UNITED STATES MILITARY ACADEMY
WEST POINT

Modeling, Validating, and Applying Mathematical Models to Determine Dietary Intake During Weight Loss Interventions?

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February 12, 2022

DEPARTMENT OF MATHEMATICAL SCIENCES
"To Infinity and Beyond"
U S M A

Disclosures

I do not have conflicts of interest or financial disclosures to declare.

The views expressed in this work are those of the authors and do not reflect the official policy or position of the United States Military Academy, Department of the Army, or the Department of Defense.

Dr. Brian Winkel

24-hour recall

What did you eat over the last 24 hours? List everything!

Self-report based estimates

The American Journal of
CLINICAL NUTRITION

Self-report–based estimates of energy intake offer an inadequate basis for scientific conclusions FREE

Dale A Schoeller, Diana Thomas, Edward Archer, Steven B Heymsfield, Steven N Blair, Michael I Goran, James O Hill, Richard L Atkinson, Barbara E Corkey, John Foreyt ... Show more

Self-report based estimates

Under-reporting Bias:

Compared to TDEE by Doubly Labeled Water: -10 to -30%

Table 1. *Summary of studies comparing reported EI by a single dietary instrument to TEE: reporting bias and correlation coefficient between EI and TEE*

Study	Subjects	Dietary Methodology	Energy Intake, MJ/day	Energy Expenditure, MJ/day	Reporting Bias, %	r
Goran and Poehlman (11)	6 F (elderly)	3-day Food record	5.99	8.75	−32	0.77*
	7 M (elderly)		9.73	11.19	−13	0.77*
Reilly et al. (22)	10 F (elderly)	3-day Food record	6.71	9.21	−27	NA
Taren et al. (28)	37 F	3-day Food record	8.25	9.33	−12	0.18†
Tomoyasu et al. (31)	28 M (African-American)	3-day Food record	9.75	11.32	−14	NA
	36 F (African-American)		7.89	8.74	−10	NA
Tomoyasu et al. (30)	39 M (older)	3-day Food record	8.73	11.30	−23	NA
	43 F (older)		6.87	8.35	−18	NA
Kaczkowski et al. (14)	53 F	4-day Food record	7.50	10.40	−28	NA
Clark et al. (7)	6 F (large eaters)	5-day Food record	10.49	8.49	+24	NA
	6 F (small eaters)		5.89	11.27	−48	NA
Goris et al. (12)	30 M (obese)	7-day Food record	10.40	16.70	−38	0.[illegible]2
Livingstone et al. (18)	16 M	7-day Food record	11.21	14.23	−21	NA
	15 F		8.00	9.93	−19	NA
Martin et al. (19)	29 F	7-day Food record	6.98	9.00	−22	0.[illegible]6‡
Prentice et al. (21)	9 F (obese)	7-day Food record	6.73	10.22	−34	NA
	13 F (lean)		7.85	7.99	−2	NA
Seale and Rumpler (27)	14 F	7-day Food record	7.88	9.57	−18	NA
	10 M		8.96	12.91	−31	NA
Lichtman et al. (16)	10 M/F (diet resistant)	14-day Food record	4.30	10.32	−59	NA
	6 M/F (control group)		7.08	11.07	−36	NA
Platte et al. (20)	10 F (control group)	14-day Food record	9.62	9.86	−2	NA
	10 F (obese)		8.43	15.51	−46	NA
Tuschl et al. (33)	11 F (unrestrained eaters)	14-day Food record	9.45	9.62	−2	NA
	12 F (restrained eaters)		8.18	8.61	−5	NA
Buhl et al. (5)	10 F (obese, diet resistant)	14-day Food record	NA	NA	−58	0.86§
Black et al. (3)	18 F	16-day Food record	8.30	9.50	−13	0.45
	27 M		10.06	11.67	−14	0.28
Rothenberg et al. (23)	12 M/F	Diet history	8.62	9.90	−13	0.27
Tran et al. (32)	35 F	24-h Recall (4 days)	9.26	11.06	−16	NA

$$\text{Reporting bias} = \frac{\text{reported energy intake (EI)} - \text{measured total energy expenditure (TEE)}}{\text{measured TEE}} \times 100$$

. A negative value for reporting bias indicates underreporting of EI. F, female; M, male; NA, not available. *Correlation coefficient determined using both genders. †$P < 0.05$; ‡$P < 0.01$; §$P < 0.001$.

Eg. Trabulsi & Schoeller Am J Physiol Endo Metab 281: E891-E899, 2001

Self-report based estimates

The NEW ENGLAND JOURNAL of MEDICINE

Discrepancy between Self-Reported and Actual Caloric Intake and Exercise in Obese Subjects

Steven W. Lichtman, Ed.D., Krystyna Pisarska, M.S., Ellen Raynes Berman, Psy.D., Michele Pestone, M.S., Hillary Dowling, Ph.D., Esther Offenbacher, Ed.D., Hope Weisel, M.S., R.D., Stanley Heshka, Ph.D., Dwight E. Matthews, Ph.D., and Steven B. Heymsfield, M.D.

CONCLUSIONS.

The failure of some obese subjects to lose weight while eating a diet they report as low in calories is due to an energy intake substantially higher than reported and an overestimation of physical activity, not to an abnormality in thermogenesis. (N Engl J Med 1992; 327:1893–8.)

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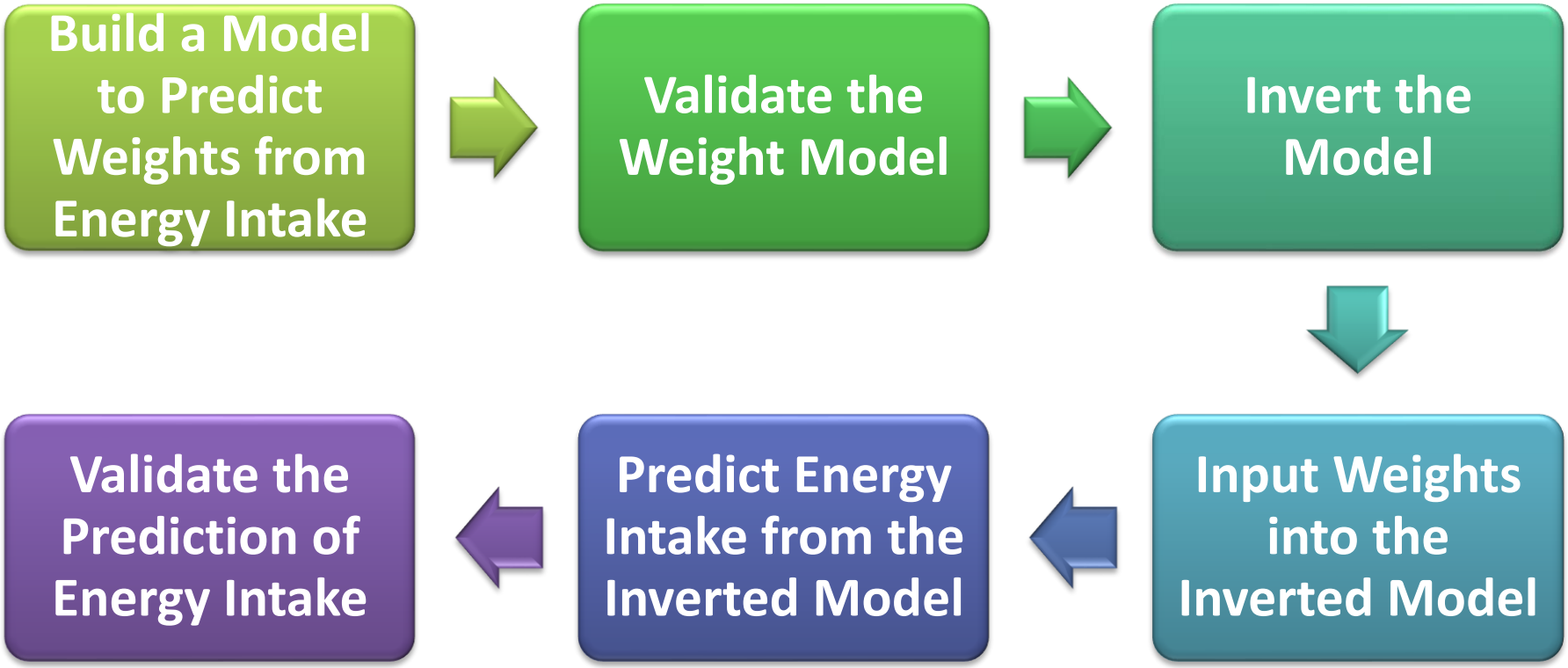
Can we use a model to estimate Energy Intake?

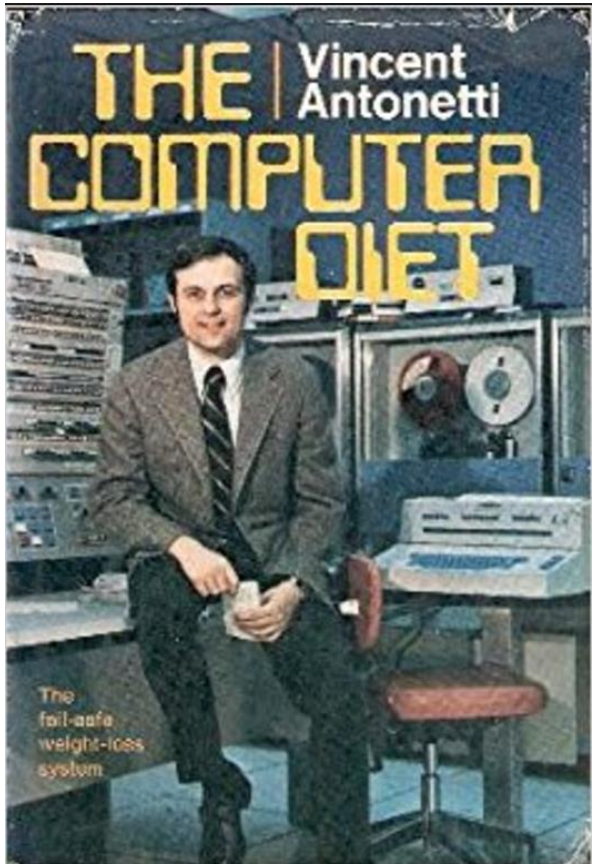


The first thermodynamic model: Antonetti

Am J Clin Nutr. 1973 Jan;26(1):64-71.

The equations governing weight change in human beings.

Antonetti VW.



Energy Balance Equation

$$ES = EI - EE$$

Rate of Energy Stores (ES) = Rate of Energy Intake (EI) – Rate of Energy Expenditure (EE)

kcal/d

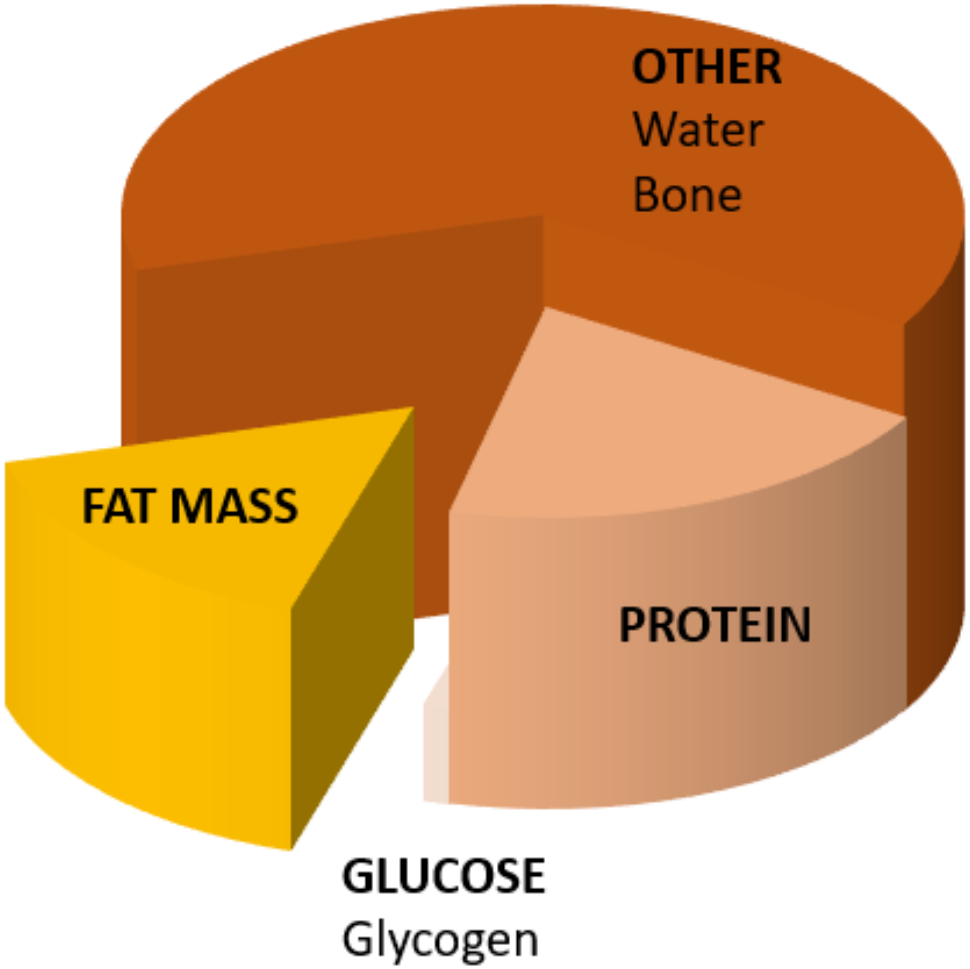
Energy Stores (ES)

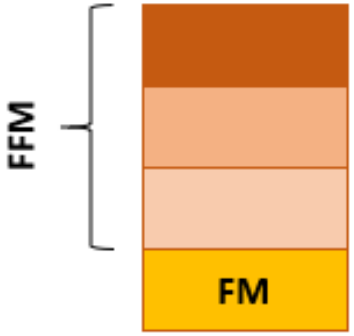
"The human body generates more bioelectricity than a 120-volt battery and over 25,000 BTUs of body heat."

Quote from Morpheus in the movie The Matrix

Energy Stores (ES)

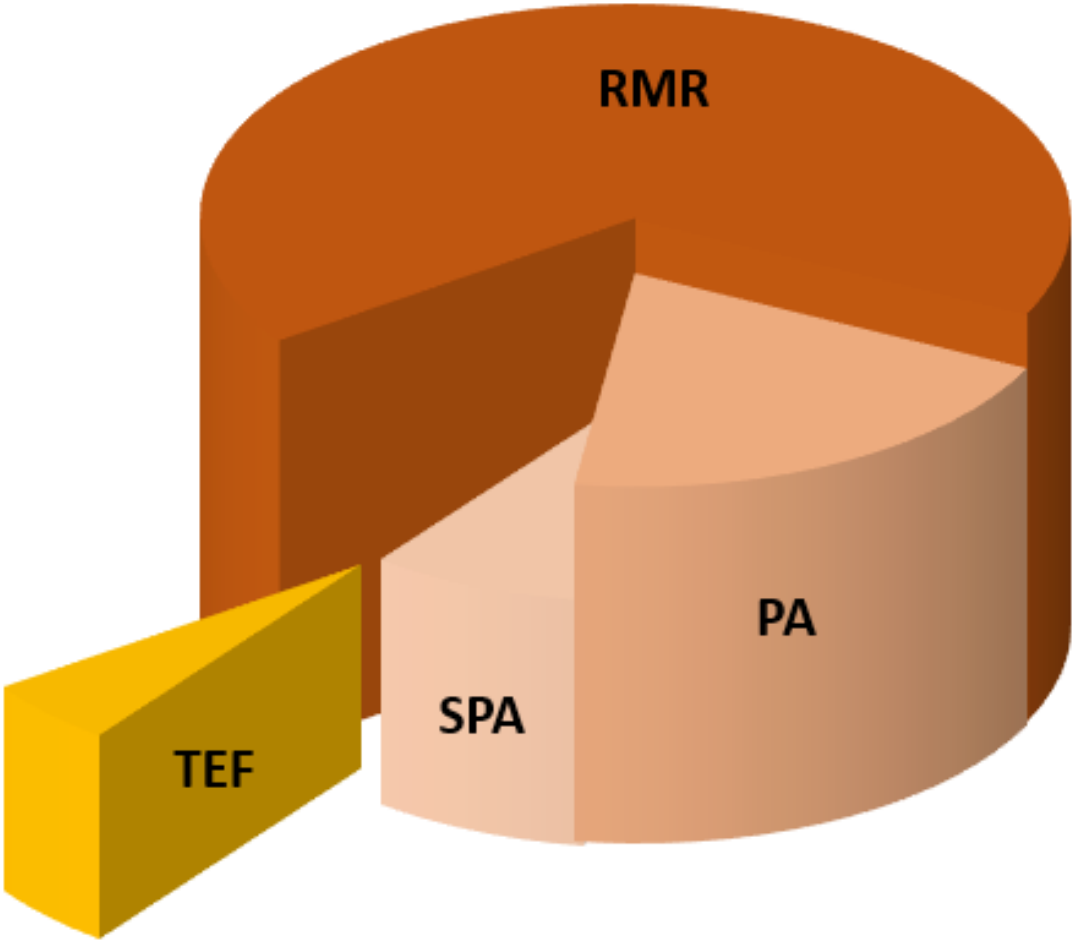
It is the energy balance modeler's *choice* on select state variables based on division of ES.

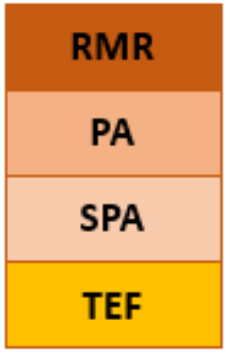




Energy Expenditure (EE)

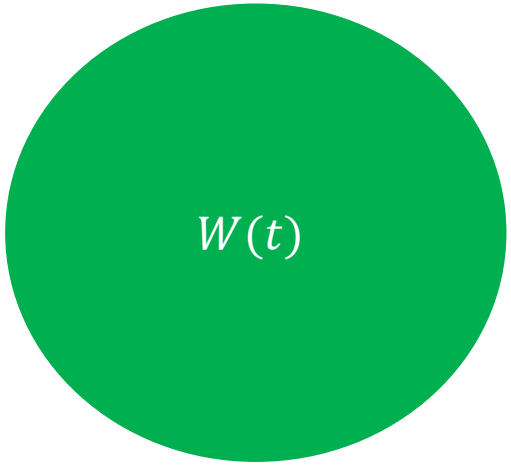
It is the energy balance modeler's choice on how to divide EE and what factors of EE to incorporate. These dictate some of the model assumptions.





The first dynamic energy balance model

$$ES = EI - EE$$



$$ES = 7700 \frac{dW}{dt} \frac{kcal}{d}$$

The equations governing weight change in human beings

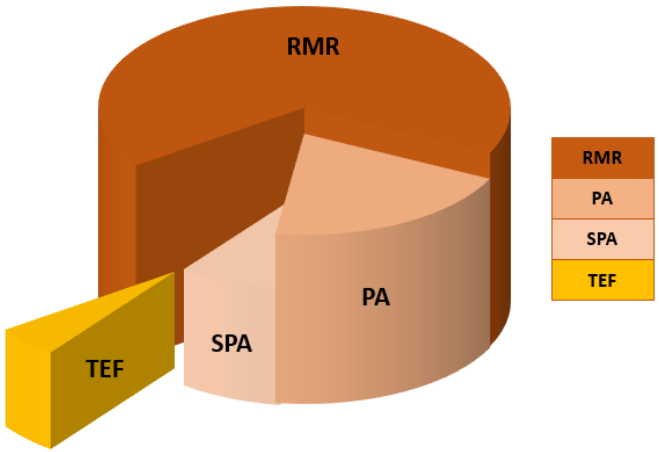
Vincent W. Antonetti[1]

The American Journal of Clinical Nutrition 26: JANUARY 1973, pp. 64–71. Printed in U.S.A.

Development of the first energy balance model

$$EE =$$

$$\mathbf{0.10}\ \boldsymbol{EI}$$



$$+$$

$$\boldsymbol{mW(t)}$$

$$+$$

Mifflin St. Jeor

$$RMR = aW(t) + bAge + cHeight + dGender$$

A new predictive equation for resting energy expenditure in healthy individuals[1–3]

Mark D Mifflin, Sachiko T St Jeor, Lisa A Hill, Barbara J Scott, Sandra A Daugherty, and Young O Koh

A thermodynamic model: Antonetti

$$ES = EI - EE$$

A thermodynamic model: Antonetti

$$ES = EI - EE$$

Rate of Energy Stores (kcal/d)

A thermodynamic model: Antonetti

$$ES = EI - EE$$

Rate of Energy Stores (kcal/d)

$$7700\frac{dW}{dt}$$

A thermodynamic model: Antonetti

$$ES = EI - EE$$

Rate of Energy Stores (kcal/d)

$$7700\frac{dW}{dt}$$

Rate of Energy Expenditures (kcal/d)

A thermodynamic model: Antonetti

$$ES = EI - EE$$

Rate of Energy Stores (kcal/d)

$$7700\frac{dW}{dt}$$

Rate of Energy Expenditures (kcal/d)

$$0.10 \times EI + m \times W(t) + Mifflin\ St.Jeor$$

Mifflin St. Jeor RMR Model

- **Men**

$$10\,W(t) + 6.25\,H - 5\,A + 5$$

- **Women**

$$10\,W(t) + 6.25\,H - 5\,A - 161$$

Energy Balance Model

An equation that involves the state variable and it's derivatives

$$7700\frac{dW}{dt} = EI - (10W(t) + mW(t)$$

$$+Everything\ else)$$

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Validate the Model

calerie™

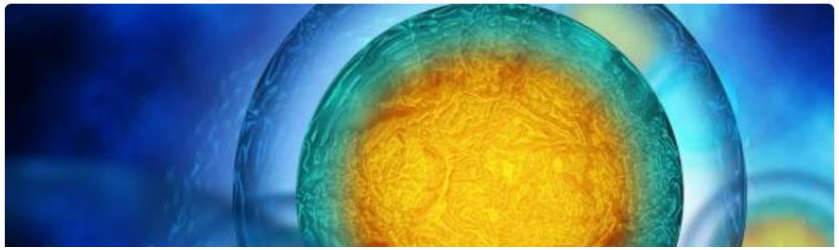
Duke University School of Medicine

Funding provided by NIH National Institute on Aging

Funding provided by NIH National Institute of Diabetes and Digestive and Kidney Diseases

QUICK NAVIGATION

- Network Resources
- About the Study
- Database Documentation



NEW PUBLICATIONS

Effects of caloric restriction on human physiological, psychological, and behavioral outcomes: highlights from CALERIE phase 2

September 21, 2020

Multi-site Consortium – Weight Loss Intervention –Doubly Labeled Water and Dual Energy X-Ray Absorpiometry

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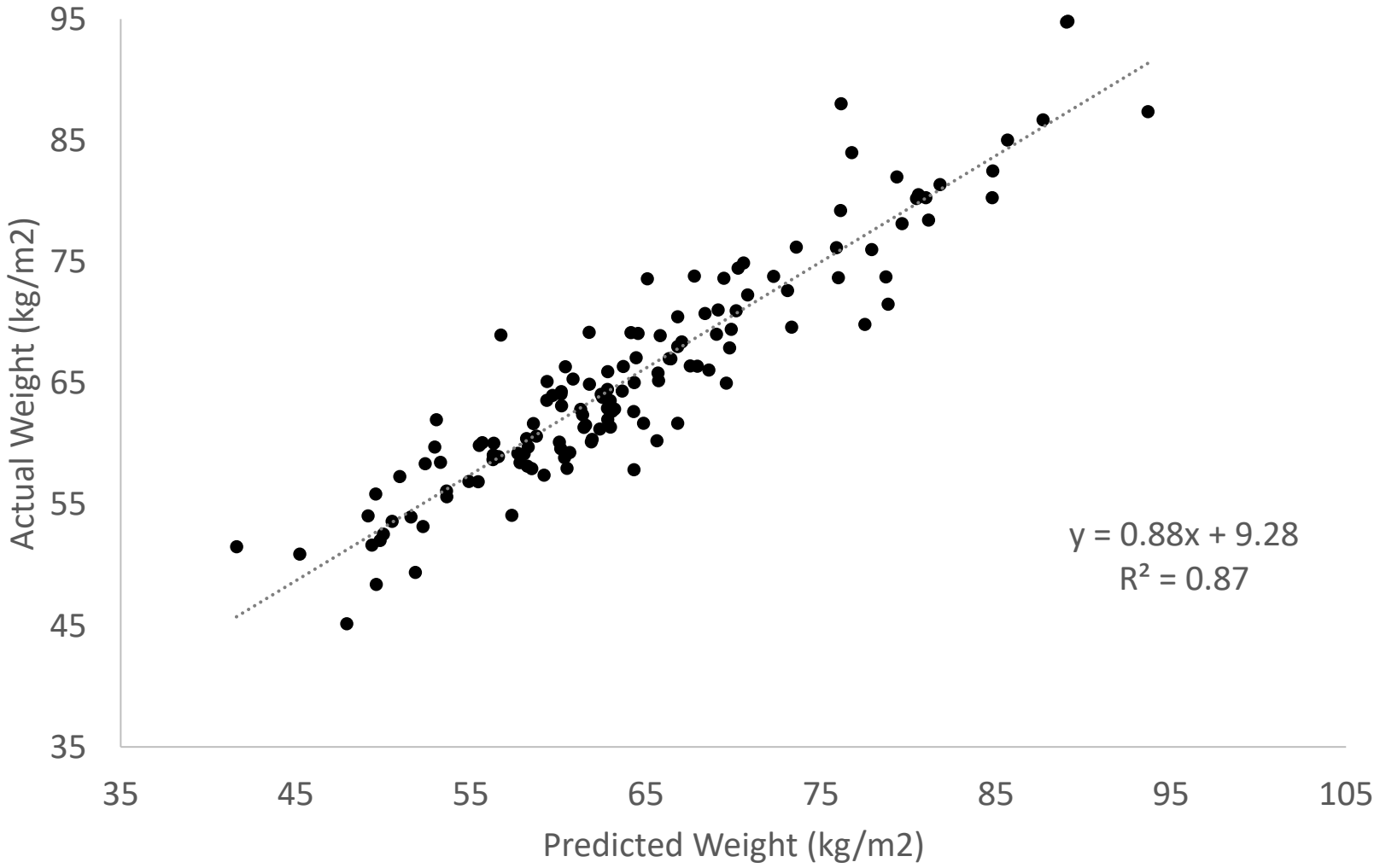
Measured EI

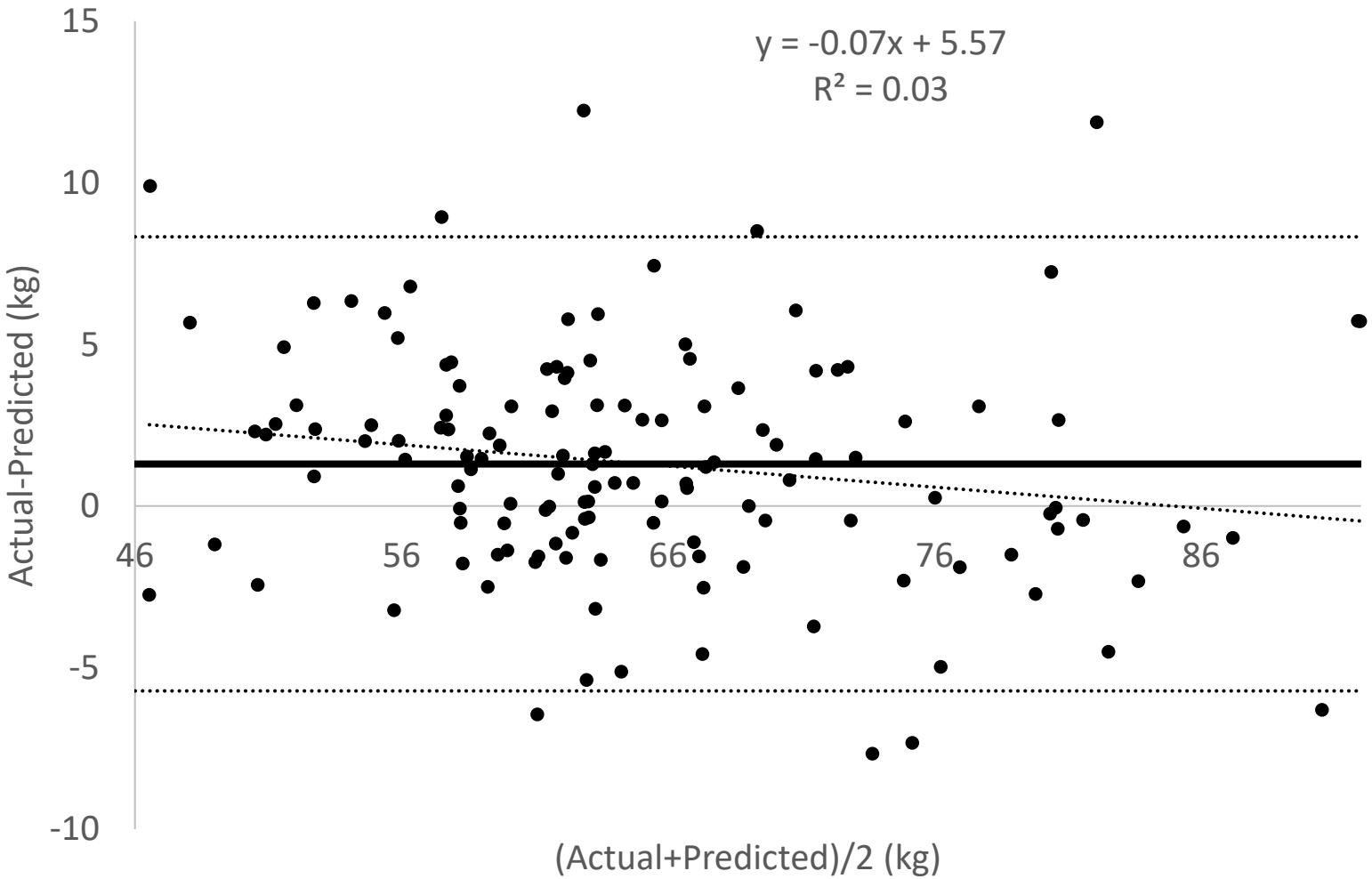
	Female CALERIE I	Male CALERIE I	Female CALERIE II	Male CALERIE II
n	7	5	95	40
age (years)	34.42 (3.97)	38.63 (7.14)	37.08 (7.10)	40.90 (6.65)
TDEE (kcal/d)	2341.00 (310.09)	3098.00 (404.24)	2246.60 (277.10)	2816.08 (342.13)
BMI (kg/m^2)	27.9 (1.9)	27.1 (1.4)	25.00 (1.78)	26.29 (1.57)

$$EI_{measured} = 9500\frac{\Delta FM}{\Delta t} + 1020\frac{\Delta FFM}{\Delta t} + EE_F$$

Validate the Model



Validate the Model



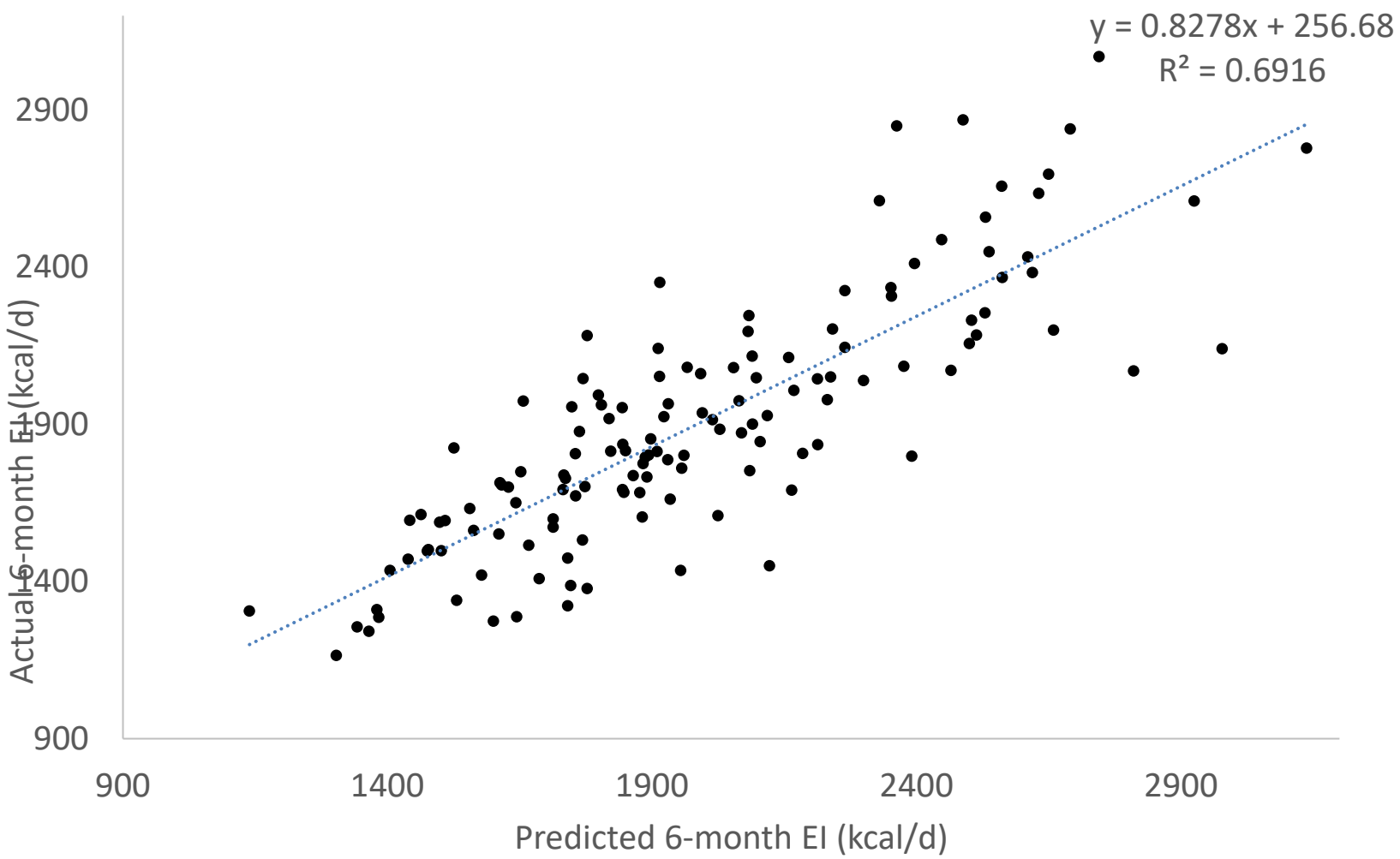
Invert the Model: EI

Corey Gerving[1], Robert Lasater[2], James Starling[2], Danielle M. Ostendorf[3], Leanne M. Redman[4], Chad Estabrooks[2], Kevin Cummiskey[2], Vincent Antonetti[5], Diana M. Thomas[2]

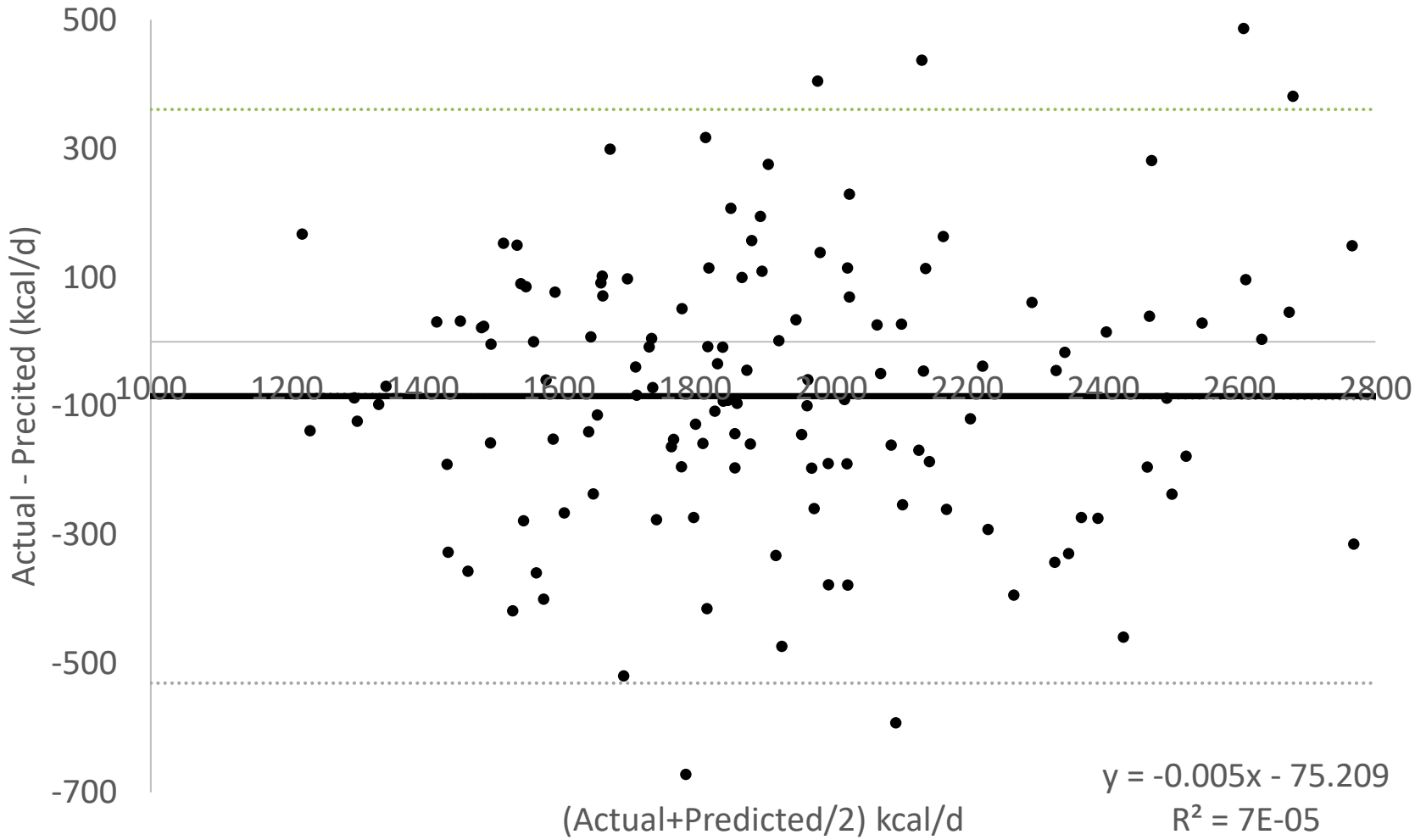
$$W(t) = -\frac{\beta}{\alpha} + \left[W_o + \frac{\beta}{\alpha}\right] \mathrm{e}^{\alpha t}$$

$$EI = \left[\frac{77000\alpha\left[W(t) - W_o \mathrm{e}^{\alpha t}\right] - 10\gamma\left(\mathrm{e}^{\alpha t} - 1\right)}{9\left(\mathrm{e}^{\alpha t} - 1\right)}\right]$$

Validate the Inverted Model



Validate the Inverted Model



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Thank you Collaborators

Pennington Biomedical Research Center

Steven Heymsfield

Leanne Redman

Corby Martin

University of Wisconsin, Madison

Dale Schoeller

West Point

LTC James Starling

COL Corey Gerving

MAJ Rob Lasater

COL Michael Scioletti

Manhattan College/Florida

Vincent Antonetti

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Back Up Slide What about Exercise?

Why do individuals not lose more weight from an exercise intervention at a defined dose? An energy balance analysis

D. M. Thomas, C. Bouchard, T. Church, C. Slentz, W. E. Kraus, L. M. Redman, C. K. Martin, A. M. Silva, M. Vossen, K. Westerterp, S. B. Heymsfield

First published: 11 June 2012 | https://doi.org/10.1111/j.1467-789X.2012.01012.x | Citations: 157

expenditures. This information combined with available measurements was used to critically evaluate explanations for low exercise-induced weight loss. We conclude that the small magnitude of weight loss observed from the majority of evaluated exercise interventions is primarily due to low doses of prescribed exercise energy expenditures compounded by a concomitant increase in caloric intake.

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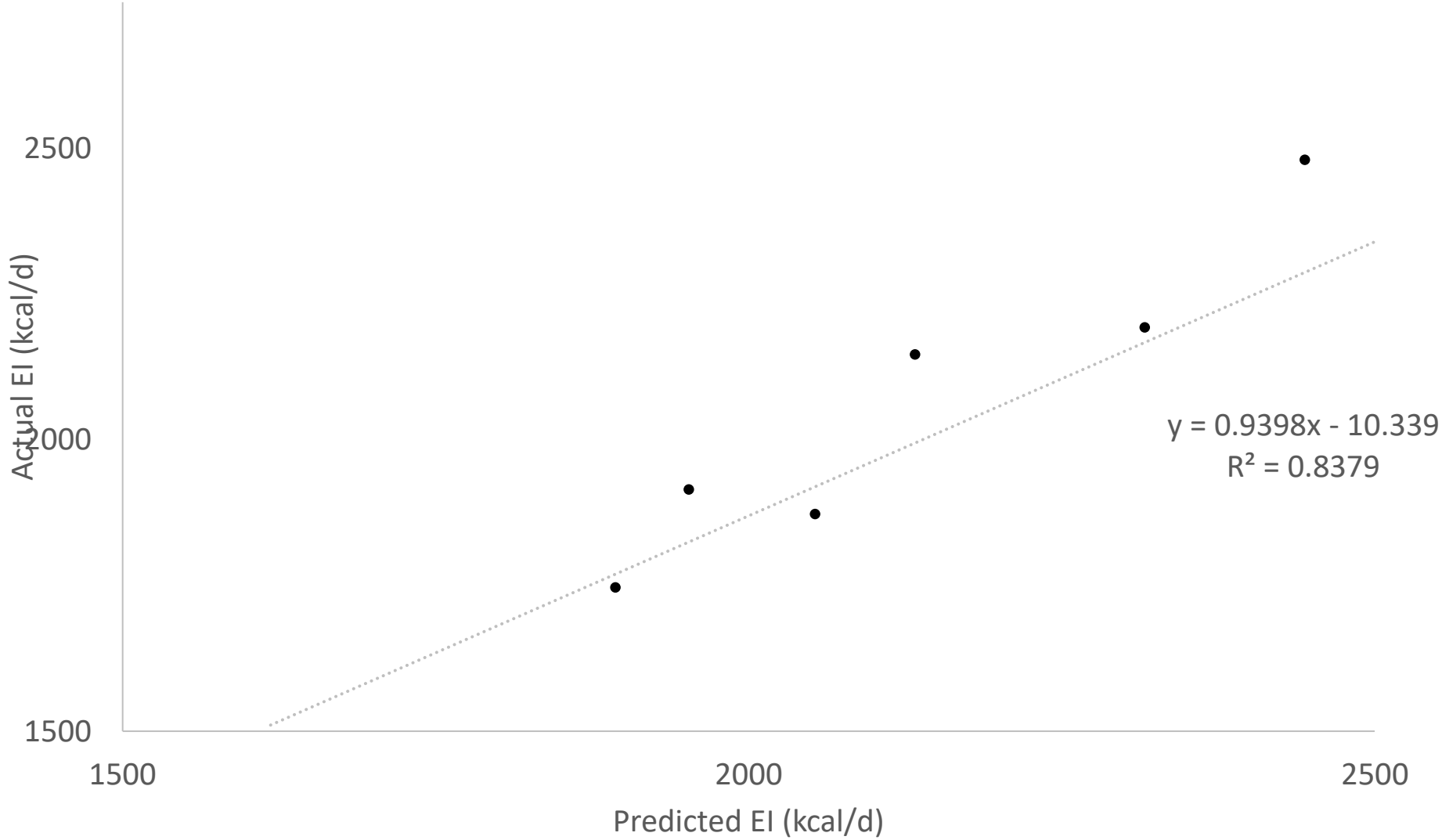
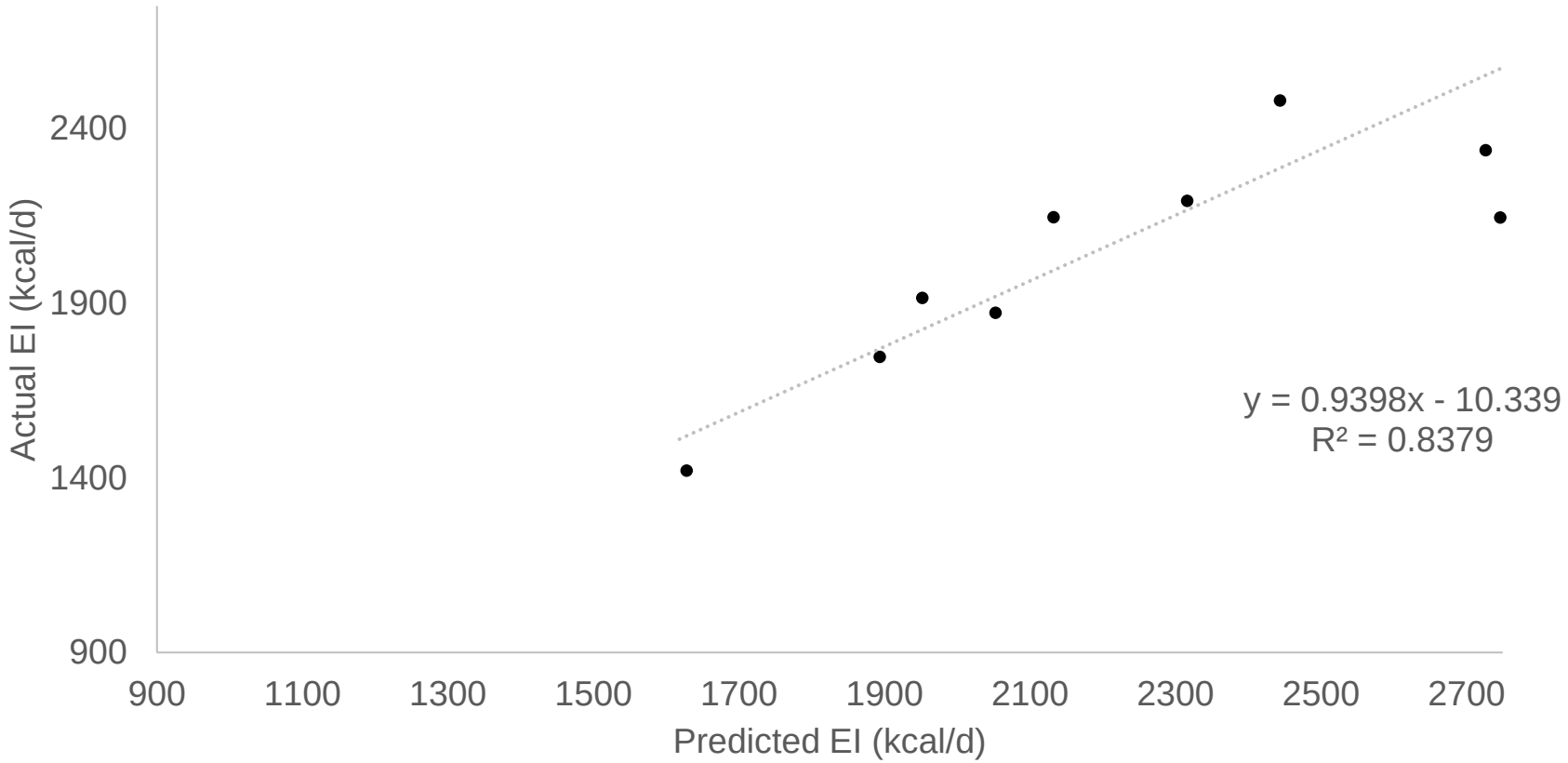
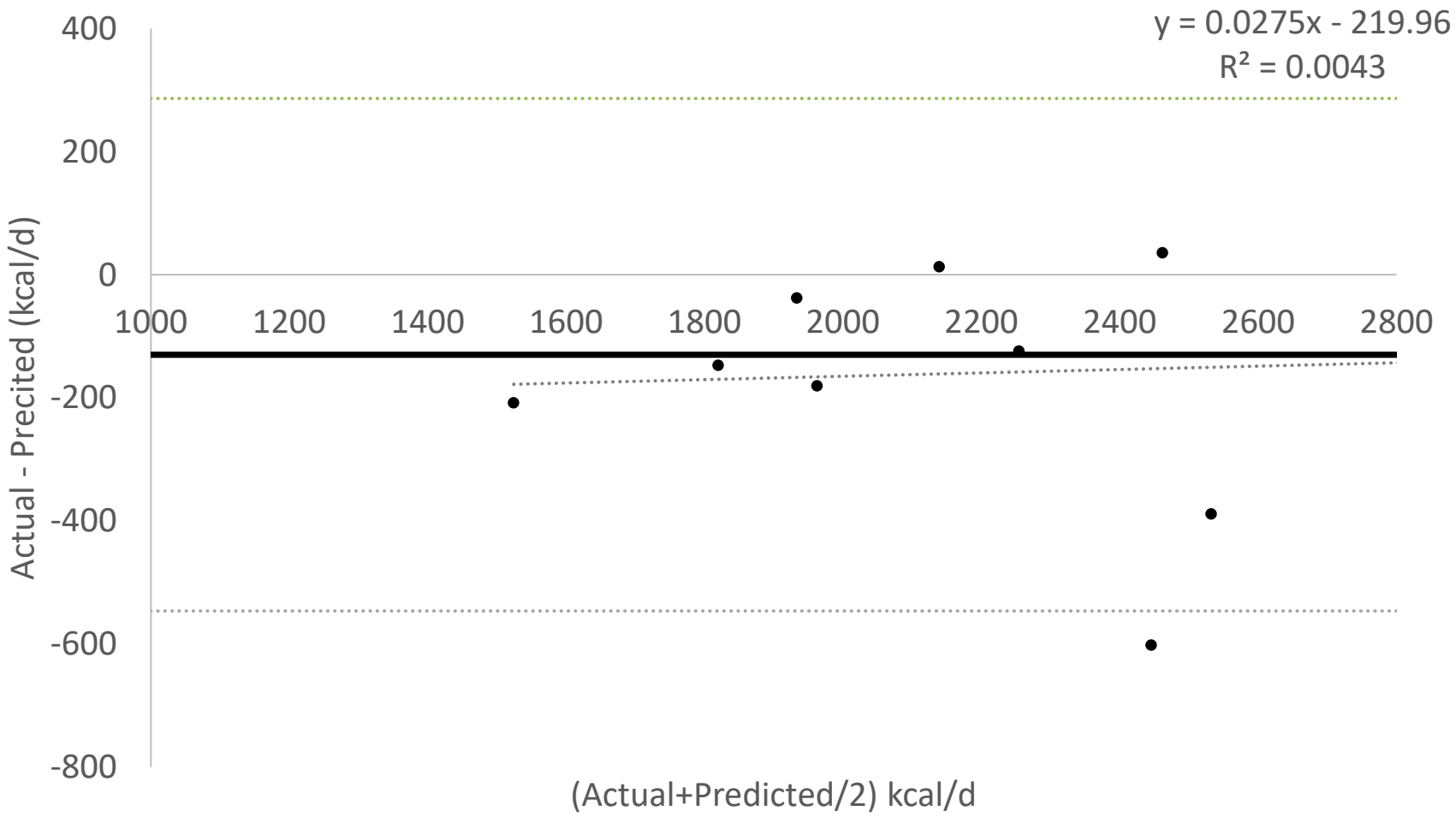
Assume ΔPAEE=0




Actual EI (kcal/d)
2400
1900
1400
900
900
1100
1300
1500
1700
1900
2100
2300
2500
2700
Predicted EI (kcal/d)
y = 0.9398x - 10.339
R² = 0.8379


y = 0.0275x - 219.96
R² = 0.0043
400
200
0
-200
-400
-600
-800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Actual - Precited (kcal/d)
(Actual+Predicted/2) kcal/d