



ARL-TR-7384 • Aug 2015



# **VO2sim 0.1: Using Simulation to Understand Measurement Error in Indirect Calorimetry**

**by Matthew S Tenan**

Approved for public release; distribution is unlimited.

## **NOTICES**

### **Disclaimers**

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.



# **VO2sim 0.1: Using Simulation to Understand Measurement Error in Indirect Calorimetry**

**by Matthew S Tenan**

*Human Research and Engineering Directorate, ARL*

**REPORT DOCUMENTATION PAGE**

Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

**PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

<b>1. REPORT DATE (DD-MM-YYYY)</b> August 2015		<b>2. REPORT TYPE</b> Final		<b>3. DATES COVERED (From - To)</b> 1 February 2015–26 May 2015	
<b>4. TITLE AND SUBTITLE</b> VO2sim 0.1: Using Simulation to Understand Measurement Error in Indirect Calorimetry				<b>5a. CONTRACT NUMBER</b>	
				<b>5b. GRANT NUMBER</b>	
				<b>5c. PROGRAM ELEMENT NUMBER</b>	
<b>6. AUTHOR(S)</b> Matthew S Tenan				<b>5d. PROJECT NUMBER</b>	
				<b>5e. TASK NUMBER</b>	
				<b>5f. WORK UNIT NUMBER</b>	
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b> US Army Research Laboratory ATTN: RDRL-HRS-B Aberdeen Proving Ground, MD 21005-5425				<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>  ARL-TR-7384	
<b>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b>				<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b>	
				<b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b>	
<b>12. DISTRIBUTION/AVAILABILITY STATEMENT</b> Approved for public release; distribution is unlimited.					
<b>13. SUPPLEMENTARY NOTES</b>					
<b>14. ABSTRACT</b> Indirect calorimetry is commonly used in military research to examine the energetic cost of exercise during various perturbations and as a risk factor for injury/illness. The Army has recognized the importance of understanding oxygen consumption in the field and is developing models to aid in operational decision making. A common study design within the Army and in other exercise applications is a test-retest design. Failure to control for expected variability in testing may lead researchers to conclude that an intervention is effective when their results are only a product of chance variability within the human or machine system. This report details the development of a simulation program that accounts for system and human variability to determine if 2 testing sessions are different.					
<b>15. SUBJECT TERMS</b> metabolic, indirect calorimetry, COSMED, VO <sub>2</sub> , VCO <sub>2</sub> , caloric expenditure, statistical simulation					
<b>16. SECURITY CLASSIFICATION OF:</b>			<b>17. LIMITATION OF ABSTRACT</b>  UU	<b>18. NUMBER OF PAGES</b>  42	<b>19a. NAME OF RESPONSIBLE PERSON</b> Matthew S Tenan
<b>a. REPORT</b> Unclassified	<b>b. ABSTRACT</b> Unclassified	<b>c. THIS PAGE</b> Unclassified			<b>19b. TELEPHONE NUMBER (Include area code)</b> 410-278-5884

## Contents

---

---

<b>List of Figures</b>	<b>iv</b>
<b>1. Introduction</b>	<b>1</b>
<b>2. Methodology</b>	<b>2</b>
2.1 Calling VO2sim 0.1 Functions	6
2.2 VO2sim 0.1 Results	7
2.3 Calculating Difference Probability Curves	7
<b>3. Discussion and Conclusions</b>	<b>11</b>
<b>4. References</b>	<b>13</b>
<b>Appendix A. VO2sim Functions</b>	<b>15</b>
<b>Appendix B. R Markdown File</b>	<b>19</b>
<b>Distribution List</b>	<b>35</b>

## List of Figures

---

Fig. 1	Random uniform distribution with a mean of 1.5 L/min.....	3
Fig. 2	Comparison of random uniform distribution to an experimental value falling outside the control distribution.....	4
Fig. 3	Comparison of the random uniform distribution to a value that falls within the control distribution and where 60% of the control distribution is lower than the experimental value.....	5
Fig. 4	Comparison of the random uniform distribution to a value that falls within the control distribution and where 75% of the control distribution is greater than the experimental value.....	6
Fig. 5	VO <sub>2</sub> sim probabilities that experimental value is different from control when the experimental value is 3% higher than control.....	8
Fig. 6	VO <sub>2</sub> sim probabilities that experimental value is different from control when the experimental value is 6% higher than control.....	9
Fig. 7	VO <sub>2</sub> sim probabilities that experimental value is different from control when the experimental value is 10% higher than control.....	10
Fig. 8	VO <sub>2</sub> sim probabilities that experimental value is different from control when the experimental value is 15% higher than control.....	11

## 1. Introduction

---

Indirect calorimetry is commonly used in military research to examine the energetic cost of exercise during various perturbations and as a risk factor for injury/illness. The US Army has used indirect calorimetry to determine the metabolic cost of using functional exoskeletons (Gregorczyk et al. 2006) and when comparing rucksack design (LaFiandra et al. 2003). Indirect calorimetry has also been used to understand how military personnel acclimatize to high altitude (Amann et al. 2013) and hypoxia (Self et al. 2013). The Army has recognized the importance of understanding oxygen consumption in the field and is developing models to aid in operational decision making (Weyand 2013). Decreasing the energetic cost, or caloric expenditure, of a task is important since it results in a decreased need to carry food as well as a lower likelihood of fatigue and injury (Mair et al. 1996; Gefen 2002; Borotikar et al. 2008).

Caloric expenditure was originally quantified via direct calorimetry where a subject exists within a room-sized module insulated by a water current. The heat given off by the body heats the water current and is measured to determine the energy expended by the body (Atwater and Benedict 1983). The cumbersome direct calorimetry method was later updated so that volumes of expired oxygen ( $\text{VO}_2$ ) and carbon dioxide ( $\text{VCO}_2$ ) can be measured to determine the caloric expenditure while subjects are engaged in activities outside a singular room (Weir 1949). These volumes are calculated by determining the total gas ventilation (VE), assuming a standard inspired gas ratio (20.95%  $\text{O}_2$  and 0.03%  $\text{CO}_2$ ) and assuming that gaseous nitrogen is inert (inspired  $\text{N}_2 = \text{expired N}_2$ ); the expired fractions of  $\text{O}_2$  and  $\text{CO}_2$  determined by a metabolic system are then used to calculate  $\text{VO}_2$  and  $\text{VCO}_2$ . This indirect calorimetry method has been further refined by advances in  $\text{O}_2$  and  $\text{CO}_2$  sensors and resulted in the present generation of mobile metabolic devices from a variety of manufacturers.

The most commonly used fully portable indirect calorimetry device is the Cosmed K4b<sup>2</sup>. This is the device presently in use at the US Army Research Laboratory's Human Research and Engineering Directorate. A common study design within the Army and in other exercise applications is a test-retest design. In this design, a Soldier will be tested under normal or control conditions and then tested again during experimental conditions. The difference observed between the control and experimental conditions is theoretically a direct result of the experimental perturbation. However, testing session variability at the individual physiologic level (e.g., dietary changes, diurnal hormonal oscillations) and at the level of the measuring device (e.g.,  $\text{O}_2/\text{CO}_2$  sensor variability, ambient air temperature,

barometric pressure) may obscure any minor changes due to the experimental intervention. Therefore, it is important to account for the variability expected between 2 identical “control” testing sessions when examining the result of an experimental trial. Failure to control for expected variability in testing may lead researchers to conclude that an intervention is effective when their results are only a product of chance variability within the human or machine system.

The author developed a computer program, VO2sim, to address the concern that nonuniform results in experimental trials may be a product of natural measurement variability. VO2sim 0.1 is a simulation tool to determine if the experimental calorimetry measurement is outside the range that would be expected for normal session-to-session variability (e.g., 100% chance experimental condition is higher than control condition). If the experimental measure is determined to be within session-to-session variability, a probability measure is returned, indicating the probability that the experimental value is higher or lower than the control measure (e.g., 60% chance that experimental value is lower than control value). The general purpose of VO2sim is to provide a probabilistic context for VE, VO<sub>2</sub>, and VCO<sub>2</sub> measures that are commonly made within a test–retest study methodology.

## 2. Methodology

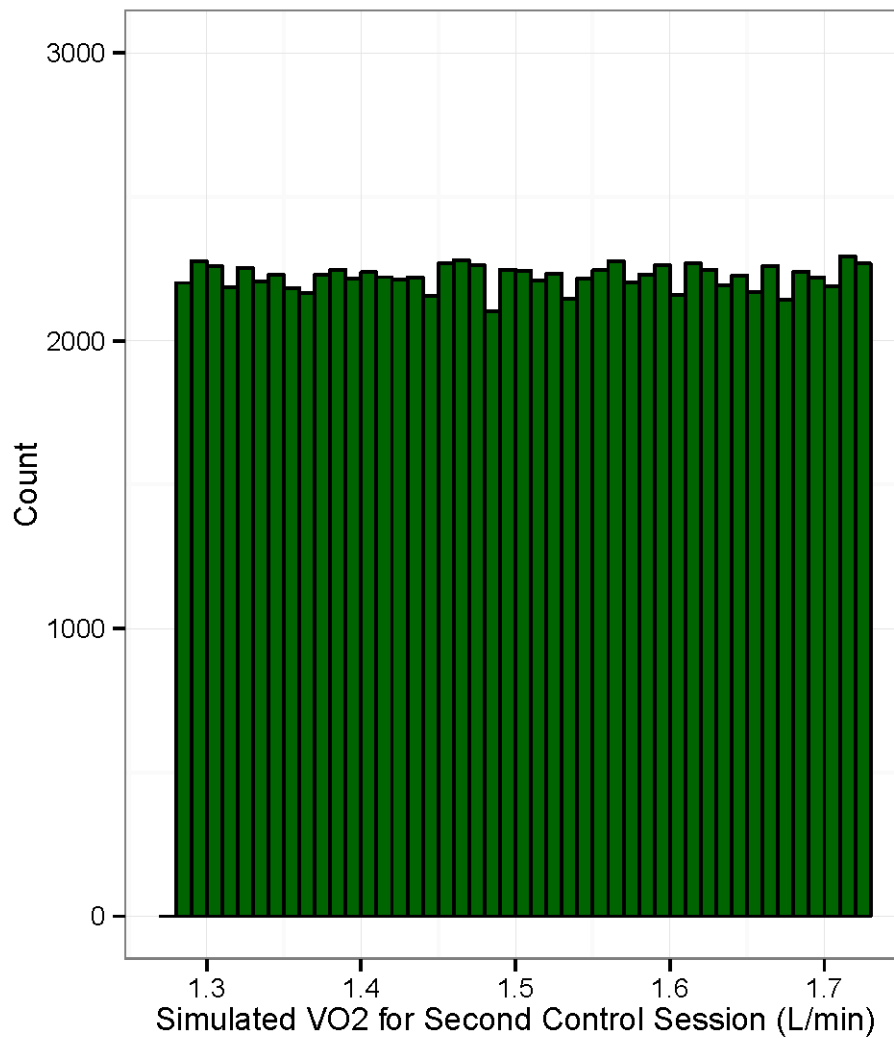
---

---

VO2sim 0.1 is written in R 3.1.2 (R Core Team 2014), which is a free programming language for statistics and data science. The present iteration of VO2sim is valid only for the Cosmed K4b<sup>2</sup> system and uses previously published reliability data to determine the distribution of measurement error (Duffield et al. 2004; Darter et al. 2013). VO2sim is an umbrella term for 3 functions: *VO2sim.repeat*, *VCO2sim.repeat*, and *VEsim.repeat*, which assess the probability of real differences between the control and experimental conditions for VO<sub>2</sub>, VCO<sub>2</sub>, and VE, respectively (raw code for functions is available in Appendix A). The operational flow for each function is the same; *VO2sim.repeat* will be used as an example.

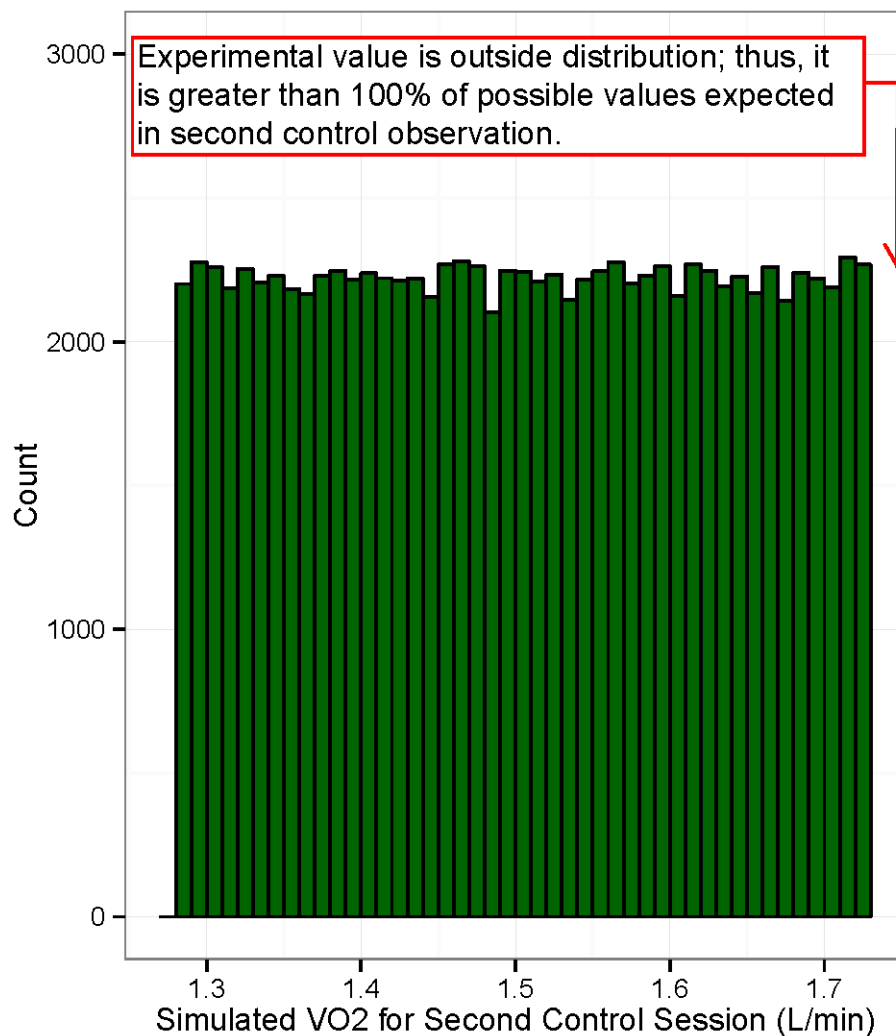
The control and experimental VO<sub>2</sub> measures (liters/minute) obtained at the same exercise workload are put into the function with the “cosmed\_k4b2” indicated as the system that collected the data. The control volume and system are used as the means to create a random uniform distribution of 100,000 observations, where the maximum and minimum of the distribution are calculated based upon the intraclass correlation (ICC) for that volume. The formula for calculating the maximum and minimum of the distribution is *Distribution max/min = volume ± [(1 – ICC) × volume]*.

For example, a  $\text{VO}_2$  measurement of 1.5 L/min has a repeatability ICC of 0.85 (Darter et al. 2013); therefore, a random uniform distribution between 1.275 and 1.725 is created from a control measurement of 1.5 L/min (Fig. 1). ICCs for session-to-session reliability differ depending upon the total volume of gas flow; therefore, the ICC differs for each system depending upon on the volume of gas measured. The random uniform distribution was selected in lieu of other distributions because previous research has demonstrated that session-to-session agreement follows a random uniform distribution (Crouter et al. 2006).

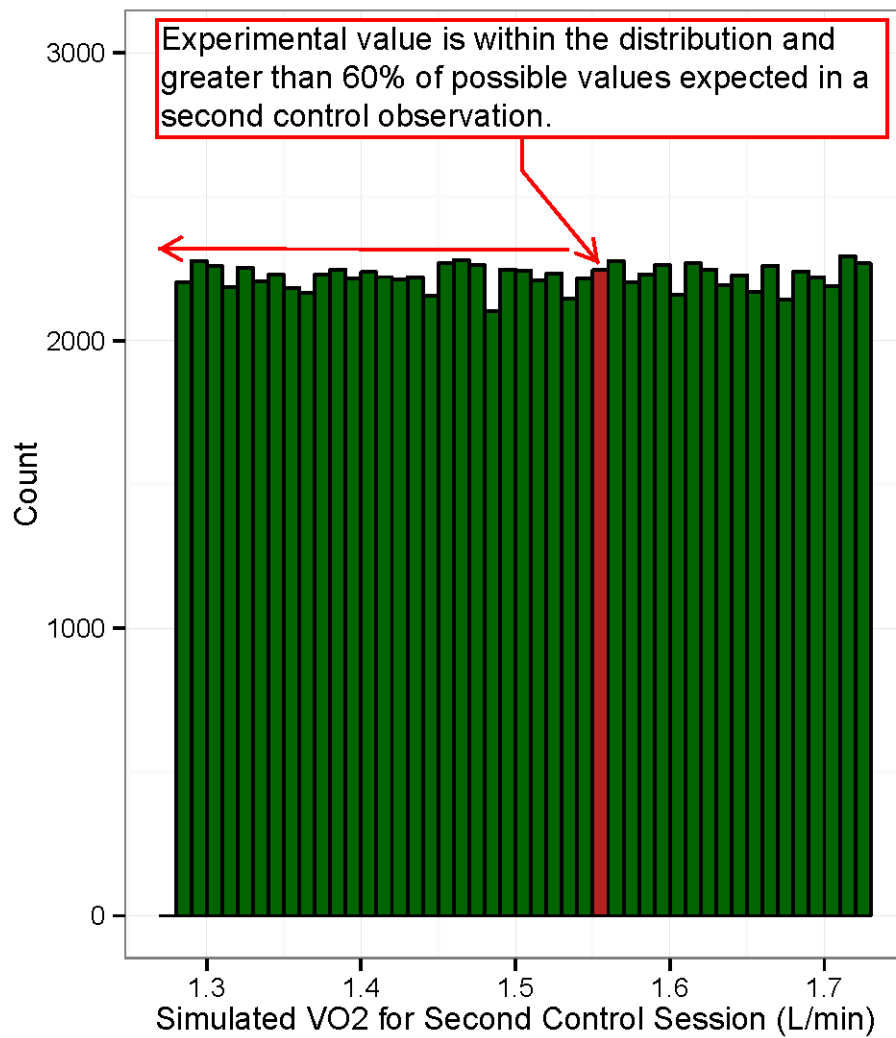


**Fig. 1 Random uniform distribution with a mean of 1.5 L/min**

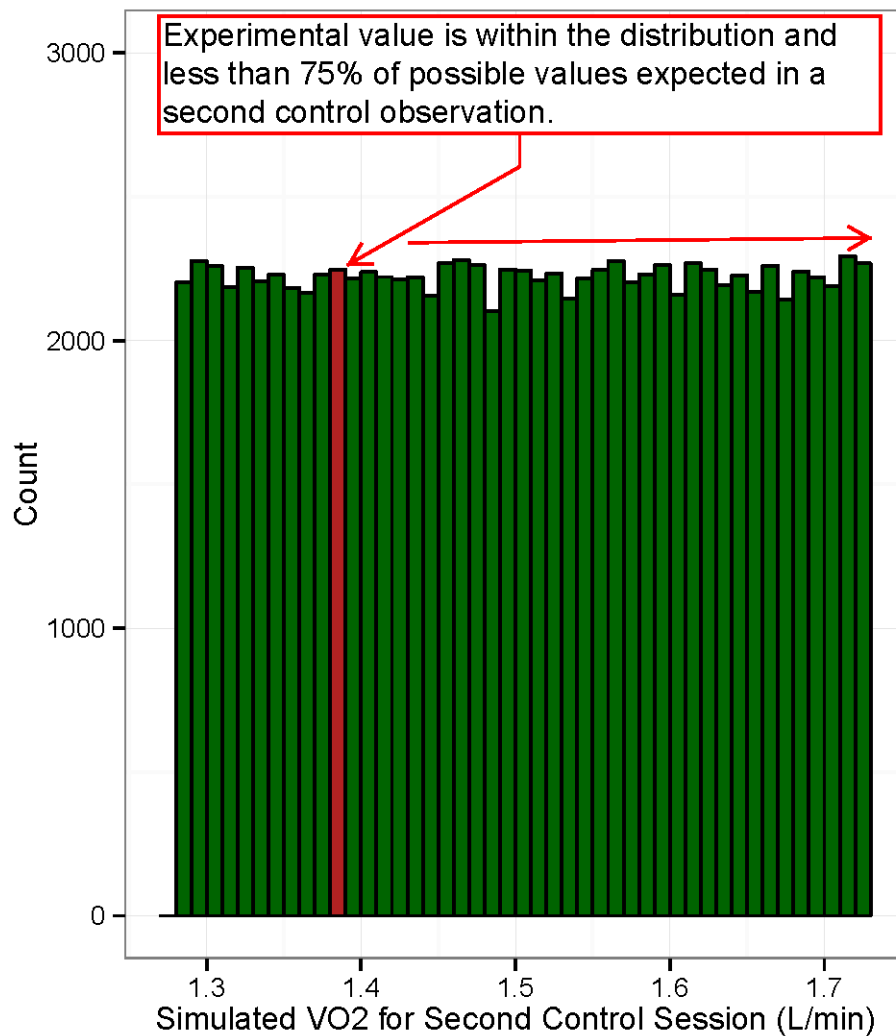
The simulated distribution of expected values for a second control condition is then compared against the measured experimental session  $\text{VO}_2$ . If the experimental value falls outside of the distribution on the high end, it will return an output that there is a 100% probability that the experimental value is higher than the control value (Fig. 2). If the experimental value falls within the expected control distribution, it is determined whether the greatest number of samples in the distribution are higher (Fig. 3), lower (Fig. 4), or identical to the experimental value. The highest number of samples is calculated in ratio with the total samples in the distribution to determine the probability that the experimental value is higher, lower, or identical to the control value.



**Fig. 2 Comparison of random uniform distribution to an experimental value falling outside the control distribution**



**Fig. 3 Comparison of the random uniform distribution to a value that falls within the control distribution and where 60% of the control distribution is lower than the experimental value**



**Fig. 4** Comparison of the random uniform distribution to a value that falls within the control distribution and where 75% of the control distribution is greater than the experimental value

## 2.1 Calling VO2sim 0.1 Functions

---

*VO2sim.repeat* is called with up to 3 arguments:

```
VO2sim.repeat(a, b, system = 'cosmed_k4b2')
```

Variable “a” is the control value and variable “b” is the experimental value. The default system is “cosmed\_k4b2”. In the current version of VO2sim, there is not presently support for other indirect calorimetry systems, so any other input will result in a system message indicating that the data are unable to be processed. Future versions of VO2sim will support other popular indirect calorimetry systems that have appropriate repeatability data available.

## 2.2 VO2sim 0.1 Results

---

The VO2sim.repeat function returns an object with 3 respective values:

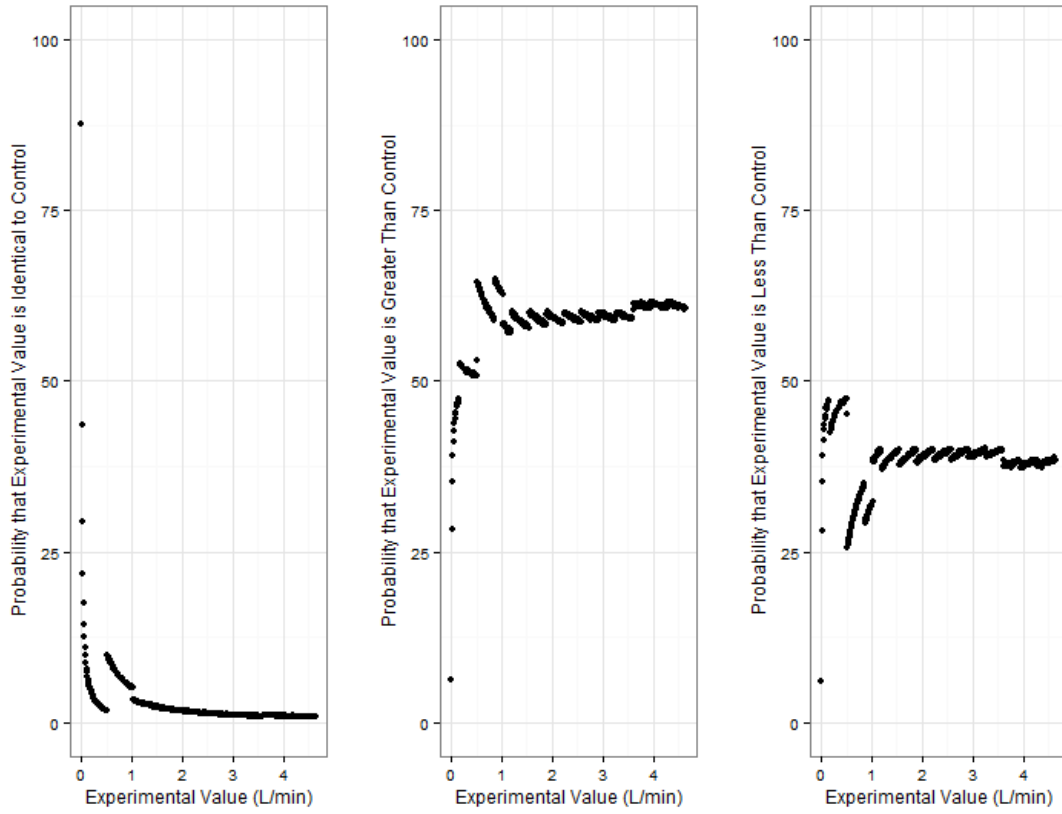
- Probability that the measures are the same
- Probability that “b” is greater than “a”
- Probability that “b” is less than “a”

A string is also returned explaining which probability in the previous object is the largest. The string is designed to explain the primary findings of VO2sim for a single subject. The data in the object allow the researcher to aggregate VO2sim results from multiple subjects and return a “net probability difference” based upon the mean of the data from the column appropriate to their a priori hypothesis.

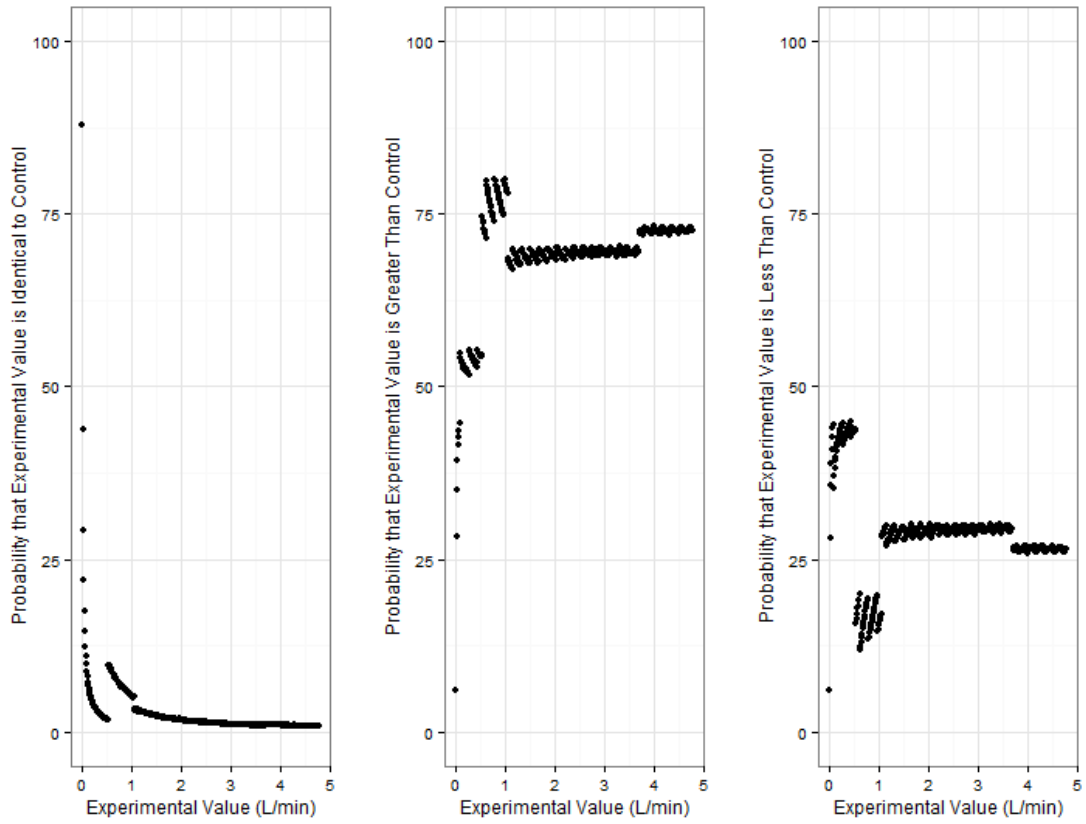
## 2.3 Calculating Difference Probability Curves

---

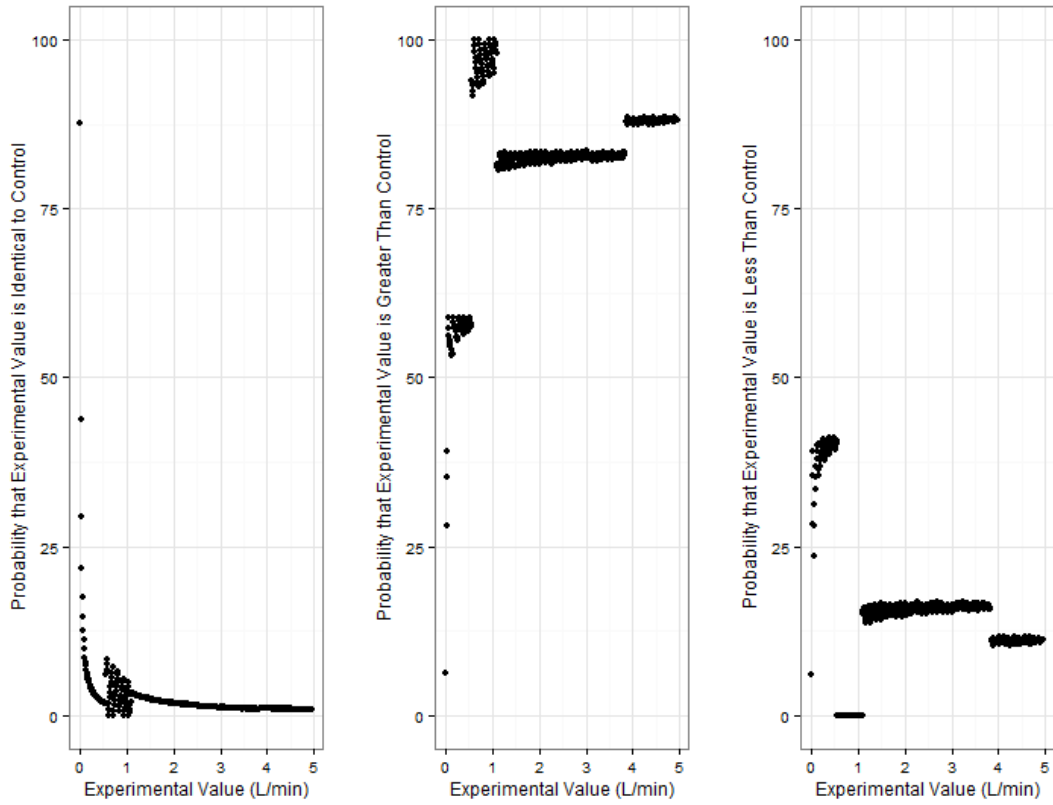
The benefit of having VO2sim functions contained within R allows for entire vectors of data to be analyzed with ease. Using simulated sequential data, curves can be constructed to demonstrate how a 3% (Fig. 5), 6% (Fig. 6), 10% (Fig. 7), and 15% (Fig. 8) measured increase in experimental VO2 result in the probability that it is actually greater than the control session. The implementation of these functions on simulated vectors for the creation of Figs. 5–8 is contained within Appendix B.



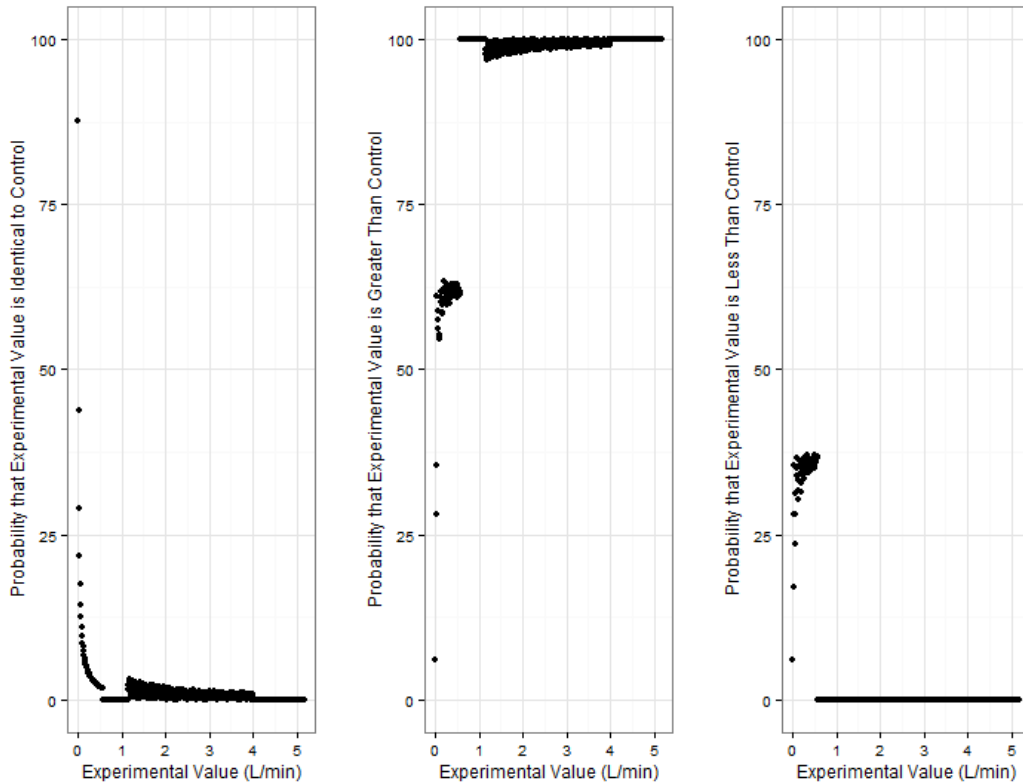
**Fig. 5** VO<sub>2</sub>sim probabilities that experimental value is different from control when the experimental value is 3% higher than control



**Fig. 6** VO<sub>2</sub>sim probabilities that experimental value is different from control when the experimental value is 6% higher than control



**Fig. 7** VO<sub>2</sub>sim probabilities that experimental value is different from control when the experimental value is 10% higher than control



**Fig. 8** VO2sim probabilities that experimental value is different from control when the experimental value is 15% higher than control

### 3. Discussion and Conclusions

VO2sim is designed to test the hypothesis that VO<sub>2</sub>, VCO<sub>2</sub>, and VE values from an experimental trial are either lower or higher than the control trial. To that end, it can be used in lieu of a standard statistical test for a single subject analysis. When data from more than one subject are obtained, best practice is to first use a repeated-measures t-test. If statistical significance of a 2-tailed test is obtained, a directional hypothesis should be made; the individual data for all subjects should be analyzed with VO2sim and a “net probability difference” can be calculated. Instances where statistical differences are achieved but the net probability of VO2sim difference is less than 85% should lead the researcher to interpret their results with heavy skepticism. The most conservative interpretation of the VO2sim output is that any difference probability less than 100% is not different between the 2 conditions. Proposed conventions for applying VO2sim are as follows:

- Experimental value definitely different from Control: 100%
- Experimental value probably different from Control: 85%–99%

- Experimental value unlikely to be different from Control: 70%–84%
- Experimental value not different from Control: Below 69%

The probability curves (Figs. 5–8) can also be used during study design. With the goal of maximizing group differences, investigators may want to consider a certain workload where measurements are less likely to be obscured by measurement error. Similarly, if there is a standard exercise protocol, they may want to purchase a system that has high test–retest reliability in their typical range of workloads.

The current iteration of VO2sim is only able to assess the measurement error for one device, the Cosmed K4b<sup>2</sup>. The reliability data for the Cosmed K4b<sup>2</sup> are reported for discrete volume measurements (e.g., VE = 45 L/min) and not as a continuous regression line (Duffield et al. 2004; Darter et al. 2013). This accounts for the visual grouping of results based upon the volume of gas measured (see Figs. 5–8). Future versions will support the assessment of other indirect calorimetry systems and will incorporate a continuous estimation of test–retest agreement. Future versions will also implement a graphical user interface to facilitate the use of VO2sim for researchers/clinicians not familiar with the R language.

## 4. References

---

- Amann M, Goodall S, Twomey R, Subudhi AW, Lovering AT, Roach RC. AltitudeOmics: on the consequences of high-altitude acclimatization for the development of fatigue during locomotor exercise in humans. *J Appl Physiol*. 2013;115(5):634–642.
- Atwater WO, Benedict FG. A respiration calorimeter with appliances for the direct determination of oxygen. *Nutrition Reviews*. 1983;41(11):353–356.
- Borotikar BS, Newcomer R, Koppes R, McLean SG. Combined effects of fatigue and decision making on female lower limb landing postures: central and peripheral contributions to ACL injury risk. *Clin Biomech*. 2008;23(1):81–92.
- Crouter SE, Antczak A, Hudak JR, DellaValle DM, Haas JD. Accuracy and reliability of the ParvoMedics TrueOne 2400 and MedGraphics VO2000 metabolic systems. *Eur J Appl Physiol*. 2006;98(2):139–151.
- Darter BJ, Rodriguez KM, Wilken JM. Test–retest reliability and minimum detectable change using the K4b2: oxygen consumption, gait efficiency, and heart rate for healthy adults during submaximal walking. *Res Q Exerc Sport*. 2013;84(2):223–231.
- Duffield R, Dawson B, Pinnington H, Wong P. Accuracy and reliability of a Cosmed K4b2 portable gas analysis system. *J Sci Med Sport*. 2004;7(1):11–22.
- Gefen A. Biomechanical analysis of fatigue-related foot injury mechanisms in athletes and recruits during intensive marching. *Med Biol Eng Comput*. 2002;40(3):302–310.
- Gregorczyk KN, Obusek JP, Hasselquist L, Bense JMS, Carolyn K, Gutekunst D, Frykman P. The effects of a lower body exoskeleton load carriage assistive device on oxygen consumption and kinematics during walking with loads. Natick (MA): Army Natick Soldier Center (US); 2006.
- LaFiandra M, Lynch S, Frykman P, Harman E, Ramos H. A comparison of the scorpion load carriage system (SLCS) to the modular lightweight load carrying equipment (MOLLE). Natick (MA): Army Research Institute of Environmental Medicine (US); 2003. Report No.: T-03/16.
- Mair SD, Seaber AV, Glisson RR, Garrett WE. The role of fatigue in susceptibility to acute muscle strain injury. *Am J Sports Med*. 1996;24(2):137–143.

- R Core Team. A language and environment for statistical computing. Vienna (Austria): R Foundation for Statistical Computing; 2014.
- Self DA, Mandella JG, White VL, Burian D. Physiological determinants of human acute hypoxia tolerance. Oklahoma City (OK): FAA Civil Aerospace Medical Institute; 2013. Report No.: DOT/FAA/AM-13/22.
- Weir JdV. New methods for calculating metabolic rate with special reference to protein metabolism. *J Physiol.* 1949;109(1-2):1-9.
- Weyand P. Locomotion with loads: practical techniques for predicting performance outcomes. Ft. Detrick (MD): Army Medical Research and Materiel Command (US); 2013 May.

## **Appendix A. VO2sim Functions**

---

---

---

This appendix appears in its original form, without editorial change.

## VO2sim.repeat

#'a' is the base condition, 'b' is experimental.

```
VO2sim.repeat<- function(a, b, system='cosmed_k4b2'){
  a.round <- round(a, digits=2)
  b.round <- round(b, digits=2)
  if (system=='cosmed_k4b2'){
    if (a.round <= 0.5){
      a.min <- a.round*0.43
      a.max <- a.round*1.57
      a.dist <- round(runif(100000,min= a.min, max= a.max), digits=2)
    } else if (a.round>0.5 & a.round<1.0){
      a.min <- a.round*0.90
      a.max <- a.round*1.10
      a.dist <- round(runif(100000,min= a.min, max= a.max), digits=2)
    } else if (a.round>=1.0 & a.round<3.5){
      a.min <- a.round*0.85
      a.max <- a.round*1.15
      a.dist <- round(runif(100000,min= a.min, max= a.max), digits=2)
    } else if (a.round>= 3.5){
      a.min <- a.round*0.87
      a.max <- a.round*1.13
      a.dist <- round(runif(100000,min= a.min, max= a.max), digits=2)
    } else{
      print('I can not process data from systems other than Cosmed k4b2
at this time')
    }
  }
  if (system =='cosmed_k4b2'){
    probsame <- (sum(a.dist == b.round)/100000)*100
    probhigh <- (sum(a.dist < b.round)/100000)*100
    problow <- (sum(a.dist > b.round)/100000)*100
    probs <- c(probsame, probhigh, problow)
    highest.prob <- probs[probs==max(probs)]
    if (highest.prob == probsame){
      print(paste0("There is a ", highest.prob, " probability that these
measures are the same VO2"))
    } else if (highest.prob == probhigh){
      print(paste0("There is a ", highest.prob, " probability that VO2 b is
greater than VO2 a"))
    } else if (highest.prob == problow){
      print(paste0("There is a ", highest.prob, " probability that VO2 b is
less than VO2 a"))
    }
    return(probs)
  }
}
```

## VCO2sim.repeat

```
# a is the base condition, 'b' is experimental.
VCO2sim.repeat<- function(a, b, system='cosmed_k4b2'){
  a.round <- round(a, digits=2)
  b.round <- round(b, digits=2)
  if (system=='cosmed_k4b2'){
    if (a.round < 3.25){
      a.min <- a.round*0.81
      a.max <- a.round*1.19
      a.dist <- round(runif(100000,min= a.min, max= a.max), digits=2)
    } else if (a.round>= 3.25){
      a.min <- a.round*0.72
      a.max <- a.round*1.28
      a.dist <- round(runif(100000,min= a.min, max= a.max), digits=2)
    }
  } else{
    print('I can not process data from systems other than Cosmed k4b2 at
this time')
  }

  if (system =='cosmed_k4b2'){
    probsame <- (sum(a.dist == b.round)/100000)*100
    probhigh <- (sum(a.dist < b.round)/100000)*100
    problow <- (sum(a.dist > b.round)/100000)*100
    probs <- c(probsame, probhigh, problow)
    highest.prob <- probs[probs==max(probs)]
    if (highest.prob == probsame){
      print(paste0("There is a ", highest.prob, " probability that these
measures are the same VCO2"))
    } else if (highest.prob == probhigh){
      print(paste0("There is a ", highest.prob, " probability that VO2 b is
greater than VCO2 a"))
    } else if (highest.prob == problow){
      print(paste0("There is a ", highest.prob, " probability that VO2 b is
less than VCO2 a"))
    }
  }
  return(probs)
}
}
```

## VEsim.repeat

```
# a is the base condition, 'b' is experimental.
VEsim.repeat<- function(a, b, system='cosmed_k4b2'){
  a.round <- round(a, digits=2)
  b.round <- round(b, digits=2)
  if (system=='cosmed_k4b2'){
    if (a.round < 80.00){
      a.min <- a.round*0.88
      a.max <- a.round*1.12
      a.dist <- round(runif(100000,min= a.min, max= a.max), digits=2)
    } else if (a.round>= 80.00){
      a.min <- a.round*0.78
      a.max <- a.round*1.22
      a.dist <- round(runif(100000,min= a.min, max= a.max), digits=2)
    }
  } else{
    print('I can not process data from systems other than Cosmed k4b2 at
this time')
  }

  if (system =='cosmed_k4b2'){
    probsame <- (sum(a.dist == b.round)/100000)*100
    probhigh <- (sum(a.dist < b.round)/100000)*100
    problow <- (sum(a.dist > b.round)/100000)*100
    probs <- c(probsame, probhigh, problow)
    highest.prob <- probs[probs==max(probs)]
    if (highest.prob == probsame){
      print(paste0("There is a ", highest.prob, " probability that these
measures are the same VE"))
    } else if (highest.prob == probhigh){
      print(paste0("There is a ", highest.prob, " probability that VO2 b is
greater than VE a"))
    } else if (highest.prob == problow){
      print(paste0("There is a ", highest.prob, " probability that VO2 b is
less than VE a"))
    }
  }

  return(probs)
}
}
```

## **Appendix B. R Markdown File**

---

---

---

This appendix appears in its original form, without editorial change.

## VO2sim Technical Note

Matthew S. Tenan, PhD ATC

Wednesday, March 18, 2015

**This is the R Markdown document detailing the use of VO2sim.repeat and creating the figures for the technical note.**

**Install VO2sim package and place it in library + load ggplot2 for graphing**

```
setwd("L:/Biomechanics/VO2sim/VO2sim")

install.packages("devtools", repos= "http://cran.rstudio.com/")

## Installing package into 'C:/Users/matthew.s.tenan/Documents/R/win-library/
3.1'
## (as 'lib' is unspecified)

## package 'devtools' successfully unpacked and MD5 sums checked
##
## The downloaded binary packages are in
## C:\Users\matthew.s.tenan\AppData\Local\Temp\RtmpKae3C6\downloaded_package
s

install.packages('gridExtra', repos = "http://cran.rstudio.com/")

## Installing package into 'C:/Users/matthew.s.tenan/Documents/R/win-library/
3.1'
## (as 'lib' is unspecified)

## package 'gridExtra' successfully unpacked and MD5 sums checked
##
## The downloaded binary packages are in
## C:\Users\matthew.s.tenan\AppData\Local\Temp\RtmpKae3C6\downloaded_package
s

library(gridExtra)

## Loading required package: grid

library("devtools")

## WARNING: Rtools is required to build R packages, but is not currently inst
alled.
```

```
##  
## Please download and install Rtools 3.1 from http://cran.r-project.org/bin/windows/Rtools/ and then run find_rtools().  
  
install('VO2sim')  
  
## Installing VO2sim  
## "C:/PROGRA~1/R/R-31~1.2/bin/x64/R" --vanilla CMD INSTALL \  
## "L:/Biomechanics/VO2sim/VO2sim" \  
## --library="C:/Users/matthew.s.tenan/Documents/R/win-library/3.1" \  
## --install-tests  
  
library('VO2sim')  
library('ggplot2')
```

## Creation of example plots to demonstrate how VO2sim.repeat works

### Simulate Data

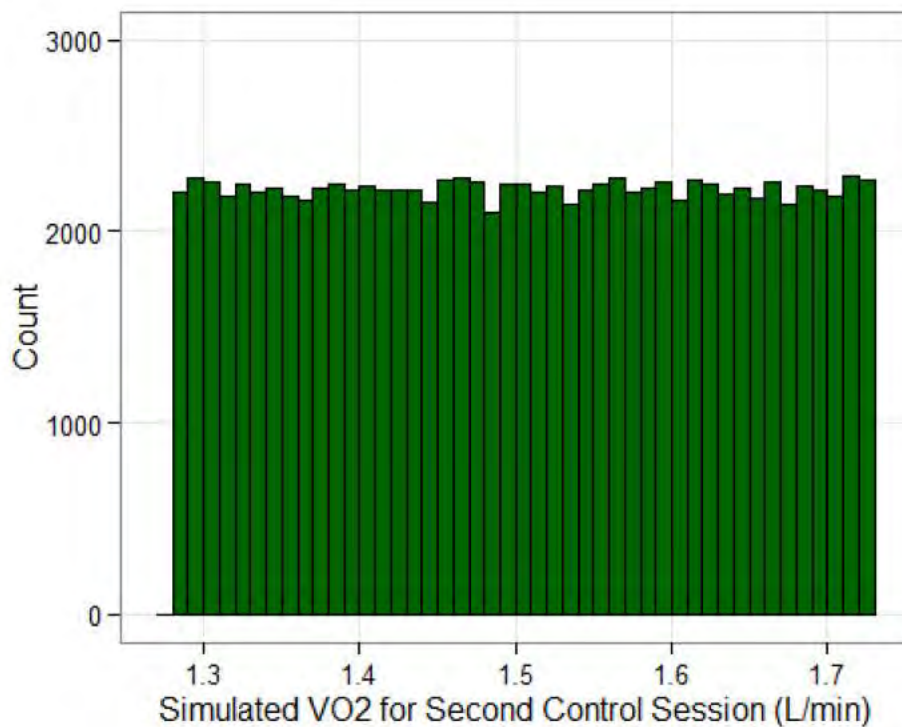
---

```
set.seed(71185)  
dist.x <- as.data.frame(round(runif(100000, min= 1.275, max= 1.725), digits=2  
)  
)  
colnames(dist.x) <- 'sim_con'
```

### Plots 1 & 2

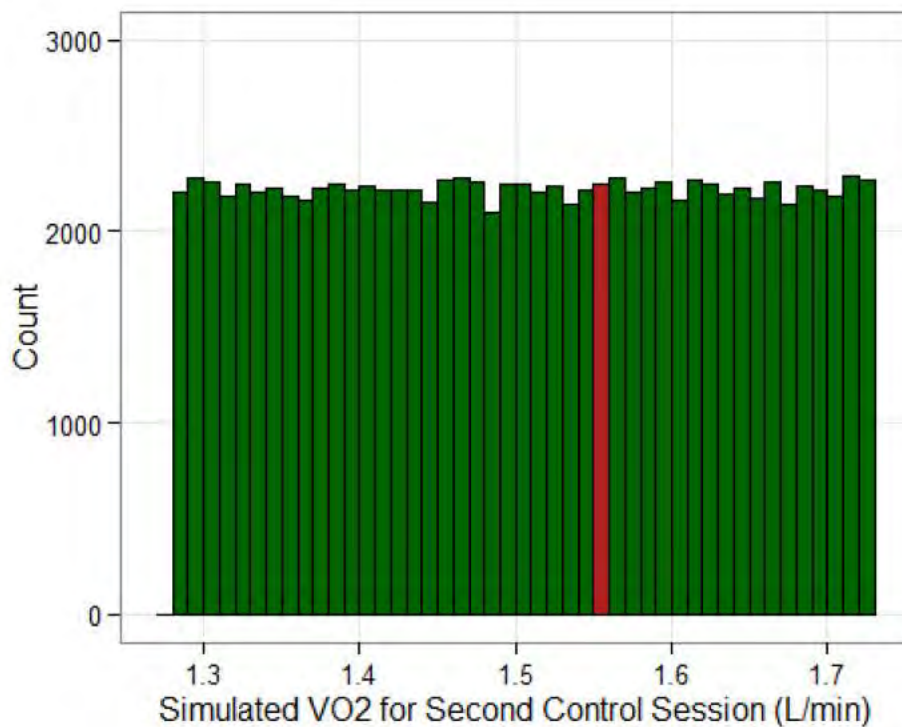
---

```
ggplot(dist.x, aes(x = sim_con)) +  
  geom_histogram(colour = "black", fill = "darkgreen", binwidth = .01) +  
  theme_bw() +  
  xlab('Simulated VO2 for Second Control Session (L/min)') +  
  ylab('Count') +  
  ylim(0, 3000)
```



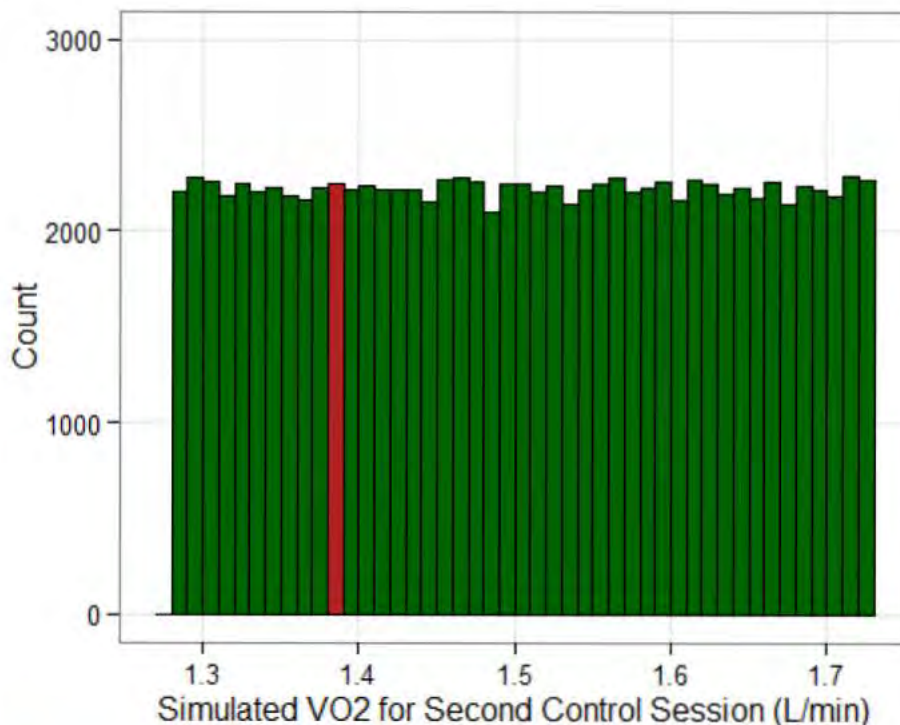
### Plot 3

```
ggplot(dist.x, aes(x = sim_con)) +
  geom_histogram(colour = "black", binwidth = .01, aes(fill = (sim_con==1.55)
)) +
  scale_fill_manual(values=c('FALSE'='darkgreen', 'TRUE'='firebrick')) +
  theme_bw() +
  xlab('Simulated VO2 for Second Control Session (L/min)') +
  ylab('Count') +
  ylim(0, 3000) +
  scale_color_identity() +
  theme(legend.position="none")
```



## Plot 4

```
ggplot(dist.x, aes(x = sim_con)) +
  geom_histogram(colour = "black", binwidth = .01, aes(fill = (sim_con==1.38)
)) +
  scale_fill_manual(values=c('FALSE'='darkgreen', 'TRUE'='firebrick')) +
  theme_bw() +
  xlab('Simulated VO2 for Second Control Session (L/min)') +
  ylab('Count') +
  ylim(0, 3000) +
  scale_color_identity() +
  theme(legend.position="none")
```



## Creating Data and Plot 5

```
###Creation of data for figure 5, 3% increase in VO2
control <- seq(from=0.01, to = 4.5, by = 0.01)
exp <- control*1.03
#Run VO2sim
fig5dat <- Map(VO2sim.repeat, a=control, b=exp)
```

```
## [1] "There is a 87.718 probability that these measures are the same VO2"
## [1] "There is a 43.869 probability that these measures are the same VO2"
## [1] "There is a 35.604 probability that VO2 b is greater than VO2 a"
## [1] "There is a 39.157 probability that VO2 b is greater than VO2 a"
## [1] "There is a 41.284 probability that VO2 b is greater than VO2 a"
## [1] "There is a 42.769 probability that VO2 b is less than VO2 a"
## [1] "There is a 43.77 probability that VO2 b is less than VO2 a"
## [1] "There is a 44.54 probability that VO2 b is greater than VO2 a"
## [1] "There is a 45.339 probability that VO2 b is less than VO2 a"
## [1] "There is a 45.77 probability that VO2 b is less than VO2 a"
## [1] "There is a 46.125 probability that VO2 b is greater than VO2 a"
## [1] "There is a 46.61 probability that VO2 b is less than VO2 a"
## [1] "There is a 46.668 probability that VO2 b is less than VO2 a"
## [1] "There is a 47.063 probability that VO2 b is greater than VO2 a"
## [1] "There is a 47.329 probability that VO2 b is greater than VO2 a"
## [1] "There is a 47.326 probability that VO2 b is less than VO2 a"
## [1] "There is a 52.852 probability that VO2 b is greater than VO2 a"
## [1] "There is a 52.284 probability that VO2 b is greater than VO2 a"
## [1] "There is a 52.094 probability that VO2 b is greater than VO2 a"
```

















```

## [1] "There is a 61.379 probability that V02 b is greater than V02 a"
## [1] "There is a 61.345 probability that V02 b is greater than V02 a"
## [1] "There is a 61.43 probability that V02 b is greater than V02 a"
## [1] "There is a 61.426 probability that V02 b is greater than V02 a"
## [1] "There is a 61.314 probability that V02 b is greater than V02 a"
## [1] "There is a 61.121 probability that V02 b is greater than V02 a"
## [1] "There is a 61.505 probability that V02 b is greater than V02 a"
## [1] "There is a 61.703 probability that V02 b is greater than V02 a"
## [1] "There is a 61.045 probability that V02 b is greater than V02 a"
## [1] "There is a 60.988 probability that V02 b is greater than V02 a"
## [1] "There is a 60.821 probability that V02 b is greater than V02 a"
## [1] "There is a 61.101 probability that V02 b is greater than V02 a"
## [1] "There is a 61.128 probability that V02 b is greater than V02 a"
## [1] "There is a 61.053 probability that V02 b is greater than V02 a"
## [1] "There is a 60.891 probability that V02 b is greater than V02 a"
## [1] "There is a 61.013 probability that V02 b is greater than V02 a"
## [1] "There is a 61.216 probability that V02 b is greater than V02 a"
## [1] "There is a 61.233 probability that V02 b is greater than V02 a"
## [1] "There is a 60.89 probability that V02 b is greater than V02 a"
## [1] "There is a 61.146 probability that V02 b is greater than V02 a"
## [1] "There is a 60.88 probability that V02 b is greater than V02 a"
## [1] "There is a 61.062 probability that V02 b is greater than V02 a"
## [1] "There is a 60.871 probability that V02 b is greater than V02 a"
## [1] "There is a 60.745 probability that V02 b is greater than V02 a"
## [1] "There is a 60.749 probability that V02 b is greater than V02 a"
## [1] "There is a 60.968 probability that V02 b is greater than V02 a"
## [1] "There is a 60.527 probability that V02 b is greater than V02 a"
## [1] "There is a 60.792 probability that V02 b is greater than V02 a"
## [1] "There is a 60.765 probability that V02 b is greater than V02 a"
## [1] "There is a 60.625 probability that V02 b is greater than V02 a"
## [1] "There is a 60.853 probability that V02 b is greater than V02 a"

fig5dat <- as.data.frame(do.call(rbind, fig5dat))
colnames(fig5dat) <- c('same', 'higher', 'lower')
fig5dat <- cbind(fig5dat, as.data.frame(exp))
##Create plots for figure 5
#Same plot
same.3 <- ggplot(fig5dat, aes(x=exp, y=same)) +
  geom_point() +
  theme_bw() +
  ylab('Probability that Experimental Value is Identical to Control
') +
  xlab('Experimental Value (L/min)') +
  ylim(0,100)

#Higher Plot
higher.3 <- ggplot(fig5dat, aes(x=exp, y=higher)) +
  geom_point() +
  theme_bw() +
  ylab('Probability that Experimental Value is Greater Than Contr

```

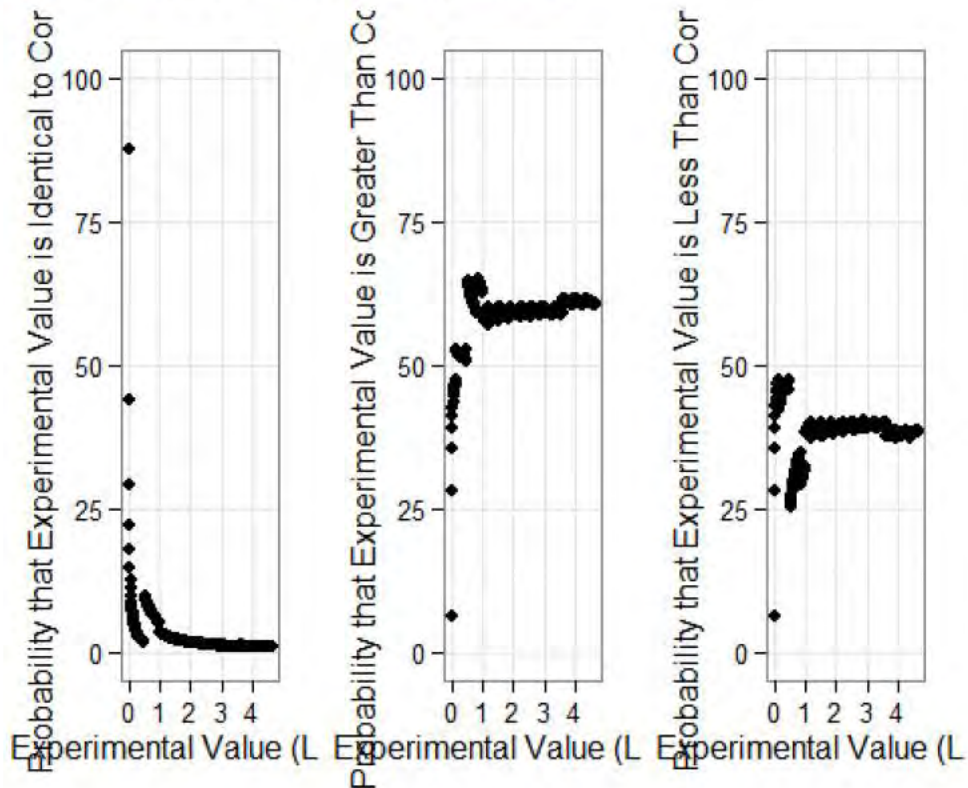
```

ol') +
  xlab('Experimental Value (L/min)')+
  ylim(0,100)

#Lower Plot
lower.3 <- ggplot(fig5dat, aes(x=exp, y=lower)) +
  geom_point() +
  theme_bw() +
  ylab('Probability that Experimental Value is Less Than Control'
) +
  xlab('Experimental Value (L/min)') +
  ylim(0,100)

#make figure 5
grid.arrange(same.3,higher.3,lower.3, ncol=3)

```



1 (PDF)	DEFENSE TECHNICAL INFORMATION CTR DTIC OCA	1 (PDF)	ARMY RSCH LAB – HRED RDRL HRM AY M BARNES 2520 HEALY AVE STE 1172 BLDG 51005 FORT HUACHUCA AZ 85613-7069
2 (PDF)	DIRECTOR US ARMY RESEARCH LAB RDRL CIO LL IMAL HRA MAIL & RECORDS MGMT	1 (PDF)	ARMY RSCH LAB – HRED RDRL HRM AP D UNGVARSKY POPE HALL BLDG 470 BCBL 806 HARRISON DR FORT LEAVENWORTH KS 66027-2302
1 (PDF)	GOVT PRINTG OFC A MALHOTRA	1 (PDF)	ARMY RSCH LAB – HRED HUMAN SYSTEMS INTEGRATION ENGR TACOM FIELD ELEMENT RDRL HRM CU P MUNYA 6501 E 11 MILE RD MS 284 BLDG 200A WARREN MI 48397-5000
1 (PDF)	ARMY RSCH LAB – HRED RDRL HRM D T DAVIS BLDG 5400 RM C242 REDSTONE ARSENAL AL 35898-7290	1 (PDF)	ARMY RSCH LAB – HRED FIRES CTR OF EXCELLENCE FIELD ELEMENT RDRL HRM AF C HERNANDEZ 3040 NW AUSTIN RD RM 221 FORT SILL OK 73503-9043
1 (PDF)	ARMY RSCH LAB – HRED RDRL HRS EA DR V J RICE BLDG 4011 RM 217 1750 GREELEY RD FORT SAM HOUSTON TX 78234-5002	1 (PDF)	ARMY RSCH LAB – HRED RDRL HRM AV W CULBERTSON 91012 STATION AVE FORT HOOD TX 76544-5073
1 (PDF)	ARMY RSCH LAB – HRED RDRL HRM DG K GUNN BLDG 333 PICATINNY ARSENAL NJ 07806-5000	1 (PDF)	ARMY RSCH LAB – HRED RDRL HRM DE A MARES 1733 PLEASONTON RD BOX 3 FORT BLISS TX 79916-6816
1 (PDF)	ARMY RSCH LAB – HRED ARMC FIELD ELEMENT RDRL HRM CH C BURNS THIRD AVE BLDG 1467B RM 336 FORT KNOX KY 40121	8 (PDF)	ARMY RSCH LAB – HRED SIMULATION & TRAINING TECHNOLOGY CENTER RDRL HRT COL G LAASE RDRL HRT I MARTINEZ RDRL HRT T R SOTTILARE RDRL HRT B N FINKELSTEIN RDRL HRT G A RODRIGUEZ RDRL HRT I J HART RDRL HRT M C METEVIER RDRL HRT S B PETTIT 12423 RESEARCH PARKWAY ORLANDO FL 32826
1 (PDF)	ARMY RSCH LAB – HRED AWC FIELD ELEMENT RDRL HRM DJ D DURBIN BLDG 4506 (DCD) RM 107 FORT RUCKER AL 36362-5000		
1 (PDF)	ARMY RSCH LAB – HRED RDRL HRM CK J REINHART 10125 KINGMAN RD BLDG 317 FORT BELVOIR VA 22060-5828		
1 (PDF)	ARMY RSCH LAB – HRED RDRL HRM AR J CHEN 12423 RESEARCH PKWY ORLANDO FL 32826-3276		

1 ARMY RSCH LAB – HRED  
(PDF) HQ USASOC  
RDRL HRM CN R SPENCER  
BLDG E2929 DESERT STORM DR  
FORT BRAGG NC 28310

1 ARMY G1  
(PDF) DAPE MR B KNAPP  
300 ARMY PENTAGON  
RM 2C489  
WASHINGTON DC 20310-0300

ABERDEEN PROVING GROUND

12 DIR USARL  
(PDF) RDRL HR  
L ALLENDER  
P FRANASZCZUK  
K MCDOWELL  
RDRL HRM  
P SAVAGE-KNEPSHIELD  
RDRL HRM AL  
C PAULILLO  
RDRL HRM B  
J GRYNOVICKI  
RDRL HRM C  
L GARRETT  
RDRL HRS  
J LOCKETT  
RDRL HRS B  
M LAFIANDRA  
M TENAN  
RDRL HRS D  
A SCHARINE  
RDRL HRS E  
D HEADLEY