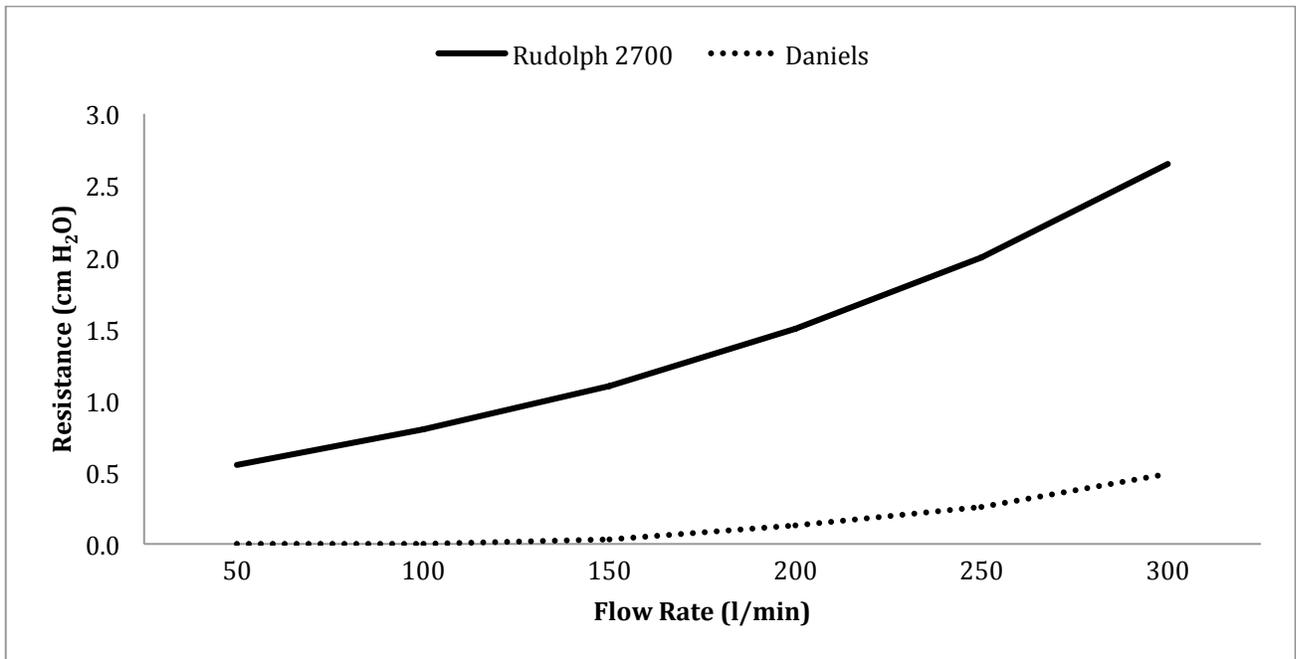


Figure 1. Resistances to airflow for flow rates in the Hans Rudolph 2700 and the Daniels' two-way breathing valve (Daniels. 1971; Hans Rudolph Inc. 2014). Both valves have a non-linear increase in resistance as flow rate increases. The Hans Rudolph 2700 has higher resistance values at all flow rates compared to the Daniels' valve.

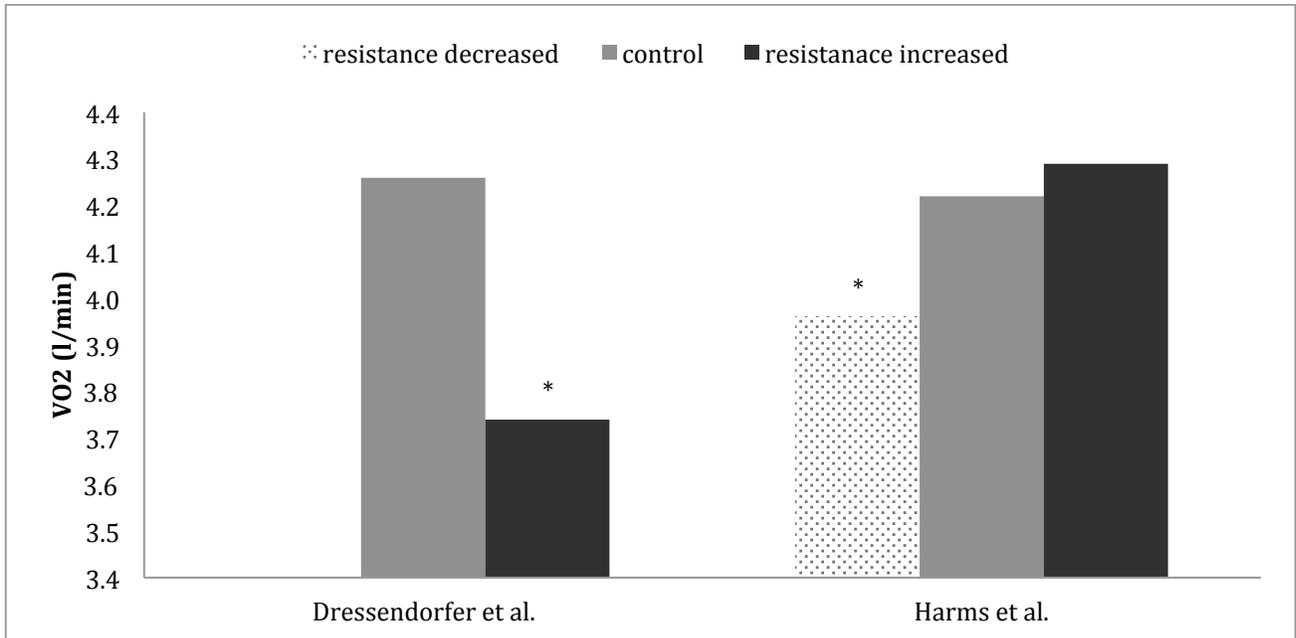


Figure 2. Conflicting results from two studies that show how oxygen consumption changes due to different resistances to airflow. Dressendorfer et al. (1977) found that adding airflow resistance decreased oxygen consumption. Harms et al. (1997) found no difference in oxygen consumption when airflow resistance was added. However, this study found decreases in oxygen consumption when airflow resistance was reduced. * Significantly lower than control.

Table 1. Subject characteristics

	Recreationally active		Endurance trained	
	Hans Rudolph 2700	Daniels'	Hans Rudolph 2700	Daniels'
Age (years)	21 ± 3		24 ± 4	
Height (cm)	173.8 ± 7.1		181.0 ± 6.8	
Weight (kg)	70.9 ± 10.9	71.0 ± 10.8	70.4 ± 5.7	70.3 ± 5.7

Table 2. Results from the pulmonary function tests. Forced vital capacity (FVC), forced expiratory volume at 1 second (FEV1) and inspiratory vital capacity (IVC) values were recorded before and after each GXT.

Recreationally active	Hans Rudolph 2700		Daniels'	
	Pre	Post	Pre	Post
FVC (L)	5.23 ± 1.23	5.07 ± 1.09	5.31 ± 1.01	5.27 ± 2.24
FEV1 (L)	4.30 ± 1.21	4.11 ± 1.07	4.33 ± 0.91	4.35 ± 1.75
IVC (L)	5.16 ± 1.38	5.12 ± 1.20	5.20 ± 1.28	5.20 ± 2.12
Endurance trained	Pre	Post	Pre	Post
FVC (L)	5.85 ± 0.40	5.86 ± 0.46	5.95 ± 0.45	5.78 ± 0.44
FEV1 (L)	4.62 ± 0.67	4.69 ± 0.42	4.62 ± 0.49	4.66 ± 0.59
IVC (L)	5.63 ± 0.51	5.59 ± 0.70	5.86 ± 0.46	5.73 ± 0.42

Table 3. Peak oxygen consumption (VO_2), expired ventilation (V_E), heart rate (HR), arterial oxygen saturation ($S_a\text{O}_2$) and time to exhaustion (time) data from both GXTs. † n= 6 for endurance trained, ^ n=4 for both groups. *Significantly different from endurance trained ($p < 0.01$)

	Recreationally active		Endurance trained	
	Hans Rudolph 2700	Daniels'	Hans Rudolph 2700	Daniels'
VO_2 (ml/kg/min)	55.5 ± 6.0 *	56.2 ± 5.0 *	68.1 ± 5.5	69.1 ± 5.1
V_E (l/min)	146.6 ± 27.0	151.9 ± 20.1	167.4 ± 17	167.4 ± 17.6
HR (bpm) †	184 ± 12	187 ± 14	189 ± 9	189 ± 8
$S_a\text{O}_2$ (%) ^	91.2 ± 2.6	92.6 ± 2.0	87.6 ± 2.4	90.4 ± 2.5
Time (min:sec)	7:50 ± 1:34	8:00 ± 1:32	9:05 ± 2:20	9:26 ± 2:04

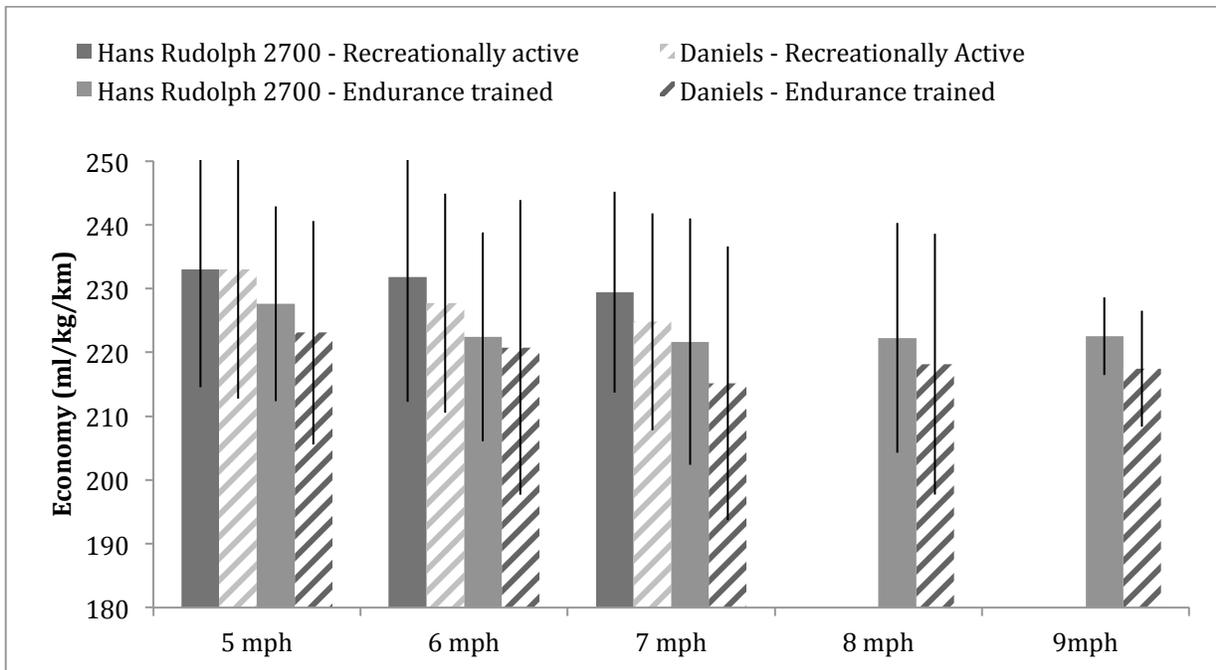


Figure 3. Running economy for recreationally active and endurance trained groups when using the Hans Rudolph 2700 and Daniels' two-way breathing valves. There was an effect of valve ($p < 0.02$) on RE for the endurance trained group. Recreationally active were significantly less economical compared to the endurance trained during speeds 5-7 mph ($p < 0.03$).

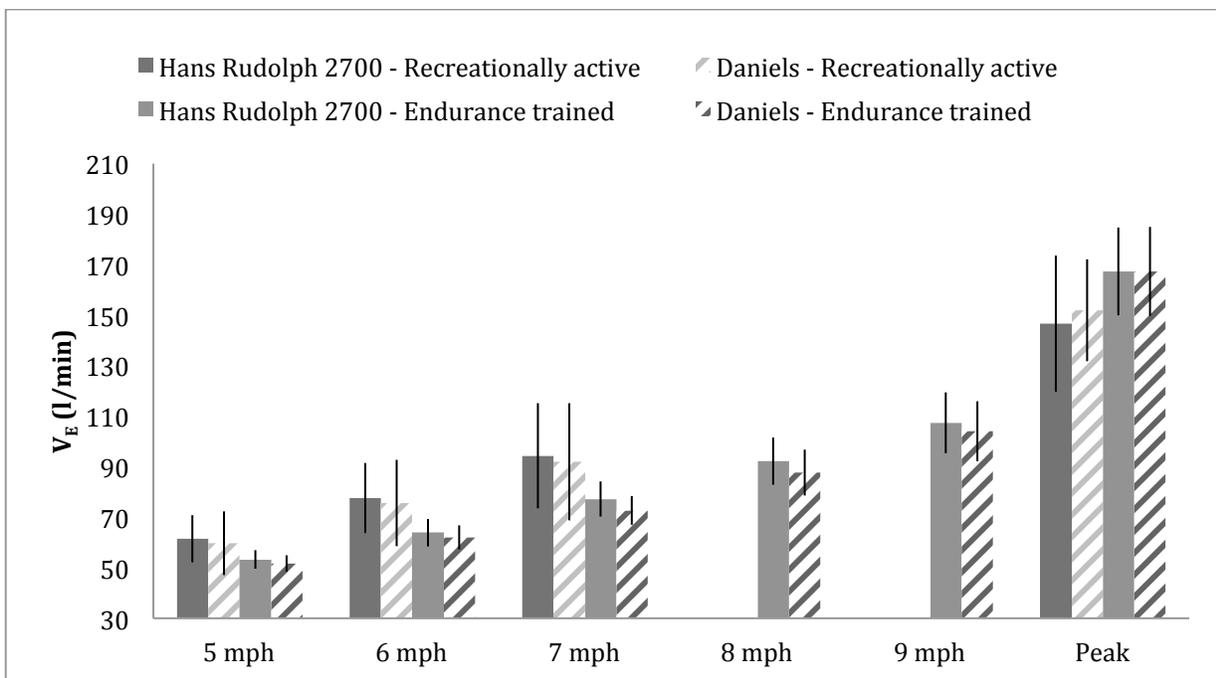


Figure 4. Expired ventilation for recreationally active and endurance trained groups when using the Hans Rudolph 2700 and Daniels' two-way breathing valves. There was an effect of valve ($p < 0.01$) on V_E for the endurance trained group. The recreationally active group had significantly higher V_E than the endurance trained group ($p < 0.04$).

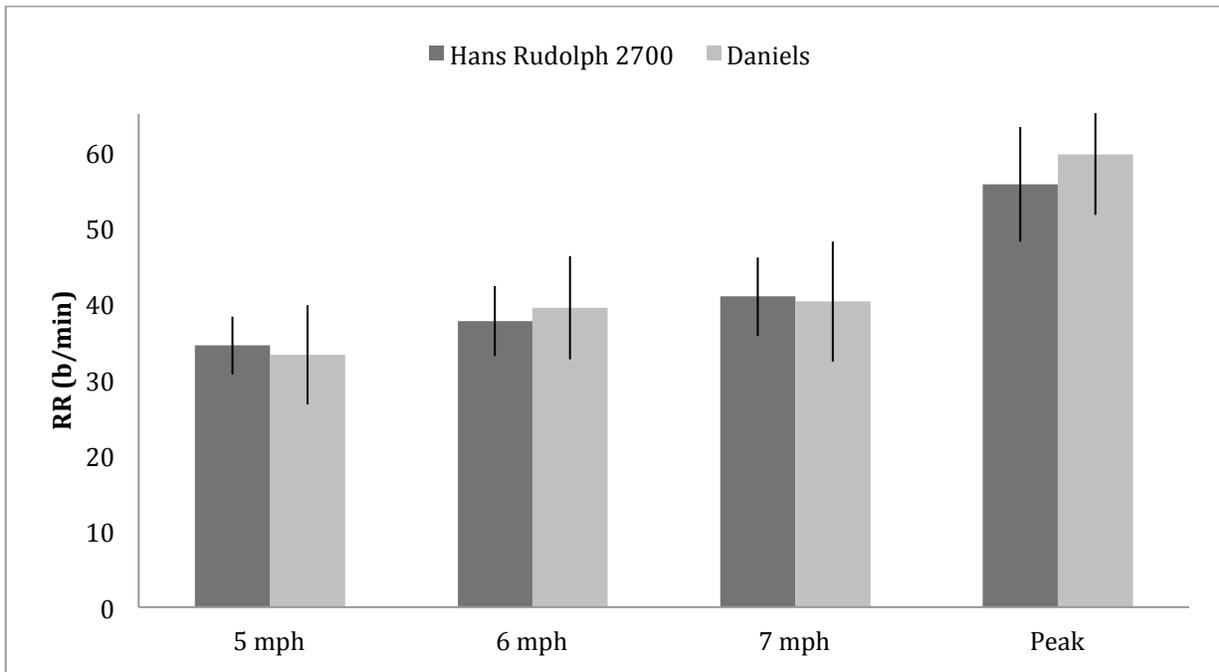


Figure 5. Respiratory rate for recreationally active individuals using the Hans Rudolph 2700 and Daniels' two-way breathing valves.

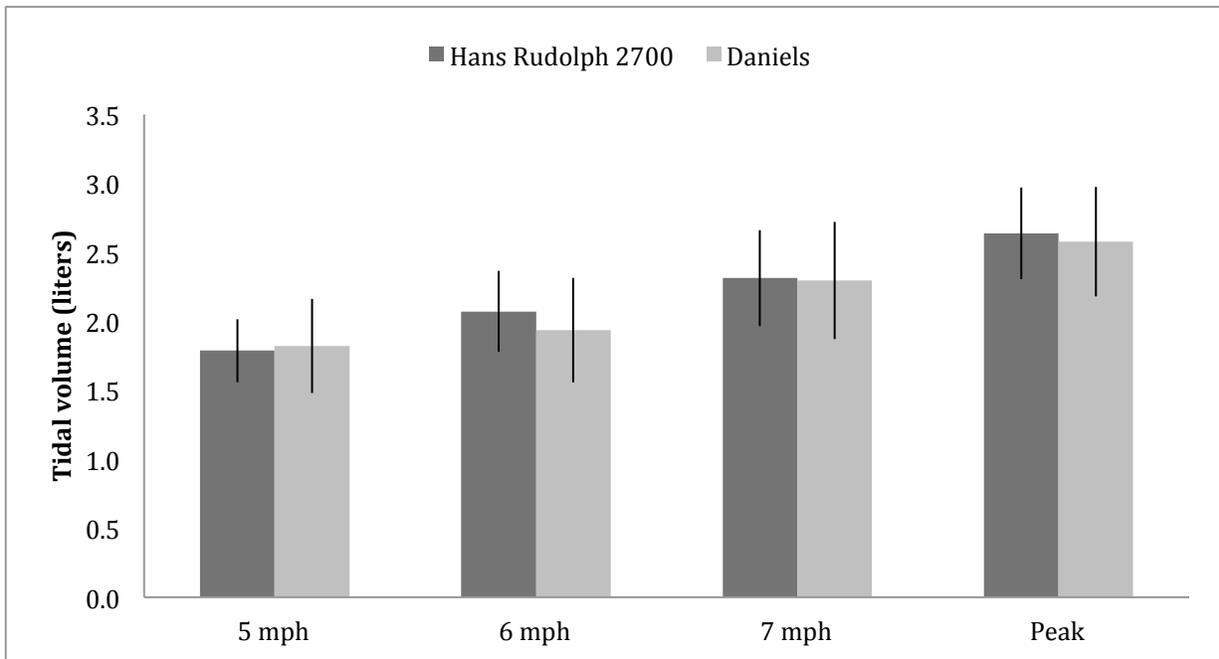


Figure 6. Tidal volume for recreationally active subjects using the Hans Rudolph 2700 and Daniels' two-way breathing valves.

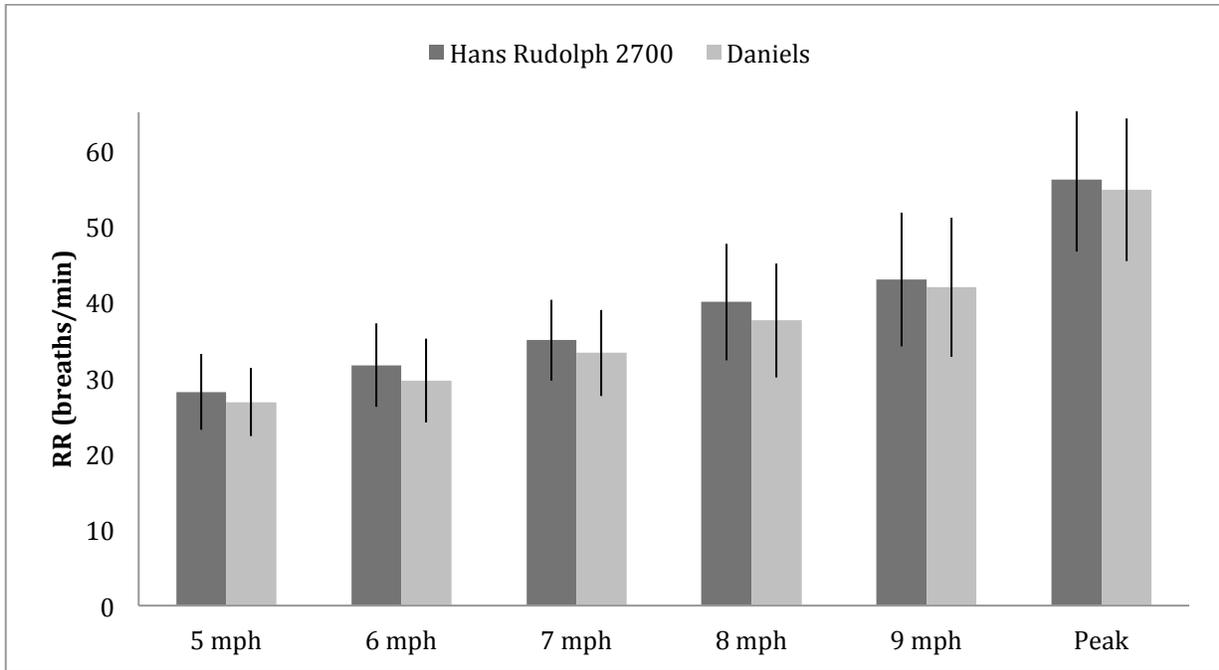


Figure 7. Respiratory rate for endurance trained individuals using the Hans Rudolph 2700 and the Daniels' two-way breathing valves.

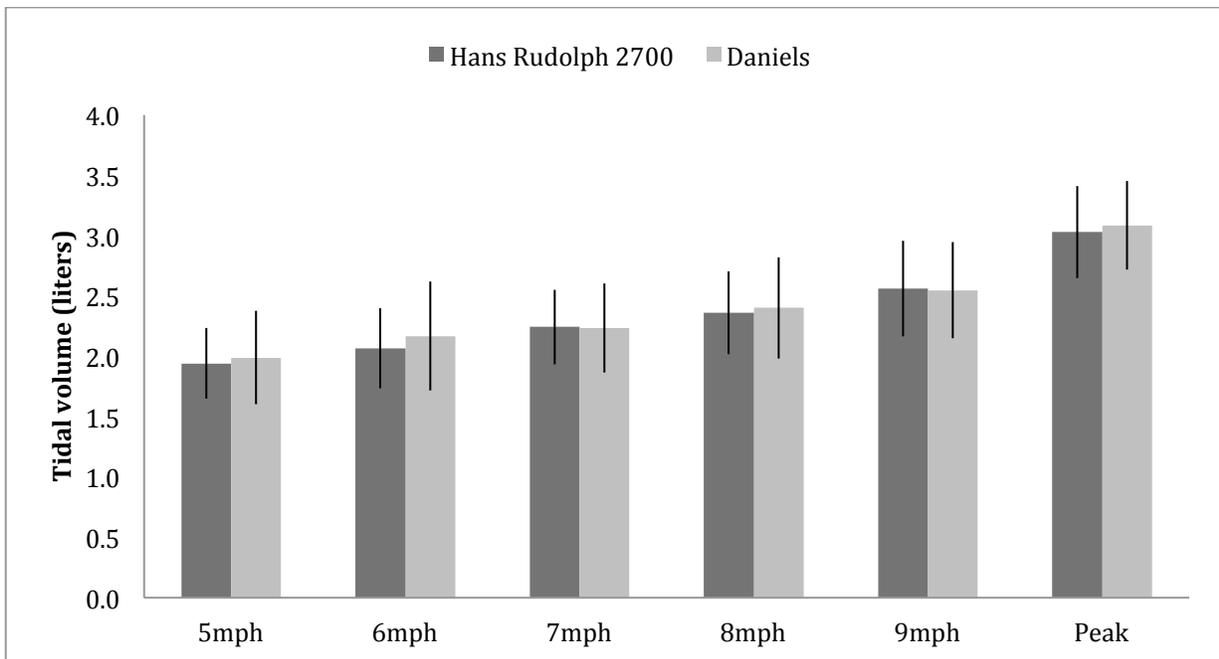


Figure 8. Tidal volume for endurance trained individuals using the Hans Rudolph 2700 and the Daniels' two-way breathing valves.

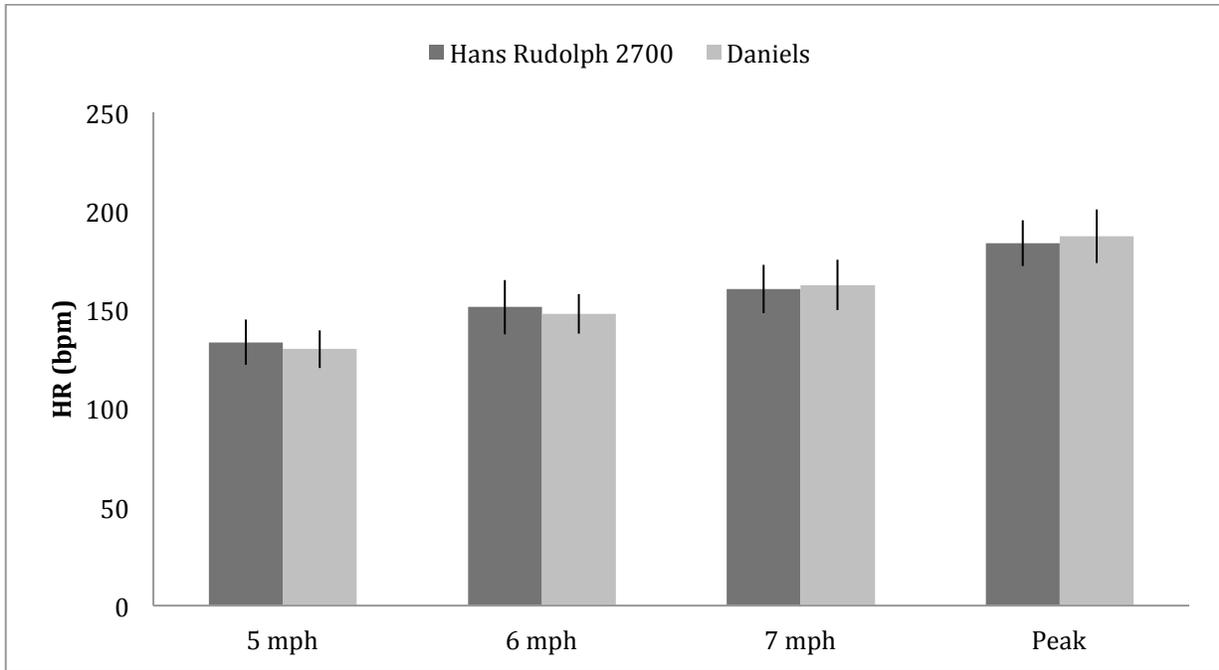


Figure 9. Heart rate for recreationally active individuals using the Hans Rudolph 2700 and Daniels' two-way breathing valves.

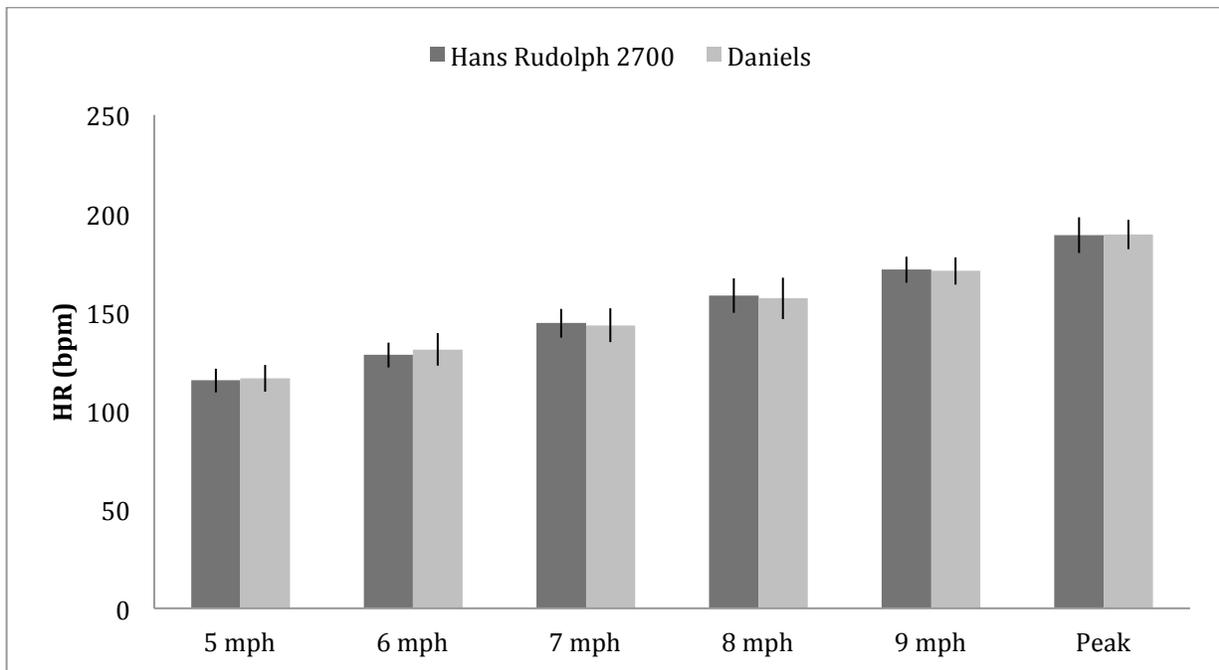


Figure 10. Heart rate for endurance trained individuals using the Hans Rudolph 2700 and Daniels' two-way breathing valves. Peak n=6.

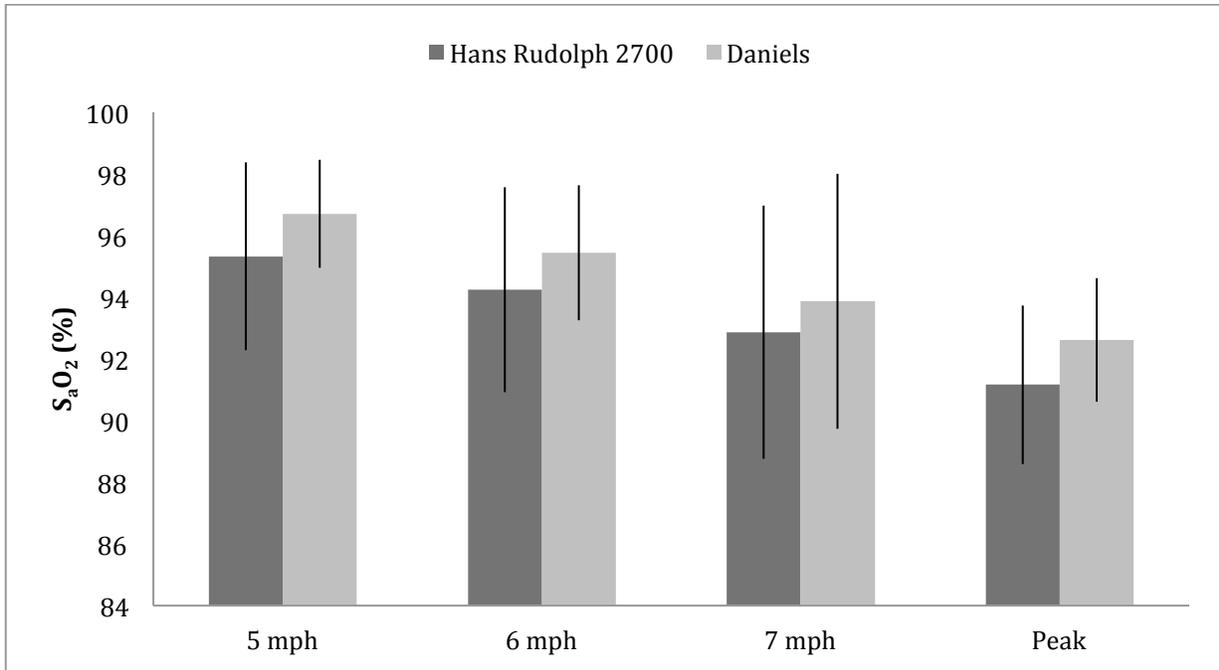


Figure 11. Arterial oxygen saturation for recreationally active individuals using the Hans Rudolph 2700 and the Daniels' two-way breathing valves. Peak data n=4.

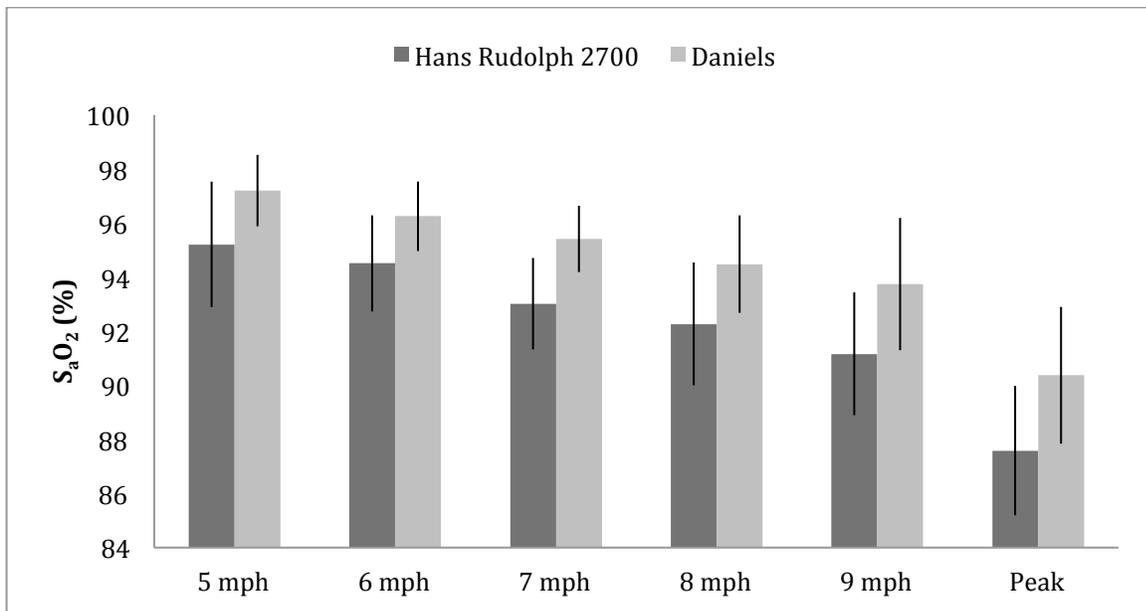


Figure 12. Arterial oxygen saturation for endurance trained individuals using the Hans Rudolph 2700 and Daniels' two-way breathing valves. There was an effect of valve ($p < 0.01$) on S_aO_2 . Peak data n=4.