International Journal of Sports Science 2020, 10(3): 68-72
DOI: 10.5923/j.sports.20201003.03

Comparison of Treadmill and Simultaneous Arm and Leg Ergometry in VO_{2MAX} Analysis

Jacob A. Kostuck, Corey A. Selland, Jeremy M. Frost*

Department of Human Performance, Minnesota State University, Mankato, 1400 Highland Center, Mankato, MN, USA

Abstract Maximal oxygen consumption (VO_{2MAX}) testing can be performed on a variety of modalities ranging from treadmills to rowing ergometers. The purpose of VO_{2MAX} testing is to determine a person's aerobic capacity and has been shown to elicit the highest response in treadmill (TM) testing. Very few studies have examined the idea of incorporating arm cycling combined with leg cycling in VO_{2MAX} testing. The purpose of this study was to compare a simultaneous arm and leg ergometry (SALE) testing protocol to a TM VO_{2MAX} test. Forty-seven college-aged individuals (female: n=27) volunteered for this study, completing both TM and SALE VO_{2MAX} tests. VO_{2MAX} was higher for TM than SALE (45.6 ± 8.7 vs. 41.0 ± 8.0 ml/kg/min, respectively; $p < 0.05$), and total length of VO_{2MAX} test was longer for TM than SALE (11.1 ± 2.1 vs 7.9 ± 3.2 min, respectively; $p < 0.05$); however, the tests were highly correlated ($r = 0.92$). Heart rate at VO_{2MAX} ($p = 0.31$), was not different between tests. The ratio of SALE/TM results ranged from 68.9-104.6%. VO_{2MAX} values were more similar for females than males ($F(1, 45) = 5.08$, $p = 0.03$). The main finding is the addition of arm-ergometry to leg-ergometry produced lower VO_{2MAX} and test length compared to a treadmill test. Future research should look into modifying the resistances of the SALE protocol to be adapted to the subject's body weight and fitness level to determine if this elicits a higher VO_{2MAX}.

Keywords VO_{2MAX}, Treadmill, Simultaneous Arm and Leg Ergometry

1. Introduction

Maximal oxygen consumption (VO_{2MAX}) is an objective measurement of the human body's ability to perform aerobically [1]. The concept of measuring VO_{2MAX} has been researched extensively with evidence of articles from the early 1920s discussing this idea. Assessment of VO_{2MAX} can be performed on a variety of modalities and can be considered valid if the subject reaches the researcher's inclusion criteria (Heart rate (HR) within 10 beats per minute (beats/min) of age-predicted max (220-age), respiratory exchange ratio (RER) > 1.1, rating of perceived exertion (RPE) ≥ 18 on the Borg scale, and a plateau in VO_2) [1,2,3,4]. These tests can be performed to assess baseline cardiorespiratory fitness, predict race results, or to monitor progress over time [5,6].

Arguments have been made in the past stating that specificity of the testing protocol will maximize the relative VO_{2MAX} achieved during testing, meaning cyclists should test on a cycle ergometer, and runners should test on a treadmill [7]. However, little research exists that shows this relationship [7]. Typically, individuals of any training status performing a VO_{2MAX} test on a treadmill will achieve a higher relative VO_{2MAX} than on any other modality [7,8,9,10].

The selection of the testing modality may vary based on the availability of equipment or the comfortability or capability of the subject being tested. The option of using a cycle ergometer could be appealing to those who may not be comfortable testing on a treadmill, but has been shown to yield a lower VO_{2MAX} than a treadmill test [7,10]. This may be due in part to an increased amount of muscle mass being recruited while ambulating when compared to cycling while seated. The addition of arm cycling while peddling on a cycle ergometer has been glossed over in past research [11,12,13] but could theoretically increase the amount of muscle mass being recruited and lead to a higher relative VO_{2MAX}.

The purpose of this study was to investigate whether simultaneous arm and leg ergometry (SALE) could be used as a valid VO_{2MAX} testing modality when compared to a treadmill (TM) VO_{2MAX} test. It was hypothesized that simultaneous arm and leg ergometry would yield a higher relative VO_{2MAX} than the TM VO_{2MAX} test due to the increased amount of muscle mass being recruited. The possibility of exceeding the VO_{2MAX} attained during a TM test while in a seated position would allow more populations to perform a VO_{2MAX} test, and to decrease impact stress on the lower extremities.

* Corresponding author:
Jeremy.frost@mnsu.edu (Jeremy M. Frost)
Published online at http://journal.sapub.org/sports

2. Methods

2.1. Experimental Design

Subjects completed two VO_{2MAX} tests allowing 7-14 days between each test. The tests were conducted on a treadmill (TM), requiring the subject to be standing while walking and/or running, and simultaneous arm and leg ergometry (SALE), requiring the subjects to be in a seated position (Figure 1). The testing order was randomly assigned when each subject arrived at the testing site.

Figure 1. Setup for simultaneous arm and leg ergometry (SALE)

2.2. Subjects

Forty-seven subjects: twenty males and twenty-seven females (Mean ± SD: age 21.2 ± 1.9, weight: 159.8 ± 30 lb) participated in this study. Subjects did not need to be physically active to participate in this study but were excluded if they had any conditions that would prevent them from performing a VO_{2MAX} test. Subjects were instructed not to deviate from their normal exercise routines but were asked not to exercise before their VO_{2MAX} test. Data collection was performed between September-March. All subjects completed an informed consent and health history questionnaire before testing. This study and all its testing procedures were approved by the university's institutional review board.

2.3. Procedures

Subjects signed up for testing times online allowing at least seven (7) days between each test but no more than 14 days between each test. On the first day of testing, subjects completed the informed consent and health history questionnaire which included age and activity level, then resting blood pressure, height, and weight was collected and recorded. The testing order was randomly assigned when each subject arrived at the testing site. Subjects were briefed on testing procedures and expectations before starting the test. Breath by breath data collection was performed using a Parvo Medics metabolic analyzer (TrueOne 2400, Sandy, Utah) calibrated before each test using 3-liter calibration syringe (Hans-Rudolph, Kansas City, Missouri) and a gas calibration tank (4.001% carbon dioxide, 16% oxygen, and 79.999% nitrogen). This data was displayed using the associated TrueOne 32 (Version 4.3.4) computer software which displays the VO_2 in 15-second intervals. Before each test, subjects were fitted with the associated mouthpiece headgear and nose plug as well as a polar H6 HR monitor (Kempele, Finland). Subjects were given a three (3) minute warm-up period (2.5 MPH at 5% grade for TM and 40 Watts at a self-selected cadence for SALE) and the test began immediately afterward. Heart rate (HR), rating of perceived exertion (RPE), and respiratory exchange ratio (RER) were collected every minute until the subject could no longer continue the test. Subjects performing the SALE test who could not maintain 50 ± 5 RPMs on the arm ergometer were considered to have reached their point of exhaustion. To be considered a valid VO_{2MAX} test, two of the following criteria need to be achieved: a RER of at least 1.1, a HR within 10 beats per minute (beats/min) of age-predicted max heart rate (220-age), a plateau in $VO_{2,}$ and an RPE of ≥ 18 [1,2,3,4]. Blood pressure was also taken at the end of each test.

2.4. Heart Rate

Heart rate was collected using a Polar H6 heart rate monitor (Kempele, Finland) and its associated mobile app for display. The heart rate monitor was on during the entire duration of the test but was only collected once every minute. A final heart rate was collected after each test. Similar heart rate monitors have been used in similar studies and are considered valid [14,15].

2.5. Rating of Perceived Exertion

Rating of perceived exertion (RPE) was collected every minute, and at the end of the test, using the BORG 6-20 scale which has been used throughout the literature in similar studies [8,16,17].

2.6. Treadmill

A Cosmed T170DE treadmill (Rome, Italy) was used for the treadmill VO_{2MAX} test. Speed and inclination were automatically adjusted by the treadmill every three minutes to ensure the accuracy of the protocol and consistency across subjects.

2.7. Arm Ergometry

A Monark 891 E (Vansbro, Sweden) arm cycle ergometer with a 0.5kp basket was during the SALE VO_{2MAX} testing to assess upper-body power output. Calibrated weights are used in conjunction with the basket to further increase the resistance on the flywheel of the arm ergometer.

2.8. Leg ergometry

A Monark LC7 electromagnetically braked ergometer (Vansbro, Sweden) was used during the SALE VO_{2MAX} testing to assess lower body power output.

2.9. TM Protocol

The Bruce protocol is a treadmill-based test that increases in speed and grade through three-minute stages. Stage 1 is set at a speed of 1.7MPH and a grade of 10%. Stage 2 is set at a speed of 2.5MPH and a grade of 12%. Stage 3 is set at a speed of 3.4MPH and a grade of 14%. Stage 4 is set at a speed of 4.2MPH and a grade of 16%. Stage 5 is set at a speed of 5MPH and a grade of 18%. Stage 6 is set at a speed of 5.5MPH and a grade of 20%. The Bruce protocol has often been used as a valid TM protocol for determining VO_{2MAX} [18,19,20].

2.10. SALE Protocol

The arm ergometer started with a 0.5 kp basket for resistance while the subject pedaled at a cadence of 50 ± 5RPM. A metronome was used to help maintain this cadence throughout the test. Resistance for the arm ergometer was increased every two minutes by 0.1kp, while the resistance of the leg ergometer was increased by 30 watts every two minutes, starting at 50 watts. The cadence for the leg ergometer was self-selected, and the resistance continued to be added until a pace of 50 ± 5 RPM on the arm ergometer could no longer be maintained.

2.11. Statistical Analysis

A paired *t*-test was performed to determine differences in VO_{2MAX}, HR at VO_{2MAX}, and test time between TM and SALE. The level of significance was set at $\alpha = 0.05$. Correlations between TM and SALE VO_{2MAX}, as well as between TM and SALE time, were assessed using Pearson's correlation coefficient (r). A repeated-measures ANOVA was performed to compare testing modality and fitness level, as well as testing modality and gender.

3. Results

The VO_{2MAX} was significantly higher ($p < 0.05$) for TM than SALE (45.6 ± 8.7 vs. 41.0 ± 8.0 ml/kg/min, respectively (Table 1). Figure 2 shows the range of individual differences in VO_{2MAX} between testing modalities, expressed as TM VO_{2MAX} - SALE VO_{2MAX} (a higher TM score results in a positive number whereas a higher SALE score results in a negative number). TM VO_{2MAX} and SALE VO_{2MAX} had a strong correlation (r= .91 $p < 0.05$). The correlation was slightly lower when comparing by gender (Male = 0.89 $p < 0.05$; Female = 0.89 $p < 0.05$) and when categorized by fitness (High = 0.90 $p < 0.05$, Low = 0.80 $p < 0.05$). The total duration of the TM VO_{2MAX} test was significantly greater ($p < 0.05$) than that of the SALE VO_{2MAX} test (11.1 ± 2.1 vs 7.9 ± 3.2 min, respectively) There was not a statistical difference in HR recorded at the end of each test (p = 0.31). The ratio of SALE/TM VO_{2MAX} ranged from 68.9-104.6% (M = 90%).

Table 1. Summary results for each testing modality

Variable	TM	SALE
VO2 (ml/kg/min)	45.6 ± 8.7	41.0 ± 8.0*
Time to VO_{2MAX} (min)	11.1 ± 2.1	7.9 ± 3.2*
RER	1.19 ± 0.07	1.12 ± 0.05*
HR (beats/min)	187.3 ± 7.8	186.3 ± 8.9

Data are mean ± SD. *p < 0.05

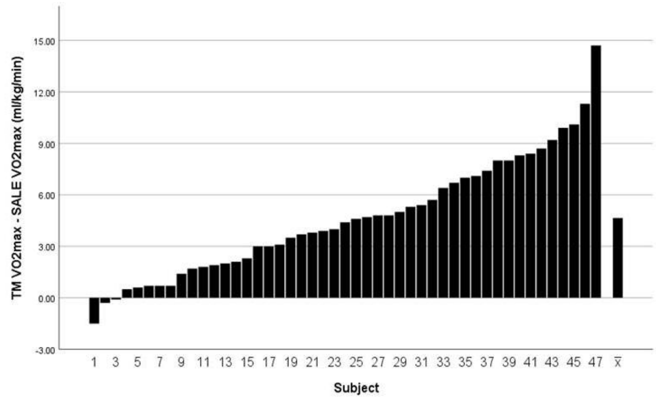

Figure 2. Individual difference in VO_{2MAX} (ml/kg/min) between testing modalities (TM VO_{2MAX} - SALE VO_{2MAX})

The analysis showed a main effect of testing modality on VO_{2MAX}, supporting the results from the previously reported *t*-test, $F(1, 45) = 24.08$, $p < 0.05$. A main effect of gender was observed, $F(1, 45) = 96.91$, $p < .001$, such that females (M = 39.1) achieved lower VO_{2MAX} results than males (M = 48.9). Finally, there was also a statistically significant interaction (Figure 3) between gender and testing modality for VO_{2MAX} results, $F(1, 45) = 5.08$, $p = .03$ indicating that the VO_{2MAX} values for females were more similar compared to males. Females achieved lower VO_{2MAX} results than males regardless of testing modality, and TM achieved higher VO_{2MAX} results than SALE regardless of gender.

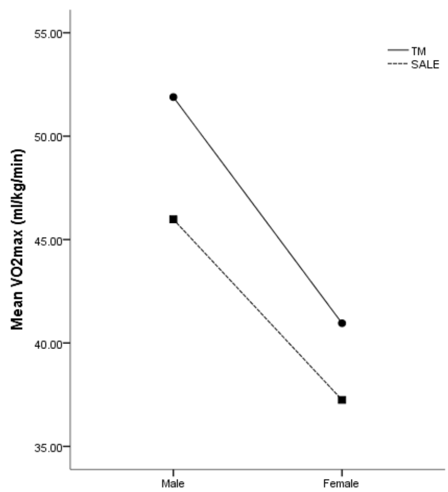

Figure 3. Repeated measures ANOVA comparing VO2max between testing modality and gender

4. Discussion

The main purpose of this study was to investigate whether SALE would yield a higher relative VO_{2MAX} when compared to the results of a TM VO_{2MAX} test. The results showed that the subjects achieved a higher relative VO_{2MAX} on the TM than SALE. This is the first study that compares TM and SALE VO_{2MAX} testing on such a large scale. The present study included 47 subjects completing both VO_{2MAX} tests compared to Secher et al., [13] study which had 16 total subjects, but only seven of them completed both TM and SALE VO_{2MAX} tests. Secher, et al [13] investigated SALE using two Monark cycle ergometers as resistance for the arms. The study included VO_{2MAX} results from arms only, legs only, SALE, and TM across a spectrum of sport disciplines. Results showed SALE to yield a higher VO_{2MAX} than arms only, and legs only, but was only able to achieve a higher VO_{2MAX} in 3 out of the 7 TM comparisons. Brown, Kueffner, O'Mahony, & Lockard [8] compared the results of TM and arm-leg elliptical ergometry. They concluded that the results from both tests were not statistically significant, showing that the arm-leg elliptical is a modality that can incorporate arm movement to match the results seen on a treadmill while also reducing lower body stress and impact. Basset & Boulay [7] studied the results of trained cyclists, runners, and triathletes comparing their VO_{2MAX} tests between TM and leg ergometry. Their results indicated VO_{2MAX} was greater for TM than leg ergometry for all groups [7]. Eston & Brodie [12], investigated submaximal exercise VO_2, HR, and RPE responses using a Schwinn Air-Dyne ergometer at three specific work rates using only arms, only legs, and SALE. VO_2, while not statistically greater when comparing only legs to SALE was greater at each submaximal workrate. This study, however, only measured submaximal responses at a fixed workrate instead of VO_{2MAX} using a graded exercise protocol. The Schwinn Air-Dyne does share a flywheel between the arms and legs but it does not allow for incremental increases to resistance via external weight but rather uses a flywheel fan to generate resistance. Results from these studies indicate the possibility of achieving similar VO_{2MAX} results witnessed on a TM by incorporation of arm ergometry [8,12,13].

Despite a statistical difference in VO_{2MAX} results, there was a strong correlation (r = .92) when comparing the sample as a whole. When comparing the data with the subjects split into a high fitness group and a low fitness group, defined as below the 60th percentile for their respective age and gender [21], the correlations dropped slightly (r = .90 and r = .80 respectively). Although such a strong correlation exists between these two modalities, the difference in relative VO_{2MAX} shows that SALE may not be the ideal method for achieving a higher VO_{2MAX}. While not a means to exclude test results, test times for TM were statically longer than SALE tests (11.1 ± 2.1; 7.9 ± 3.2; respectfully). Given these shorter test times, all subjects were still able to achieve inclusion at least 2 of the 4 inclusion criteria used for validation of testing (Table 2).

Table 2. Inclusion criteria table (n = 47)

Modality	2 of 4 inclusion criteria	3 of 4 inclusion criteria	4 of 4 inclusion criteria
TM	4	25	18
SALE	12	22	13

While some of the SALE values in the present study were similar in results compared to the TM test (n = 13, ± 2 ml/kg/min), others had larger differences reducing the validity of this modality as a true VO_{2MAX} test (Figure 2). Although arm ergometry alone has been tested to be a valid method of VO_{2MAX} testing and has been shown in swimmers to yield higher results than that of a cycle ergometer VO_{2MAX} test [13,22,23], other research has shown that arm cycle VO_{2MAX} averages 70% of leg cycle VO_{2MAX} values in general population [13,23]. In the present study, relative VO_{2MAX} for SALE was 90% of TM values. It's entirely possible that in tests with larger differences in VO_{2MAX} the arms were the reason for the cessation of the test and that the legs were not adequately taxed to yield a higher relative VO_{2MAX}. If the resistances were not properly balanced for each subject, the idea of muscular fatigue in the arms being the reason for halting the test is not completely farfetched [11,24,25]. Secher & Volianitis [25] investigated the body's ability to supply blood to different regions of the body during simultaneous arm and leg exercise. The study concluded that whole-body exercise may reduce work capacity VO_{2MAX} by 5-10%, which was observed in most cases when comparing TM and SALE relative VO_{2MAX} test results. This may help explain the results of the present study.

Presently, the SALE protocol used for this study may not be optimized to accommodate all subjects in matching the VO_{2MAX} results of the TM, but has shown the potential to be a valid testing modality. One issue that became apparent throughout testing was the use of an absolute load for SALE which has been used previously [7] but may not be the best choice for the general population. When performing SALE, all subjects used the same resistance. Finding a method of making these resistances relative to the bodyweight of the subject may have increased testing times which could have led to more similar results to the TM. Future investigations into SALE may wish to look at a graded protocol that utilizes both arms and legs on the same flywheel that also allows for incremental weights to be added throughout the test. Utilization of a Schwinn Air-dyne ergometer would allow for both arms and legs to apply force to one flywheel simultaneously. Creating an appropriate graded protocol for this type of equipment may prove problematic, but a similar setup with an electromagnetically braked flywheel may yield more favorable results than independent flywheels of upper and lower extremities.

5. Conclusions

The current study observed higher VO_{2MAX}, RER, and time to VO_{2MAX} using TM than SALE. However, both options appear to be valid for assessing VO_{2MAX}. The SALE protocol offers an additional testing modality that may be utilized with groups that are more whole-body focused or prefer to be seated during testing.

REFERENCES

[1] Midgley, A. W., McNaughton, L. R., Polman, R., & Marchant, D. (2007). Criteria for determination of maximal oxygen uptake: A brief critique and recommendations for future research. *Sports Medicine*, *37*(12), 1019–1028.

[2] Edvardsen, E., Hem, Erlend., & Anderssen, S. (2014). End criteria for reaching maximal oxygen uptake must be strict and adjusted to sex and age: A cross-sectional study. *PloS ONE, 9*(1), 18-20.

[3] Haff, G., & Dumke, C. (2018). *Laboratory manual for exercise physiology*. Champaign, IL: Human Kinetics.

[4] Howley, E. T., Bassett, D. R., & Welch, H. (1995). Criteria for maximal oxygen uptake: review and commentary. *Medicine and Science in Sports and Exercise*, *27*(9), 1292-1301.

[5] Rundell, K. (1995). Treadmill roller ski test predicts biathlon roller ski race results of elite U.S. biathlon women. *Medicine and Science in Sports and Exercise*, *27*(12), 1677-1685.

[6] Taylor, H., Buskirk, E., & Henschel, A. (1955). Maximal oxygen intake as an objective measure of cardio-respiratory performance. *Journal of Applied Physiology*, *8*, 73–80.

[7] Basset, F., & Boulay, M. (2000). Specificity of treadmill and cycle ergometer tests in triathletes, runners and cyclists. *European Journal of Applied Physiology*, 81(3), 214-221.

[8] Brown, A., Kueffner, T., O'Mahony, E., & Lockard, M. (2015). Validity of arm-leg elliptical ergometer for VO2max analysis. *Journal of Strength and Conditioning Research*, *29*(6), 1551-1555.

[9] Losnegard, T., & Hallén, J. (2014). Elite cross-country skiers do not reach their running VO2max during roller ski skating. *Journal of Sports Medicine and Physical Fitness*, *54*(4), 389–393.

[10] Mays, R., Boer, N., Mealy, L., Kim, K., & Goss, F. (2010). A comparison of practical assessment methods to determine treadmill, cycle, and elliptical ergometer VO2peak. *Journal of Strength and Conditioning Research*, *24*(5), 1325–1331.

[11] Reybrouck, T., Heigenhauser, G. F., & Faulkner, J. A. (1975). Limitations to maximum oxygen uptake in arm, leg, and combined arm-leg ergometry. *Journal of Applied Physiology*, *38*(5), 774–779.

[12] Eston, R. G., & Brodie, D. A. (1986). Responses to arm and leg ergometry. *British Journal of Sports Medicine*, *20*(1), 4–6.

[13] Secher, N. H., Ruberg Larsen, N., Binkhorst, R. A., & Bonde Petersen, F. (1974). Maximal oxygen uptake during arm cranking and combined arm plus leg exercise. *Journal of Applied Physiology*, *36*(5), 515–518.

[14] Flatt, A. A., & Esco, M. R. (2013). Validity of the ithlete™ smart phone application for determining ultra-short-term heart rate variability. *Journal of Human Kinetics*, *39*(1), 85–92.

[15] Nunan, D., Gay, D., Jakovljevic, D. G., Hodges, L. D., Sandercock, G. R. H., & Brodie, D. A. (2009). Validity and reliability of short-term heart-rate variability from the Polar S810. *Medicine and Science in Sports and Exercise*, *41*(1), 243–250.

[16] Bhambhani, Y., Maikala R., & Buckley, S. (1998). Muscle oxygenation during incremental arm and leg exercise in men and women. *European Journal of Applied Physiology and Occupational Physiology*, 78(5), 422-431.

[17] Chen, M. J., Fan, X., & Moe, S. T. (2002). Criterion-related validity of the Borg ratings of perceived exertion scale in healthy individuals: A meta-analysis. *Journal of Sports Sciences*, *20*(11), 873–899.

[18] Strzelczyk, T. A., Cusick, D. A., Pfeifer, P. B., Bondmass, M. D., & Quigg, R. J. (2001). Value of the bruce protocol to determine peak exercise oxygen consumption in patients evaluated for cardiac transplantation. American Heart Journal, 142(3), 466–475.

[19] Van Der Cammen-Van Zijp, M. H. M., Van Den Berg-Emons, R. J. G., Willemsen, S. P., Stam, H. J., Tibboel, D., & Ijsselstijn, H. (2010). Exercise capacity in Dutch children: New reference values for the Bruce treadmill protocol. *Scandinavian Journal of Medicine and Science in Sports*, *20*(1), 130–136.

[20] Will, P. M., & Walter, J. D. (1999). Exercise testing: Improving performance with a ramped Bruce protocol. *American Heart Journal*, *138*(6 I), 1033–1037.

[21] Pescatello, L. S. (2014). *ACSM's guidelines for exercise testing and prescription.* 9th ed. Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins Health.

[22] Bulthuis, Y., Drossaers-Bakker, W., Oosterveld, F., Palen, J., & Laar, M. (2010). Arm crank ergometer is reliable and valid for measuring aerobic capacity during submaximal exercise. *Journal of Strength and Conditioning Research*, *24*(10), 2809-2815.

[23] Larsen, R. T., Christensen, J., Tang, L. H., Keller, C., Doherty, P., Zwisler, A.-D., … Langberg, H. (2016). A systematic review and meta-analysis comparing cardiopulmonary exercise test values obtained from the arm cycle and the leg cycle respectively in healthy adults. *International Journal of Sports Physical Therapy*, *11*(7), 1006–1039.

[24] Castro, R.R.T., Pedrosa, S., & Nóbrega, A. C. L. (2011). Different ventilatory responses to progressive maximal exercise test performed with either the arms or leg. *Clinics*, *66*(7), 1137-1142.

[25] Secher, N. H., & Volianitis, S. (2006). Are the arms and legs in competition for cardiac output? *Medicine and Science in Sports and Exercise*, *38*(10), 1797–1803.