An Introduction to Accelerometer Data Reduction and Processing

- Scott Crouter, PhD
  - University of Massachusetts Boston
- Jacqueline Kerr, PhD
  - Active Living Research/SDSU/UCSD

- This session will focus on what you need to do after you have collected your accelerometer data. It will provide information on examining your data for valid days, valid count values, bout duration, non-wear time, etc. It will also provide a demonstration of various computer programs written to assist in preparing your accelerometer data for statistical analysis.

Outline

5 mins: Introduction JK

40 mins: Processing accelerometer data SC

10 mins: Questions

20 mins: Accelerometer processing software JK

15 mins: Questions & discussion

Further questions & discussion at breakfast roundtable on Friday 7.30-8.30am

Accelerometer best practice

- How many of you have collected accelerometer data?
- ALR accelerometer 101s online
- MSSE
  - November 2005, Volume 37, Issue 11 Supplement
- Budget for data processing
- Start by collecting good data
  - Compliance for wear time
  - Re-wear & meter checking

Promoting Compliance

- Check meters and wear time
- Show participants graphical display of data, i.e. can see non wear time
- Providing incentives contingent on compliance – money, gift certificates, coupons, extra credit
- Multiple reminders (calls, stickers)
- Clear instructions
- Logs – promotes self-monitoring
- Identify barriers to wearing and address them, make it "cool" for kids
- Get other support e.g. parents, teachers, coaches, referees, and other sport officials
- Follow up for meter retrieval, budget for loses

Factors to consider before collecting accelerometer data.

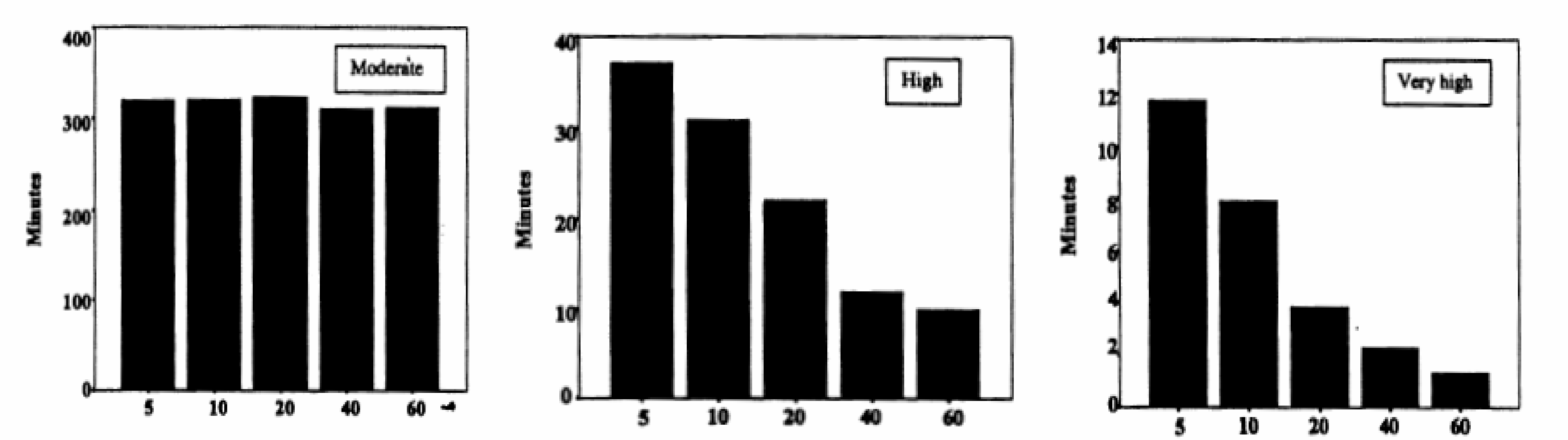
- Epoch Length
- Monitor Placement
- How many days of monitoring

Effect of Epoch Length

- Cut-points based on 1-min epochs could significantly underestimate children's highly sporadic and intermittent activity patterns.
- Over the 1-min period, bursts of vigorous activity and brief periods of inactivity are averaged
- Vigorous activity becomes "masked"

Effect of Epoch Length

- 16 children (mean age 7.5 ± 0.3 y)
- Wore monitor on right hip and lower back
- 4 monitoring days, 5-second epoch
- Mins of PA estimated via Freedson adult cut-points



Nilsson, Ekelund, Yngve,& Sjostrom (2002) *Pediatric Exercise Science*,14,87-96

Effect of Epoch Length

- Baquet et al. (2007)
- 26 children (mean age 9.95 ± 0.99 y)
- Epoch set for 2-seconds
- Minutes of PA estimated via Freedson child cut-points
  - LPA – 70.8 ± 13.2 seconds
  - MPA – 9.0 ± 2.8 seconds
  - VPA – 4.7 ± 1.2 seconds
- 80% of MPA bouts, 93% of VPA bouts lasted < 10 seconds

Baquet, Stratton, Van Praagh, Berthoin *Preventive Medicine* 2007;44:143-147

Monitor Placement

- Nilsson et al. (2002)
  - Compared MTI/CSA counts recorded at hip and lower back in 16 children
  - NS differences between the two monitor placements (751 ± 100 hip, 729 ± 112 back).
  - Hip placement resulted in higher estimated MPA - based on 5-sec epoch.
  - NS differences between the hip and back placements for estimated time spent in vigorous and very vigorous physical activity.

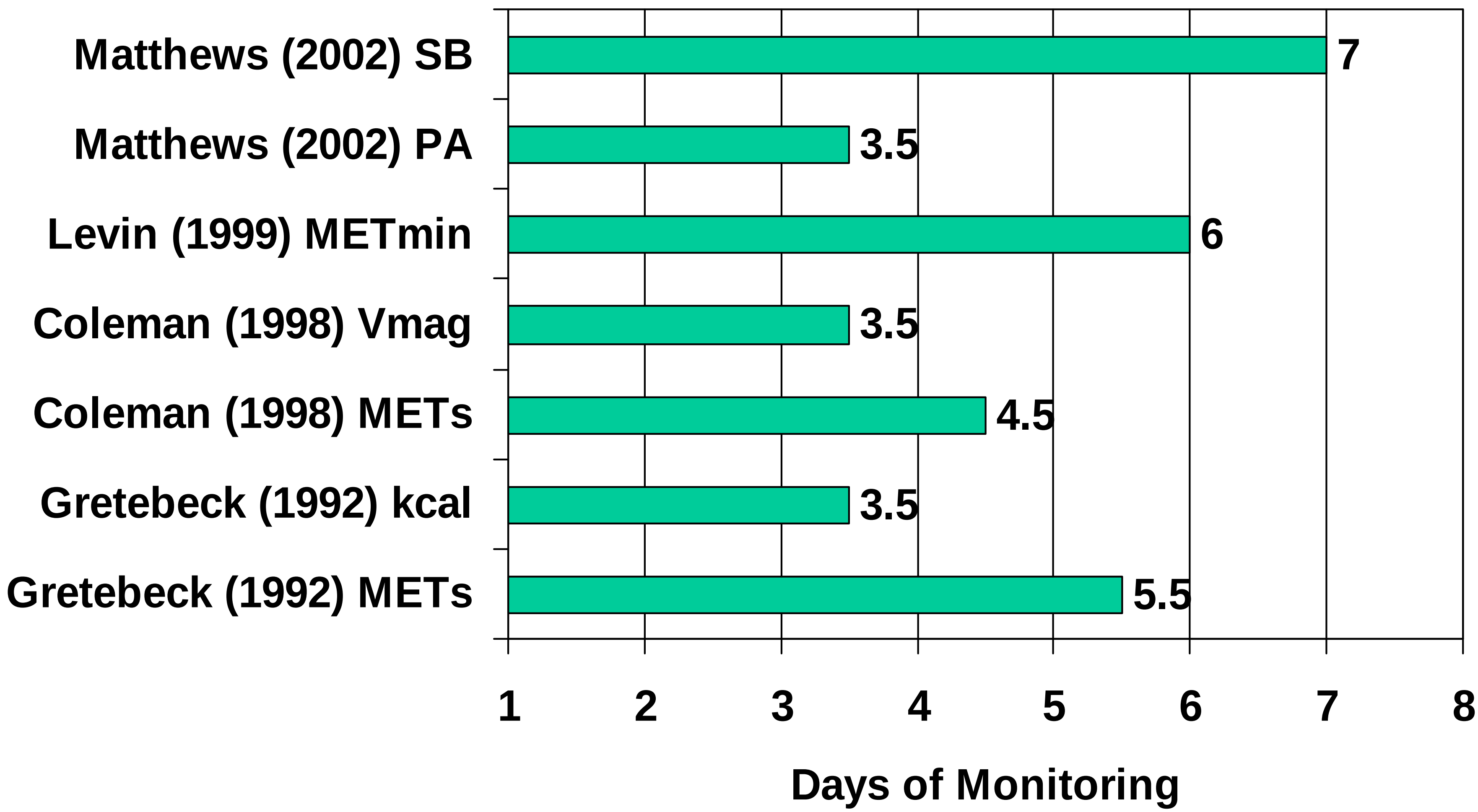
Monitor Placement

- Yngve et al. (2003)
  - Compared MTI/CSA counts recorded at hip and lower back in adults under controlled and field conditions
  - Controlled trial: Counts recorded on the back were significantly lower during walking, but significantly higher during jogging.
  - Field-based trial: NS differences for mean activity counts per min from the lower back 392 ± 139 and hip 402 ± 143.
  - Placement of the monitor had no effect on predicted time spent at moderate and vigorous physical activity.

How Many Monitors?

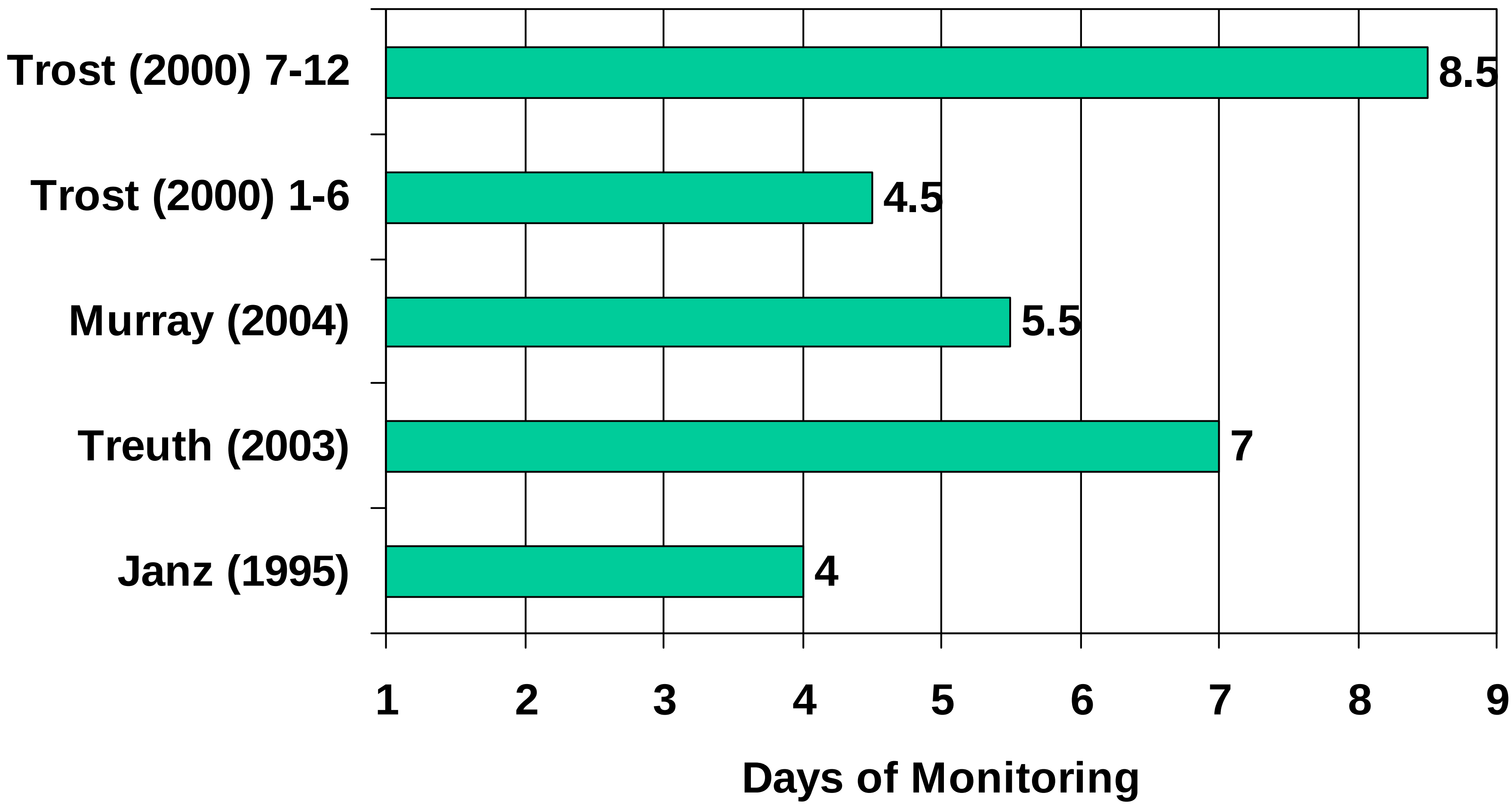
- •Multiple vs. single monitor
  - – Melanson & Freedson (1995)
  - – Swartz et al. (2000)
- •Marginal improvement in explanatory power offset by practical concerns

Days of Monitoring – Adult Studies



Trost et al. MSSE 2005

Days of Monitoring – Youth Studies



Trost et al. MSSE 2005

Accelerometer Data Reduction

- Identify invalid data
- Identify non-wear time
- What is a complete day
- Number of valid days needed
- Bouts

Identifying Invalid Data

- Masse et al. (MSSE 2005)
  - ActiGraph ≥16,000 or 20,000 counts per minute
    - Assumed to be beyond biologically plausible range
  - Counts > 0 and constant for 10 minutes
    - Assumed to be accelerometer malfunction
    - May appear as 32767 counts per minute
- Values can be set to missing
- Use an average of the surrounding values to compute new value

Identifying Non-wear Time

- Zero Count Method
  - Deletion of strings of consecutive 0 counts
    - Allows for 1-2 min of counts of less than a specified value (e.g. <100 counts per minute)
  - 60-minutes
  - 20-minutes
  - 10-minutes

20, 30 or 60 consecutive minutes of zeros? (Evenson, 2008)

	20	30	60
>= 1952 counts	2.5%	2.4%	2.3%
>= 573 counts	17.3%	16.7%	16.4%
<= 100 counts	54.3%	55.9%	56.7%
Total minutes invalid data	694	423	326

Non-wear: What to do

- Caution should be used:
  - Could identify device removed (e.g. bathing, recreation physical activity, social event), or could be true inactivity (e.g., sleeping, sitting still for extended periods).
- Use of activity log may help identify non-wear more accurately
  - Use activity log to impute MET/EE value for non-wear periods
- Clearly report how non-wear time was computed and number of wearing interruptions

What is a complete day ?

- Depending on study outcomes, wear time may need to be standardized
  - Bouts of MVPA vs. time spent in sedentary and light activities.
- 24-hour counts minus non-wear time
  - Minimum 10-12 hours
  - 60% of waking time
  - 80% of standard day

Cut-off for "complete" day

- 70/80 rule
  - Find 70th percentile of on and off times
  - Define adherence as 80% of the difference in on/off times.
- Weekdays
  - on: 7:15 AM; off: 9:15 PM (14 hrs)
  - Adherence 11.2 hours
- Weekends
  - on: 12:15 PM; off: 9:15 PM (9 hrs)
  - Adherence 7.2 hours

Number of valid days needed

- Masse et al (MSSE, 2005)
  - To compute outcome variables
    - 3-4 days of valid data
    - Based on 7 days and impute missing days
  - To compute physical activity recommendation
    - 4-5 days of valid data

Bouts

- Bouts can be operationalized in many different ways.
  - Strict definition: Minutes are accumulated if and only if they were performed as part of a 10-min or longer bout in which 10 or more consecutive 1-min epochs were above the count cutoff for moderate intensity activity.
  - The bout, and hence the accumulation of MVPA minutes, ends as soon as the program encounters a single count below the moderate cut-point.

Bouts

- Another approach allows an interruption interval.
- Counts are permitted to dip below the count cut-point for 1 or 2-min
- The bout and hence the accumulation of MVPA minutes will continue if the program encounters a count above the threshold *immediately* after reading the count below threshold.

Bouts

- For example, if a program reads the following sequence of counts :
- 200, 100, 2000, 2500, 1985, 2005, 2505, 2501, 2685, 3240, 5123, 1500, 900, 3510, 2008, 100, 500 500

We have our data cleaned now what?

- Calibration of accelerometer data
- Choice of equation
- Choice of outcome
  - Counts/min, Counts/day, Total counts
  - Energy expenditure
  - Time spent in different activity categories

Calibration of Accelerometer Output

- Relationship between energy expenditure (METs, kcals/min) and accelerometer counts
  - Regression models
- Accelerometer counts are related to energy expenditure
- Develop regression models to describe this relationship
  - Locomotion
  - Other activities

Calibration Studies

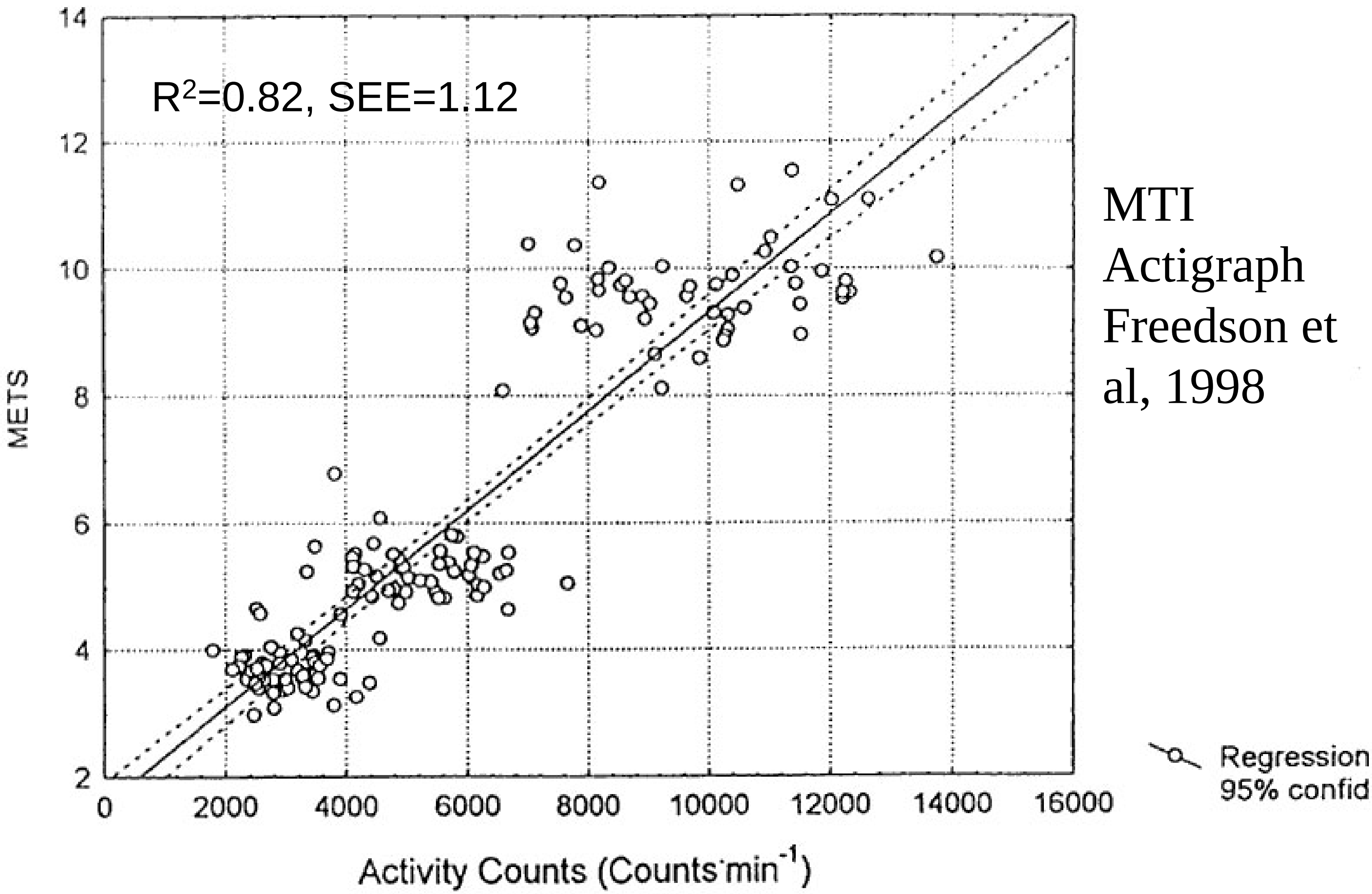
- Activities used
- Population
  - Age
  - BMI
- Lab vs. field setting
- Epoch setting

Accelerometer Outcomes for Adults

Actigraph					
	N	**Equation**	**Activities**	**R^2**	**SEE**
MET Predictions					
Freedson et al. (1998)	50	$1.439008 + (0.000795 * cnts \cdot min^{-1})$	TM Walk (2)/run (1)	0.82	1.12
Hendelman et al. (2000)	25	$1.602 + (0.000638 * cnts \cdot min^{-1})$	OG Walk (4 self-selected)	0.59	0.89
Hendelman et al. (2000)	25	$2.922 + (0.000409 * cnts \cdot min^{-1})$	OG Walk (4 self-selected) and 6 lifestyle activities	0.35	0.96
Swartz et al. (2000)	70	$2.606 + (0.0006863 * cnts \cdot min^{-1})$	OG Walk (2) and 26 Lifestyle activities	0.32	1.16
Leenders et al. (2003)	28	$2.240 + (0.0006 * cnts \cdot min^{-1})$	TM Walk (5)	0.74	0.53
Yngve et al. (2003)	28	$1.136 + (0.0008249 * cnts \cdot min^{-1})$	TM Walk (2)/run (1)	0.85	1.14
Yngve et al. (2003)	28	$0.751 + (0.0008198 * cnts \cdot min^{-1})$	OG self-selected walk(2)/run (1)	0.86	1.10
Heil et al. (2003)	58	$(0.00171 \times counts \cdot min^{-1}) + (1.957 \times height\ in\ cm) - (0.000631 \times counts \cdot min^{-1} \times height\ in\ cm) - 1.883$	OG self-selected walk(2)/run (1)	0.71	0.59
Brooks et al. (2005)	72	$2.32 + (0.000289 * counts \cdot min^{-1})$	OG walk (1 self selected)	0.51	0.44
Brooks et al. (2005)	72	$3.33 + (0.000370 * counts \cdot min^{-1}) - (0.012 * BM)$	OG walk (1 self selected)	0.61	0.40
Kcal·min^{-1} Predictions					
Manufacturer's equation (net EE)*		$0.0000191 \times (counts \cdot min^{-1}) \times body\ mass\ in\ kg$			
Freedson et al. (1998)	35	$(0.00094 * cnts \cdot min^{-1}) + (0.1346 * BM) - 7.37418$	TM Walk(2)/run (1)	0.82	1.40
Brooks et al. (2005)	72	$3.377 + (0.000370 * counts \cdot min^{-1})$	OG walk (1 self selected)	0.17	0.95
Brooks et al. (2005)	72	$(0.000452 * counts \cdot min^{-1}) + (0.051 * BM) - 0.774$	OG walk (1 self selected)	0.77	0.50
VO_2 (ml·kg^{-1}·min^{-1}) Predictions					
Nichols et al. (2000)	60	$6.057359 + (0.002545 * cnts \cdot min^{-1})$	Walk(2)/jog (1)	0.89	3.72

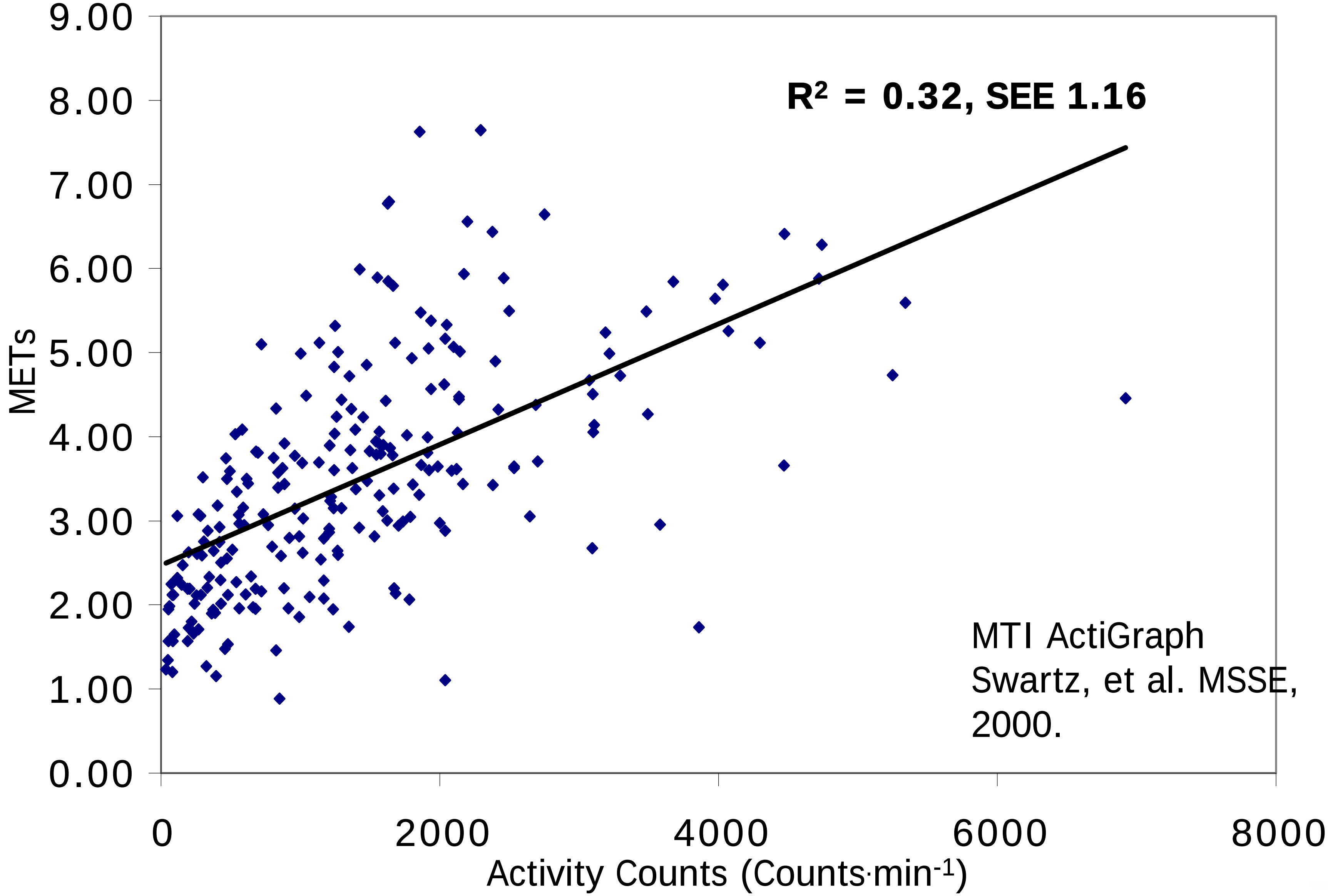
Crouter et al, EJAP, 2006

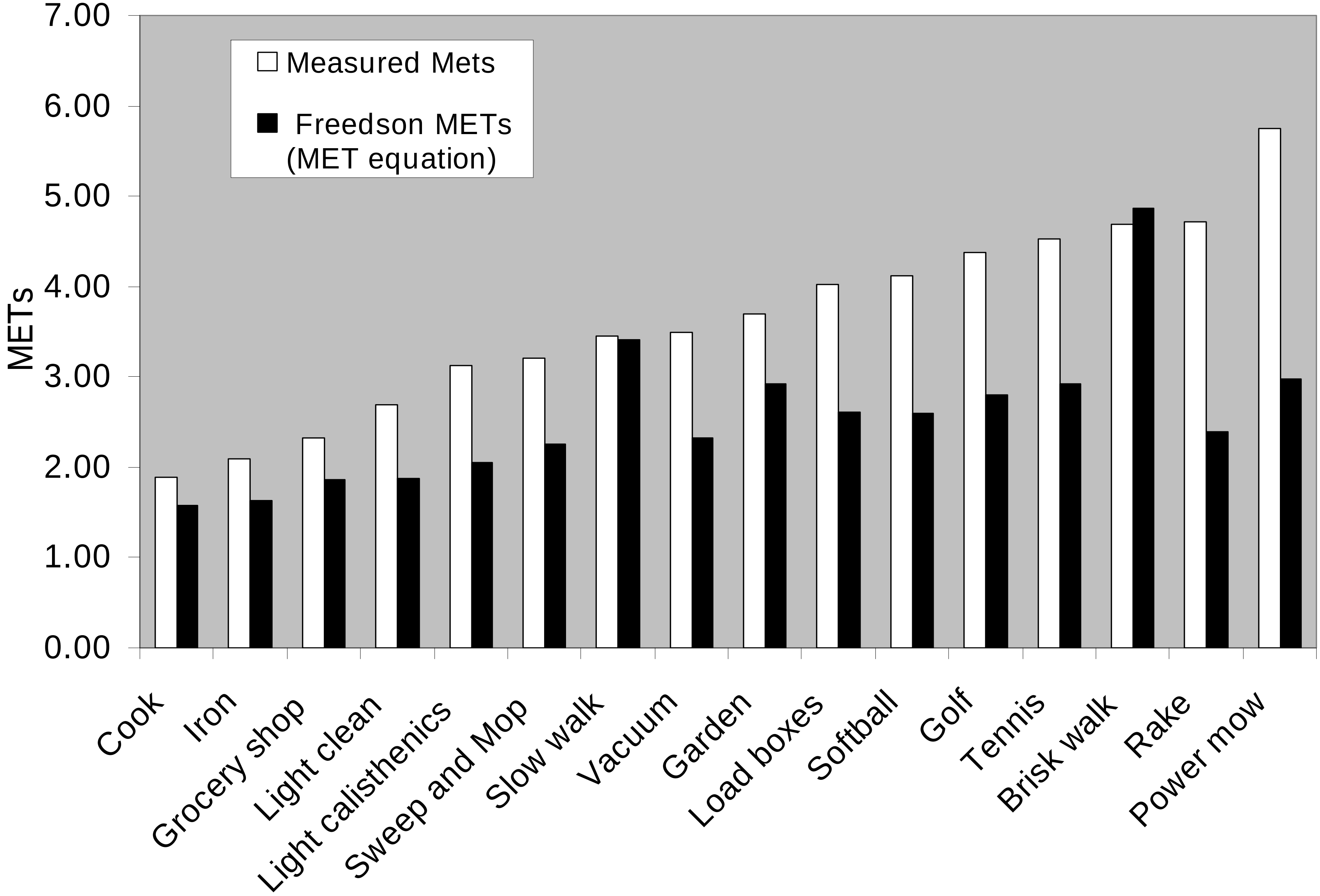
Treadmill Walk-Run Regression



MTI Actigraph Freedson et al, 1998

Lifestyle Physical Activity

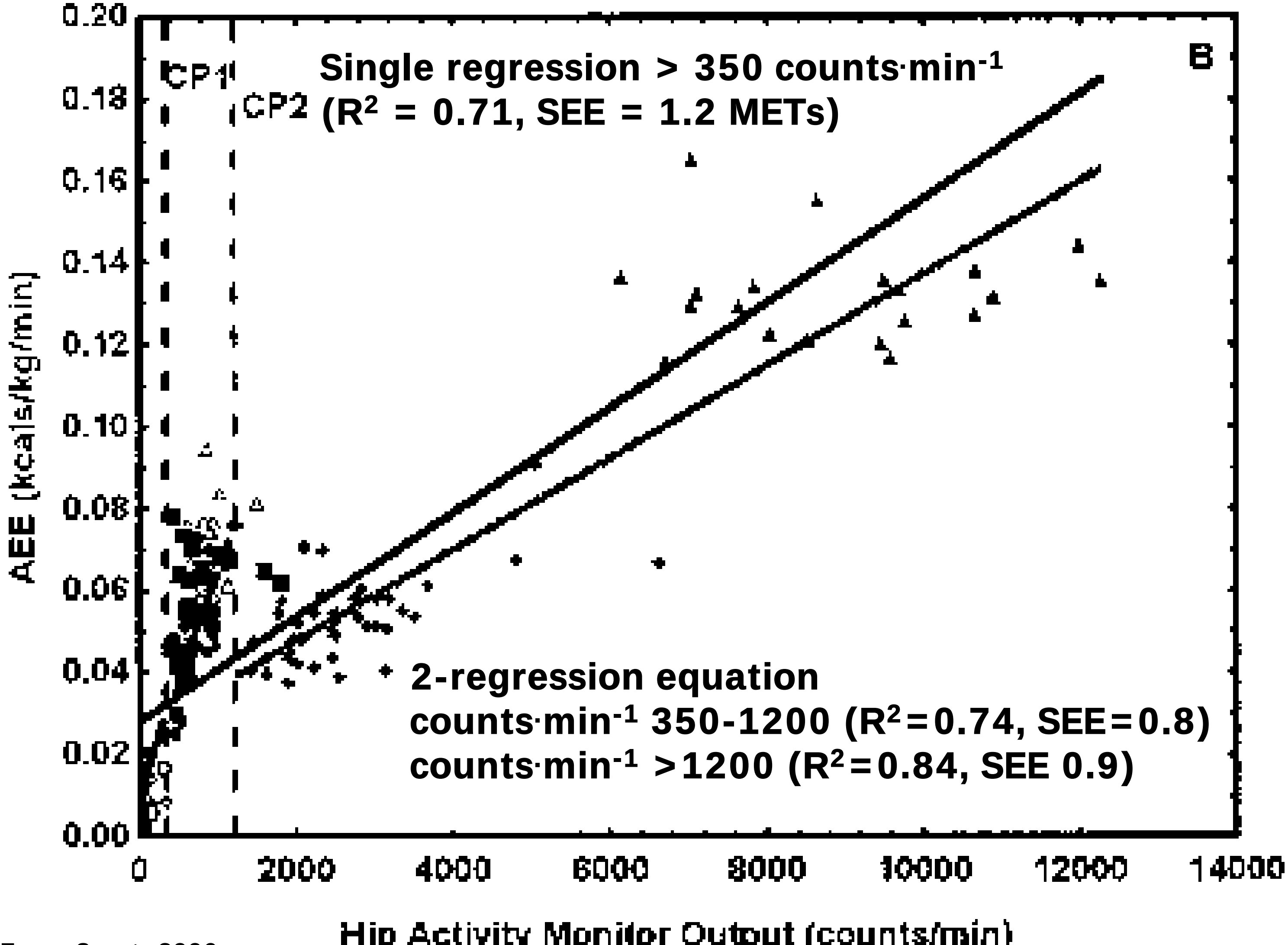




S. Crouter, re-analysis of Bassett et al. MSSE 2000

Actical Calibration

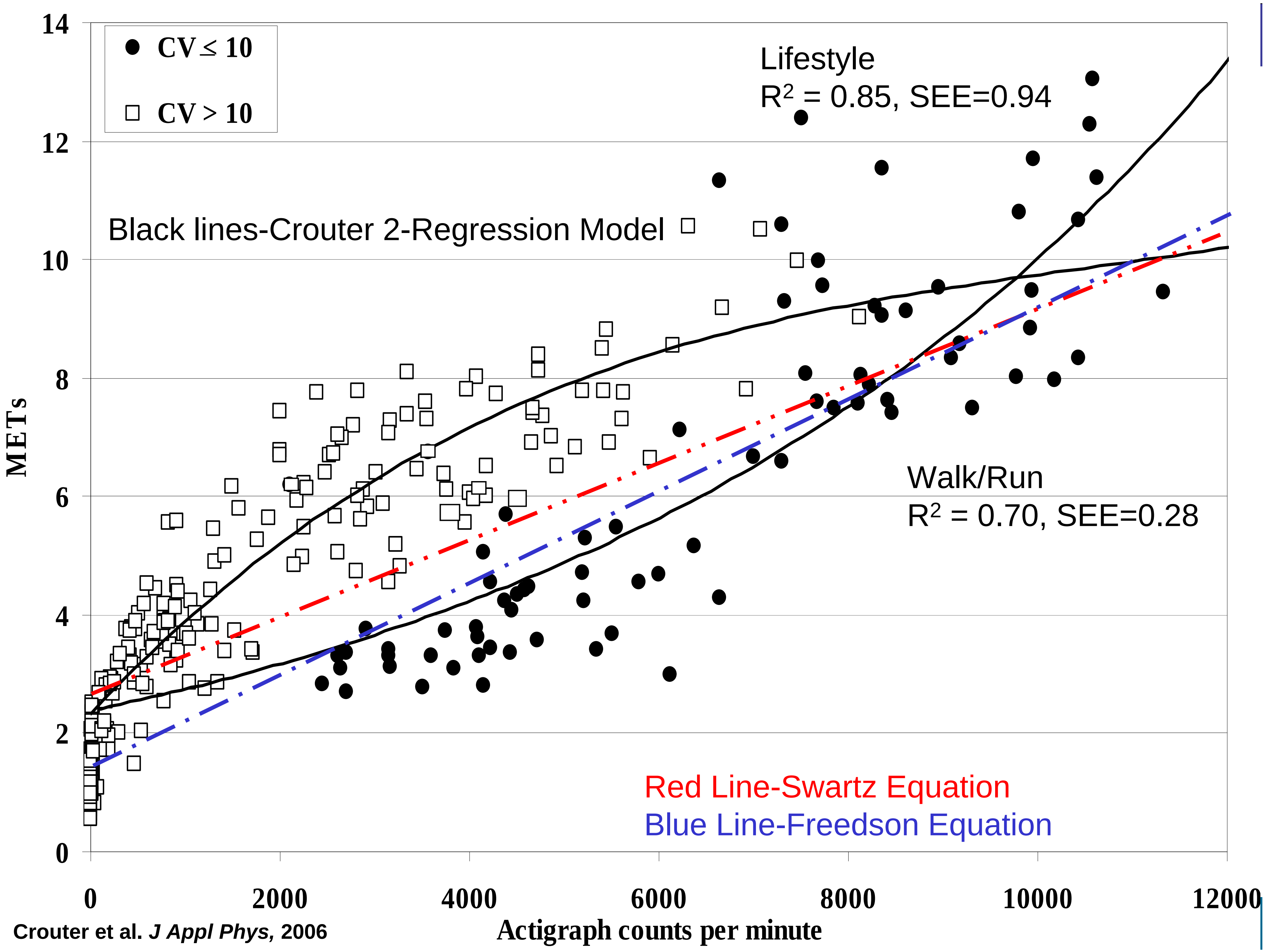
Activity counts·min^{-1} < 50 = 1.0 METs.
Activity counts·min^{-1} 50-350 = 1.83 METs.



Heil, Res Q Exerc Sport, 2006.

Calculation of CV [(SD/Average)*100)]

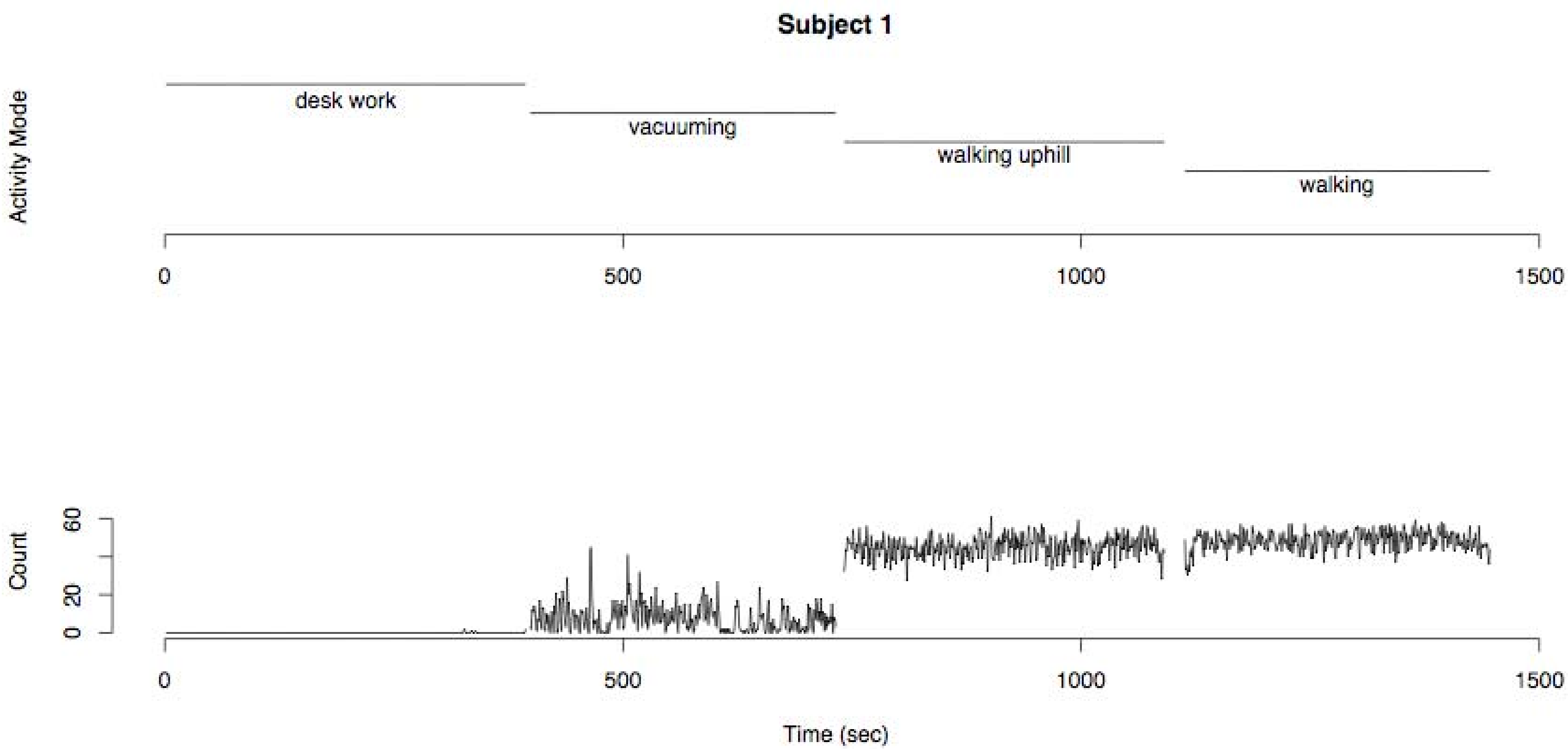
Time	Counts/10 sec	SD	Average	CV
13:02:10	918.0	15.319	917.333	1.670
13:02:20	907.0			
13:02:30	936.0			
13:02:40	923.0			
13:02:50	927.0			
13:03:00	893.0			
13:03:10	858.0	372.060	618.0	60.204
13:03:20	877.0			
13:03:30	421.0			
13:03:40	0.0			
13:03:50	556.0			
13:04:00	996.0			



Crouter et al. *J Appl Phys,* 2006

Hidden Markov Model

Model Training



Results: HMM

Truth

Estimate

	Walking	Walking Up Hill	Vacuuming	Computer Work
Walking	62.6%	37.3%	0.0%	0.0%
Walking Up Hill	36.9%	62.5%	0.0%	0.0%
Vacuuming	0.3%	0.2%	98.8%	2.7%
Computer Work	0.2%	0.0%	1.2%	97.3%

Pober, et al. MSSE, 2006.

Calibration Summary

- Linear Regression Equation
  - 1-min epochs
- 2-regression Model
  - 10-sec epochs
- HMM
  - 1-sec epochs

Defining Intensity of Activity Using Different Cut-points: Adults

TABLE 1. Cut points for 3, 6, and 9 METs determined from three prediction models using counts·min^{-1} from the CSA 7164 accelerometer worn on the hip.

Gross MET Value	Freedson et al. (1998)	Hendelman et al. (2000)	Swartz et al. (2000)
<3	0–1951	0–190.6	0–573
3–6	1952–5724	190.7–7525.7	574–4944
7–8	5725–9497	7525.8–14860.5	4945–9318
≥9	≥9498	≥14860.6	≥9317

Ainsworth, et al, 2000

Use of Different Regression Models to Establish Time in Moderate and Vigorous Activity: Adults

TABLE 1. Estimates of daily participation in moderate and vigorous physical activity by measurement method, overall, and stratified by BMI.

	CSA Cut Points							
	Freedson et al. ($min \cdot d^{-1}$)		Hendelman et al. ($min \cdot d^{-1}$)		Swartz et al. ($min \cdot d^{-1}$)		Physical Activity Log	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total sample (*N* = 58)								
Total activity[a] (≥ 3 METs)	38.1	26.8	312.6	101.1	162.7	69.2	75.1	51.7
Moderate (3–5.99 METs)	33.6	20.1	311.2	102.1	157.1	66.9	65.6	48.4
Vigorous (≥ 6 METs)	4.5	16.8	1.4	4.1	5.6	17.7	9.5	18.0
BMI < 25 $kg \cdot m^{-2}$ (*N* = 41)								
Total activity (≥ 3 METs)	40.7	30.6	313.2	104.7	162.8	73.3	75.5	43.9
Moderate (3–5.99 METs)	35.3	22.6	311.7	106.0	156.1	69.9	65.0	41.2
Vigorous (≥ 6 METs)	5.4	19.8	1.4	4.6	6.8	20.8	10.5	20.5
BMI ≥ 25 $kg \cdot m^{-2}$ (*N* = 16)								
Total activity (≥ 3 METs)	31.9	13.5	313.0	97.4	162.8	62.2	73.9	71.0
Moderate (3–5.99 METs)	29.7	11.8	311.6	98.0	159.7	63.0	66.2	66.0
Vigorous (≥ 6 METs)	2.2	3.7	1.3	2.7	3.1	4.8	7.8	10.3

[a] Total activity = moderate activity + vigorous activity.

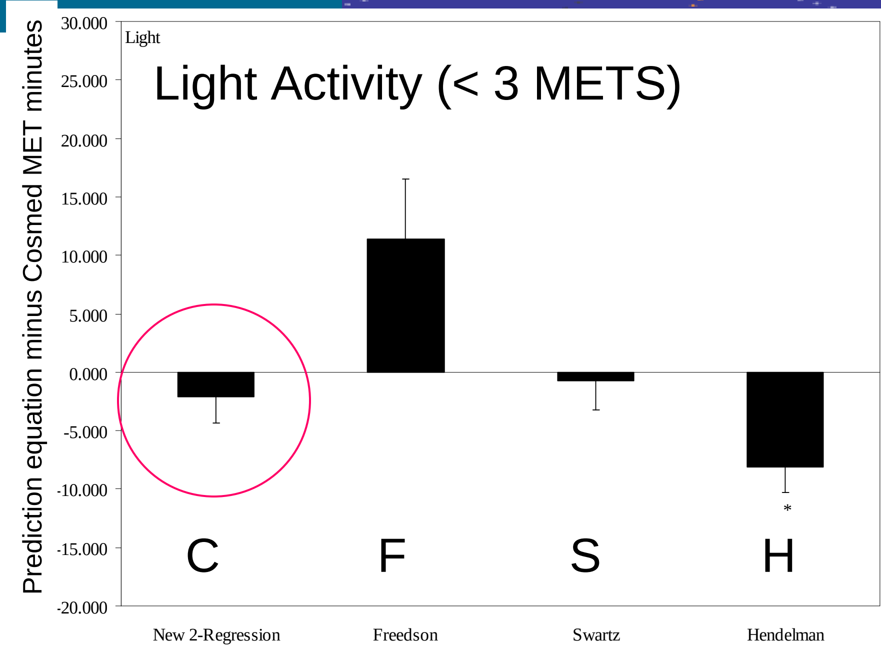
Schmidt, Freedson and Chasan-Taber, 2003

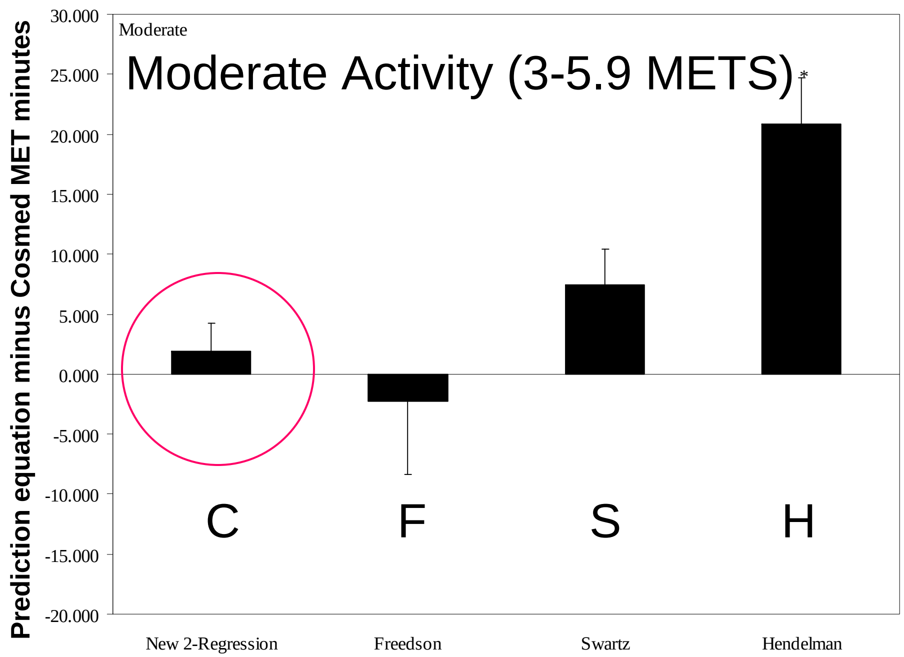
C = 2-regression model

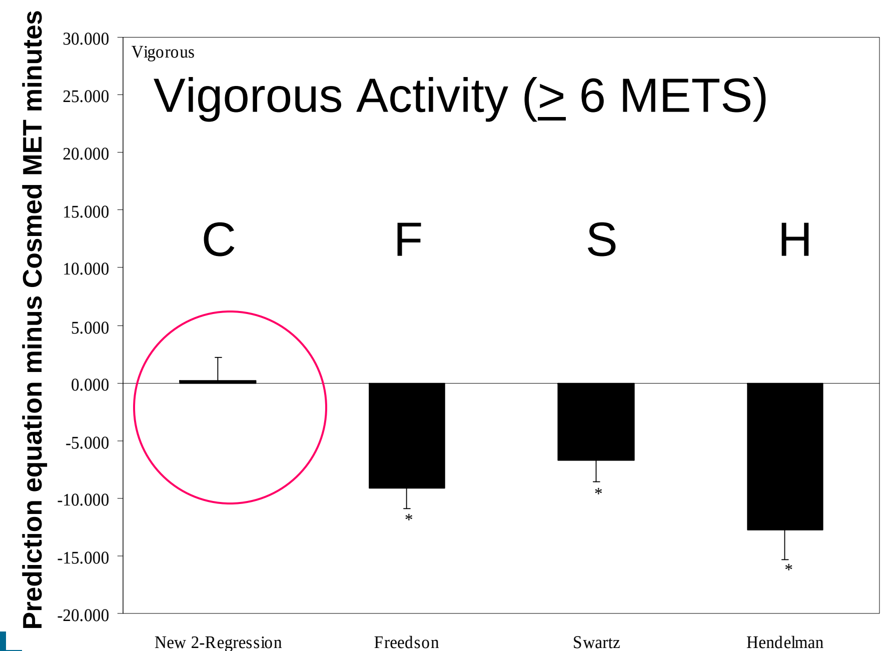
F = Freedson equation

S = Swartz equation

H = Hendelman equation







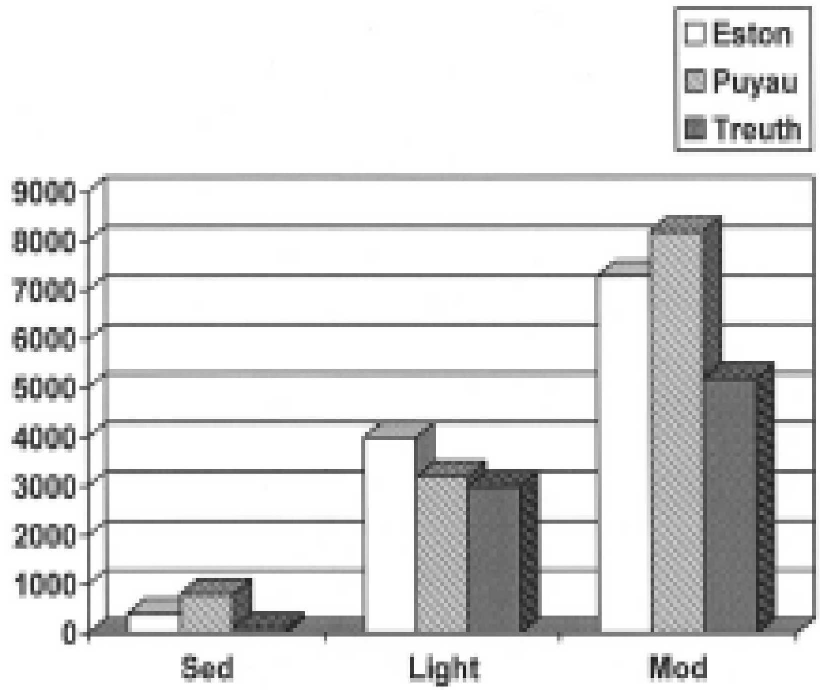
Accelerometer Outcomes for Children

ActiGraph						
	N	Age	Equation	Activities	R^2	SEE
MET Predictions						
Freedson, et a. (1997)	80	6-18	2.757+(0.0015*cnts/min)-(0.08957*age)-(0.000038*cnts/min*age)	Walk(2), run(1)	0.74	1.10
Treuth, et al. (2004)	74	13-14	2.01+(0.00171*cnts/30sec)	Walk(2), run(1), 8 lifestyle activities	0.84	1.36
$KJ \cdot min^{-1}$ Predictions						
Schmitz et al. (2005)	74	13-14	7.6628+(0.1462*((cnts/min-3000)/100)+(0.2371*BM)-(0.00216*((cnts/min-3000)/100)^2+(0.004077*(((cnts/min-3000)/100)*BM)	Walk(2), run(1), lifestyle(7)	0.85	5.61
AEE: $Kcals \cdot kg^{-1} min^{-1}$ Predictions						
Puyau, et al. (2002)	26	6-16	0.0183+(0.000010*cnts/min)	Walk(4), run(1), lifestyle (9)	0.75	0.0172
$Kcals \cdot min^{-1}$ Predictions						
Trost et al. (1998)	20	10-14	-2.23+(0.0008*cnts/min)+(0.08*BM)	Walk(2), run(1)	0.83	0.97
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$) Predictions						
Pate et al. (2006)	29	3-5	10.0714+(0.02366*cnts/15sec)	Walk(2)/jog (1)	0.904	4.70

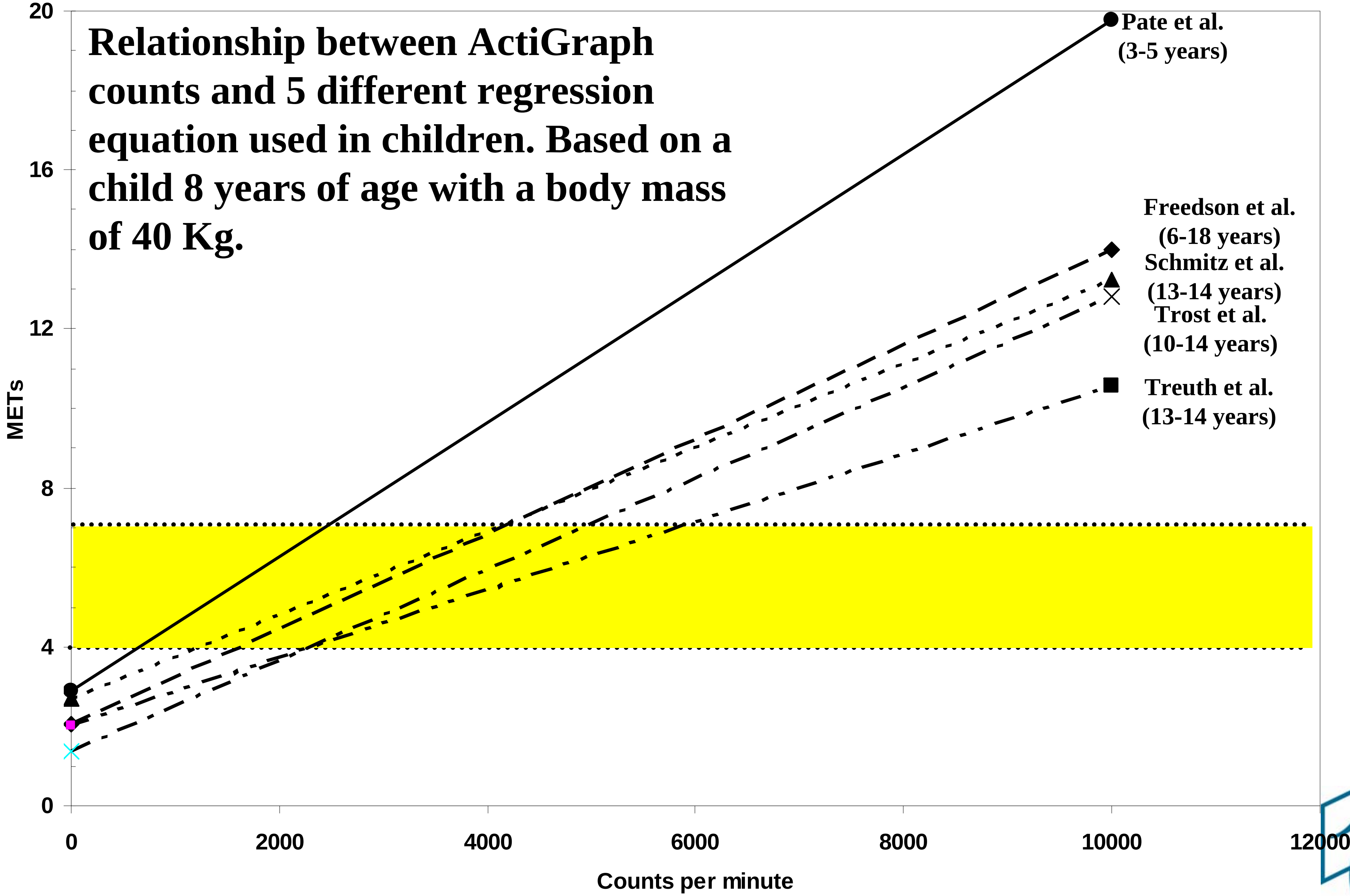
N, sample size; Age, range of ages used for study; SEE, standard error of estimate; BM, body mass (kg); cnts, counts; "Activity" column represents the types of activities used to develop the regression equation with the number of walking or running speeds in parenthesis.

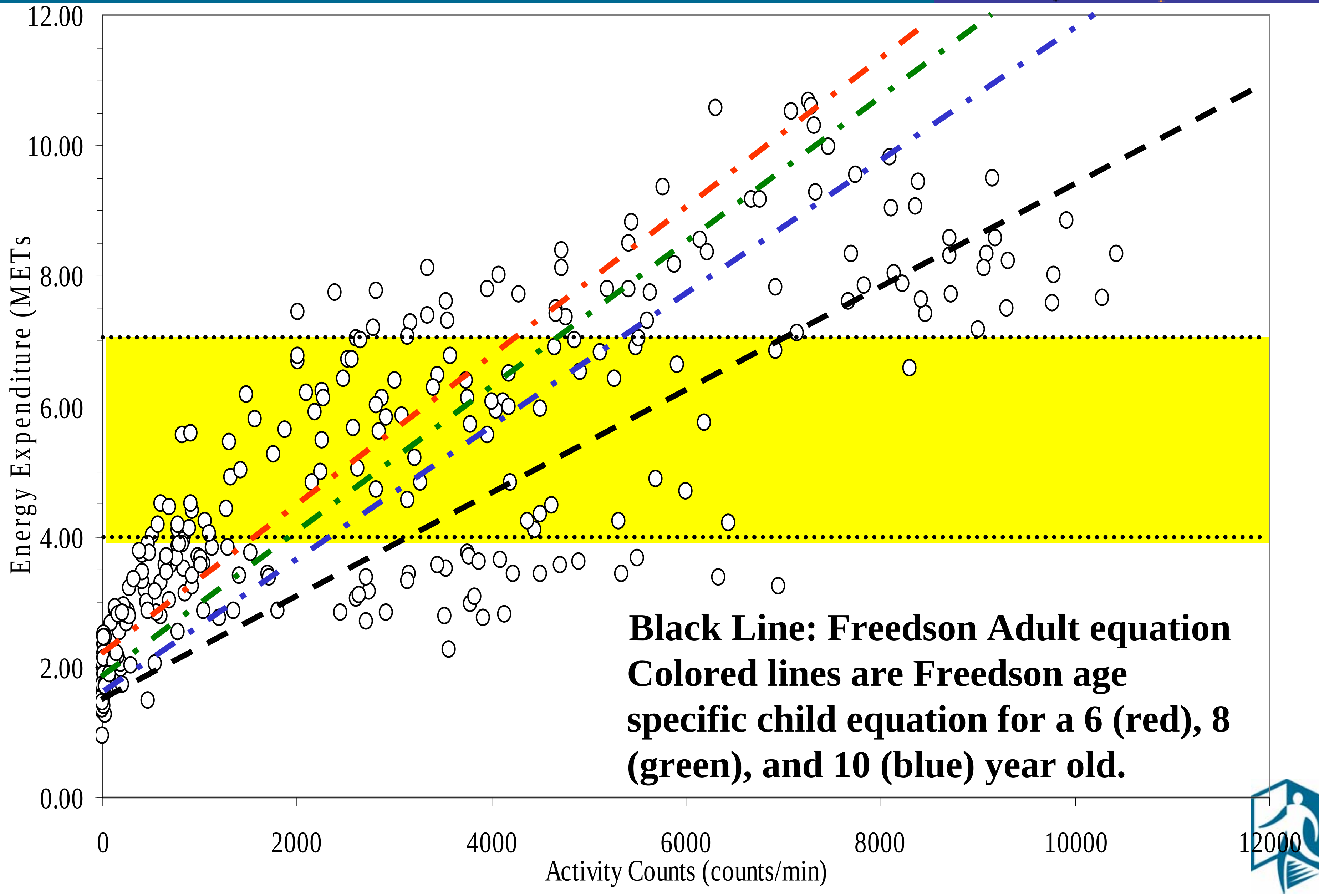
Use of Different Regression Models to Establish Cut-points: Children

- •Large differences between studies
- •Upper boundary for moderate activity ranges from ~5000 - 8000 cts/min
- •Different age groups used to establish cut-points
- •All included lifestyle activities



Freedson, Pober & Janz, 2005


Relationship between ActiGraph counts and 5 different regression equation used in children. Based on a child 8 years of age with a body mass of 40 Kg.
Pate et al. (3-5 years)
Freedson et al. (6-18 years)
Schmitz et al. (13-14 years)
Trost et al. (10-14 years)
Treuth et al. (13-14 years)
METs
Counts per minute
0
4
8
12
16
20
0
2000
4000
6000
8000
10000
12000



12.00
10.00
8.00
6.00
4.00
2.00
0.00
Energy Expenditure (METs)
0
2000
4000
6000
8000
10000
12000
Activity Counts (counts/min)
Black Line: Freedson Adult equation
Colored lines are Freedson age specific child equation for a 6 (red), 8 (green), and 10 (blue) year old.

Accelerometer Outcome Summary for Adults and Children

- Large differences between regression equations for EE and time spent in activity categories
- In adults, the 2-regression model appears to improve the estimate of EE and time spent in different activity categories.
- HMM and neural networking
  - Show promise, however more developmental work is needed
- Caution with youth and adolescents
  - Chose equation to match demographics of your population

QUESTIONS?

Accelerometer processing software

- See handout

MeterPlus Demonstration

- See handout

Questions

Further questions & discussion at breakfast roundtable on Friday 7.30-8.30am