MRC | Epidemiology Unit

investigating the causes and prevention of diabetes and obesity

Methods for the evaluation of physical activity in epidemiologic studies

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Descriptive

- assessing prevalence differences between populations
- monitoring temporal trends within populations

Aetiological

- quantifying the effect size of an association
- specifying which dimension of physical activity is of most importance for a particular health outcome

Predictive

- stratifying populations to target interventions on inactive individuals who are “at risk”

Evaluative

- detecting physical activity response to an intervention

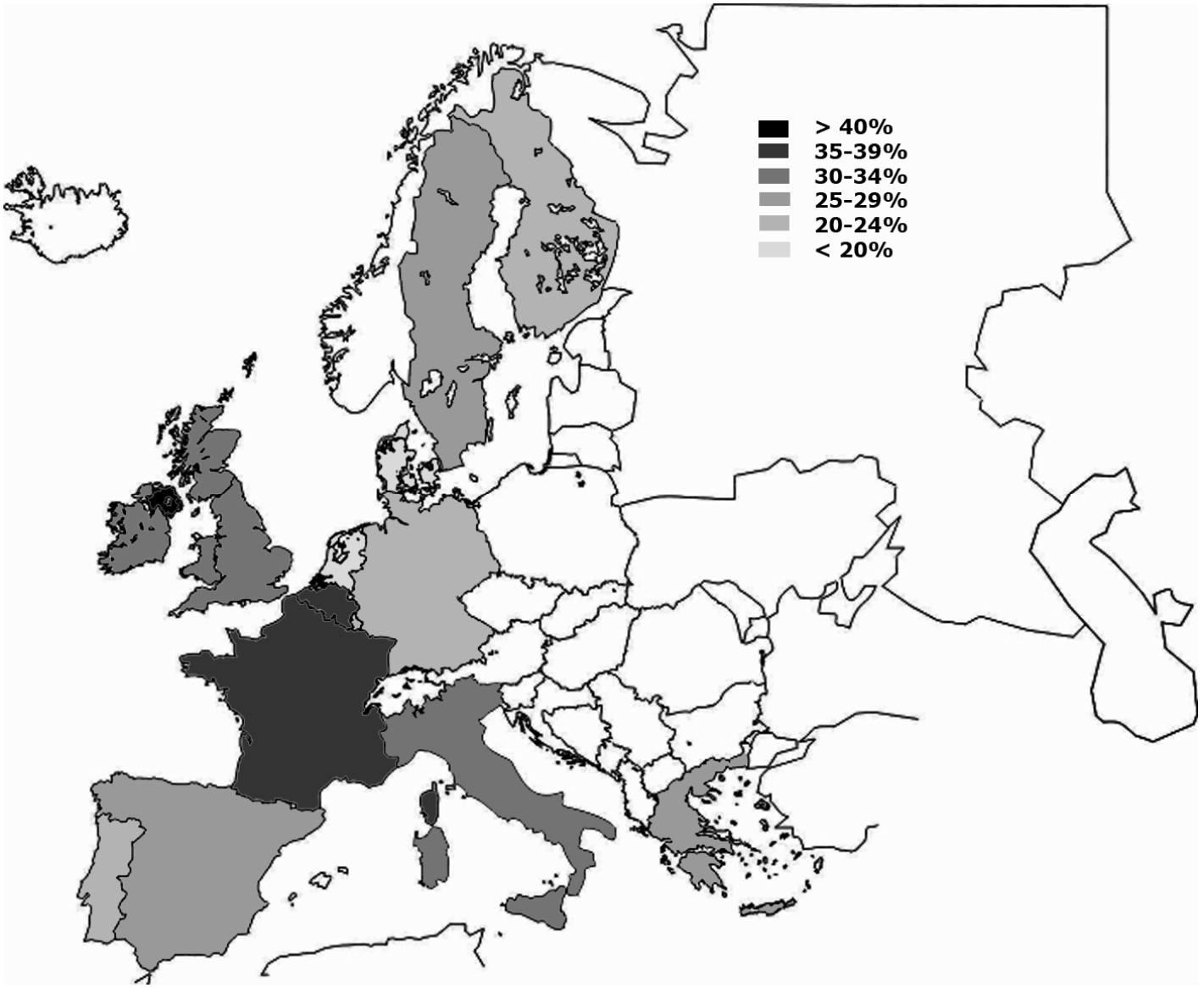
Vigorous physical activities refer to activities that take hard physical; effort and make you breathe much harder than normal
Moderate activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal

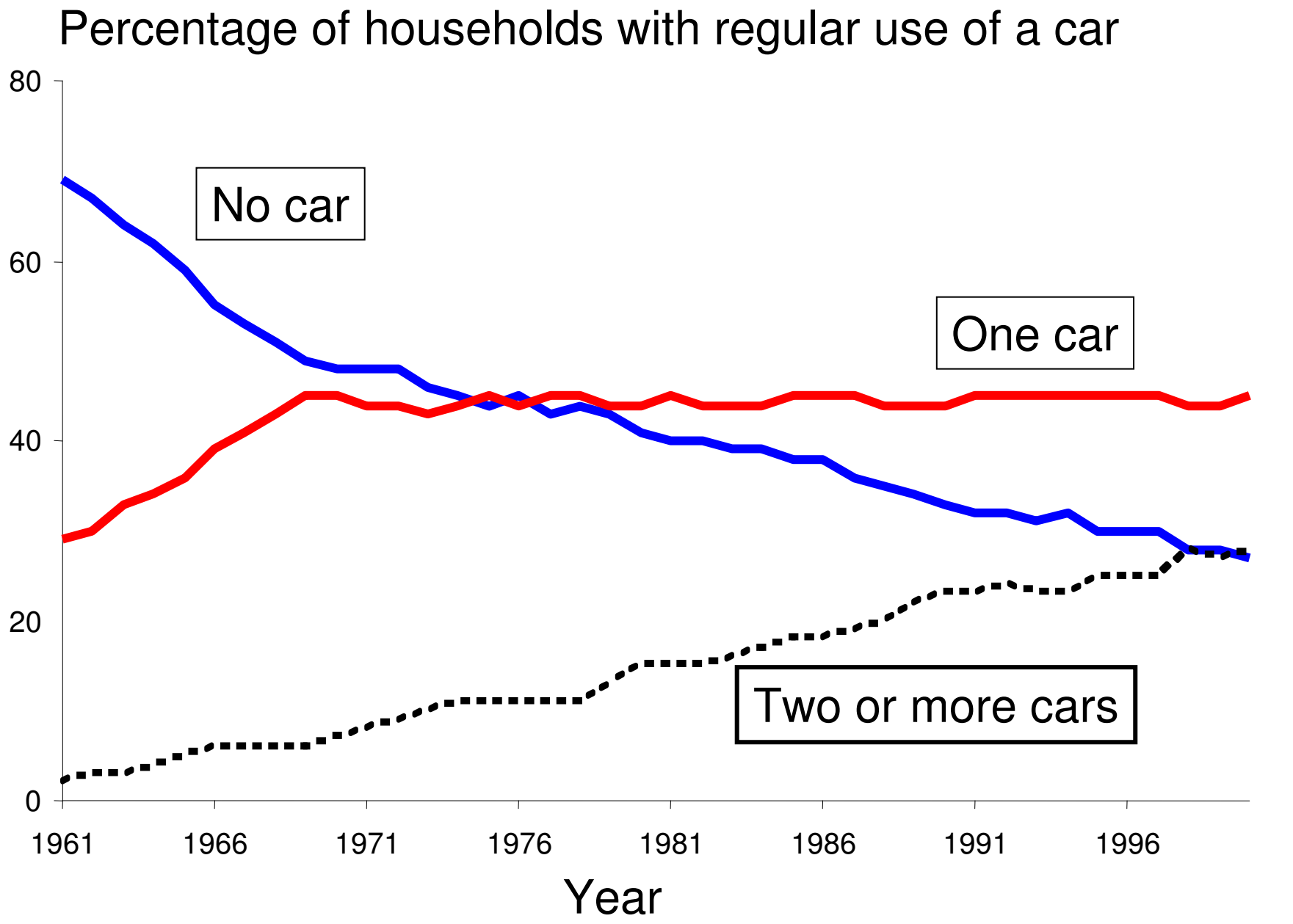
In answering the questions, think about only those activities that you did for at least 10 minutes at a time.

1a) During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting digging, aerobics, or fast bicycling? ___ days (*if none, proceed to Q2*)

1b) How much time in total did you usually spend on one of those days doing vigorous physical activities? ___hrs___mins

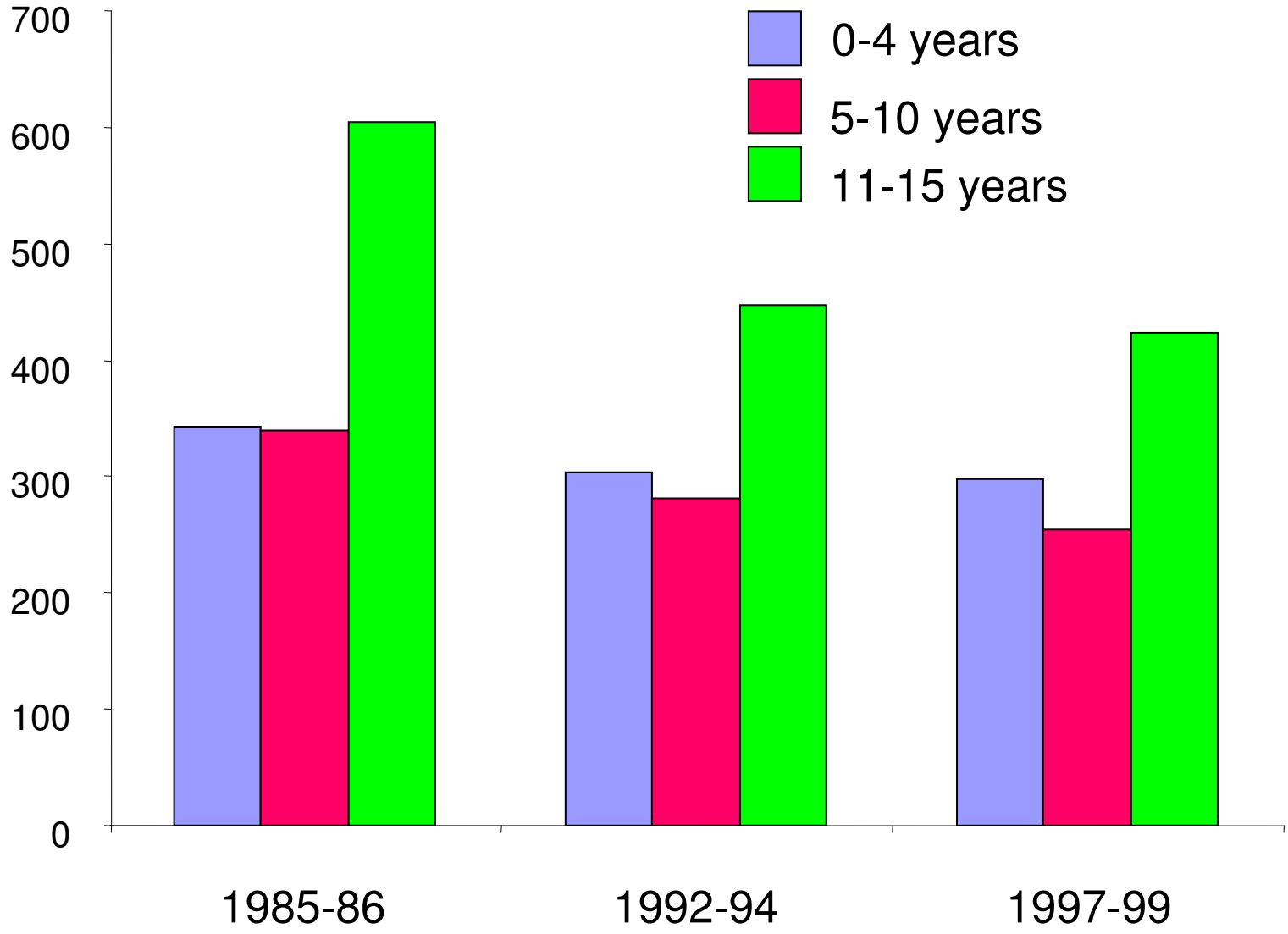
Prevalence of low activity – Eurobarometer data



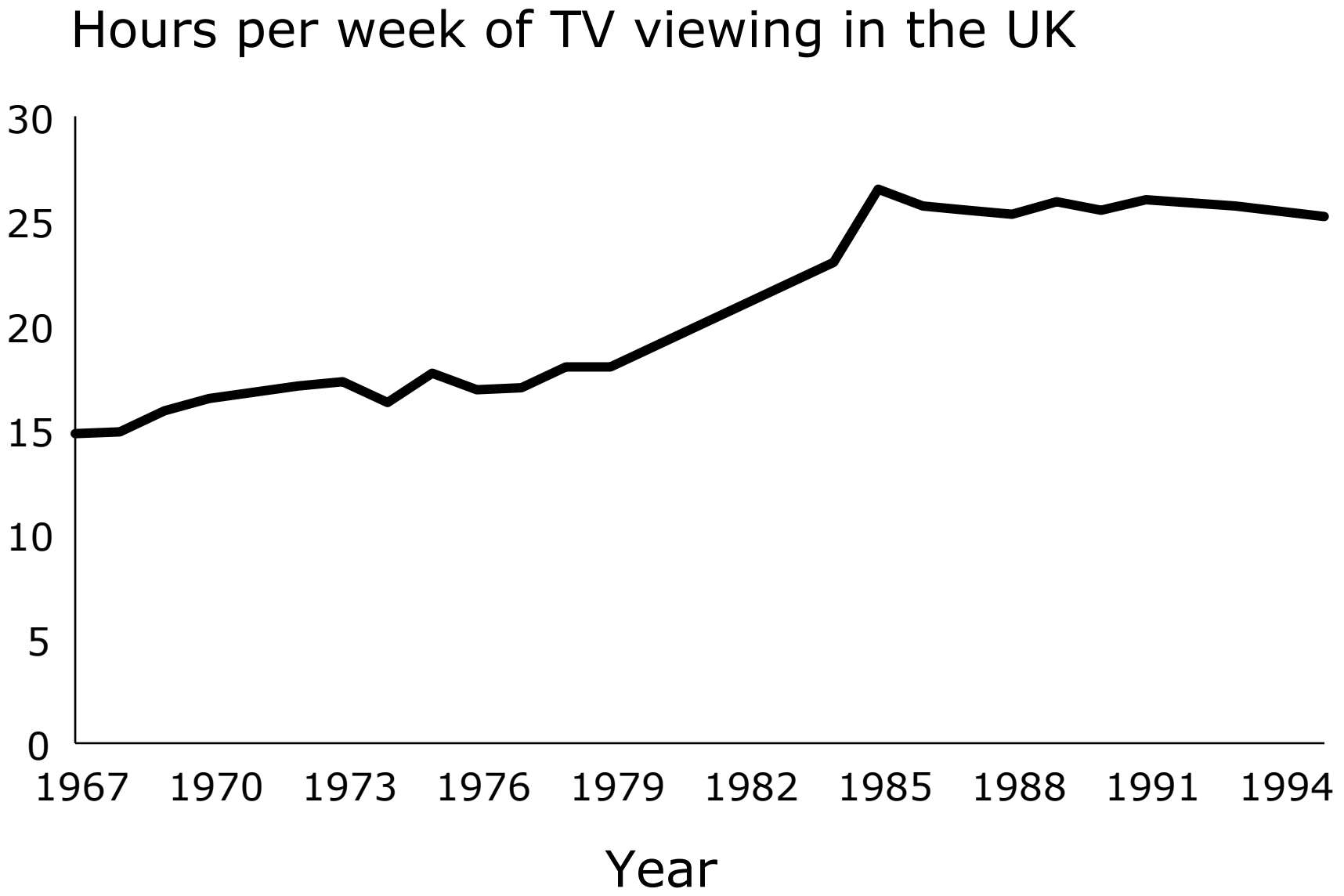


Source: National Travel Survey, Department for Transport

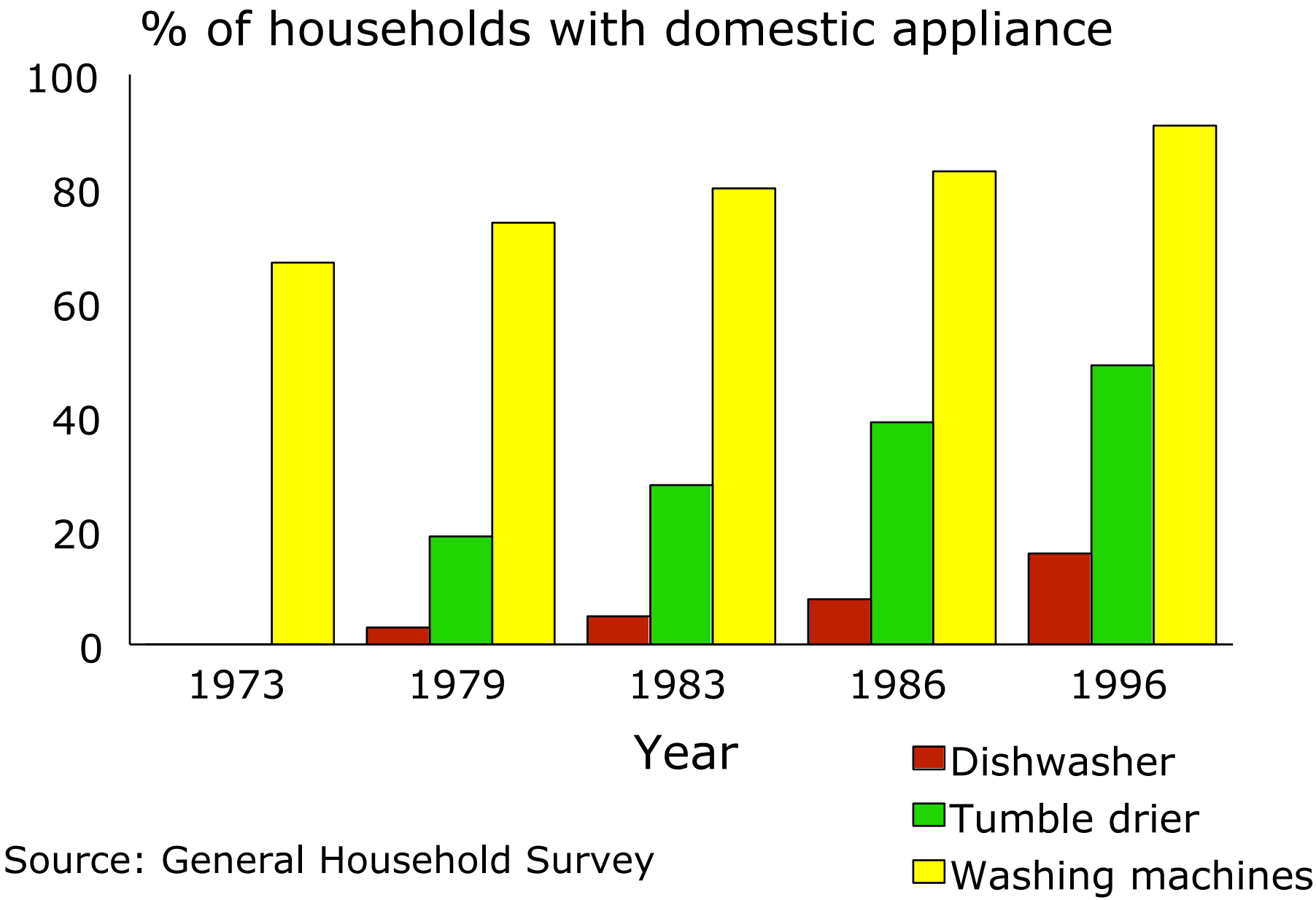
Average distance walked by child by age (km)



Source: National Travel Survey, DETR

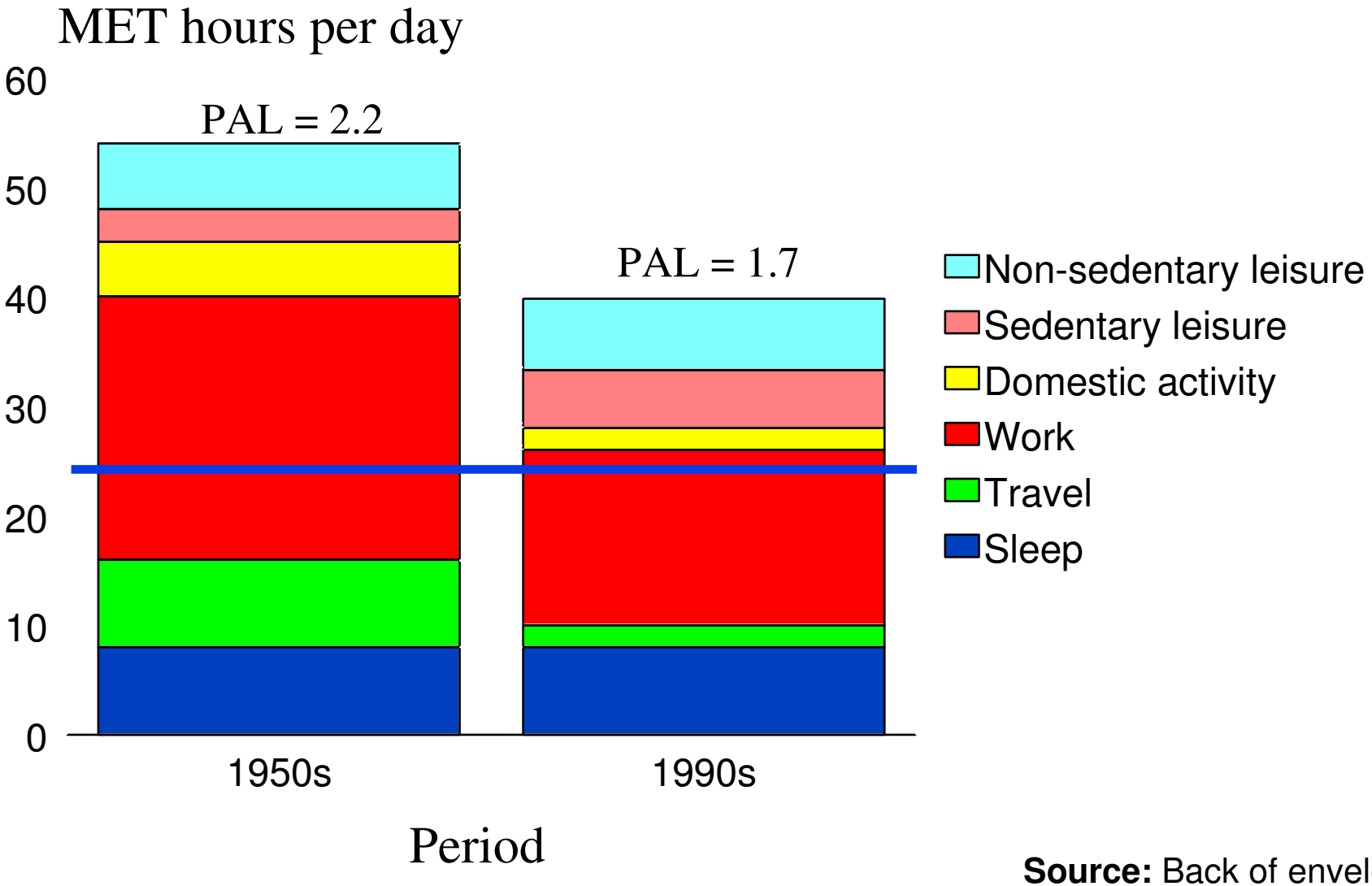


Source: Social Trends Series



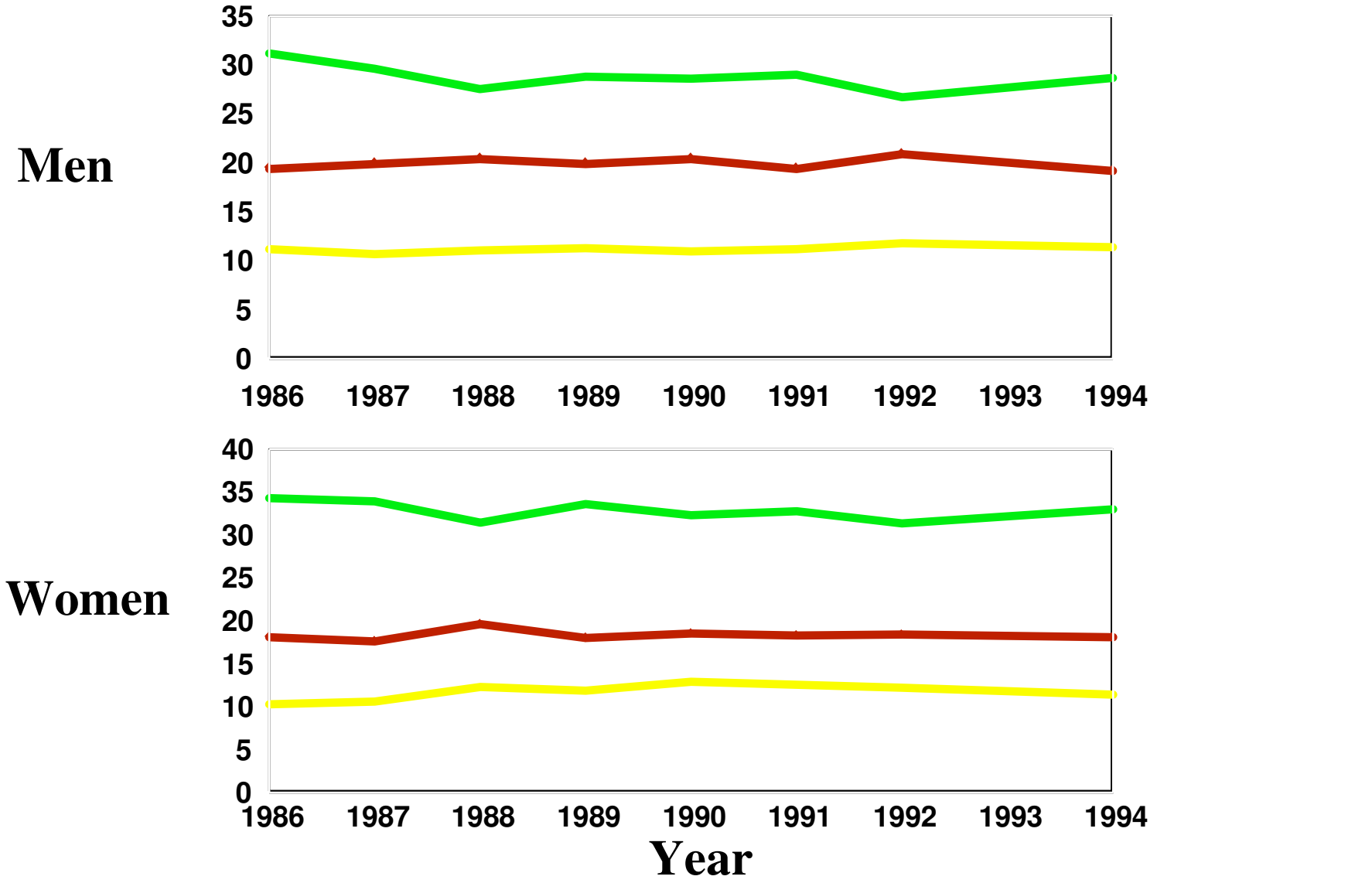
Source: General Household Survey

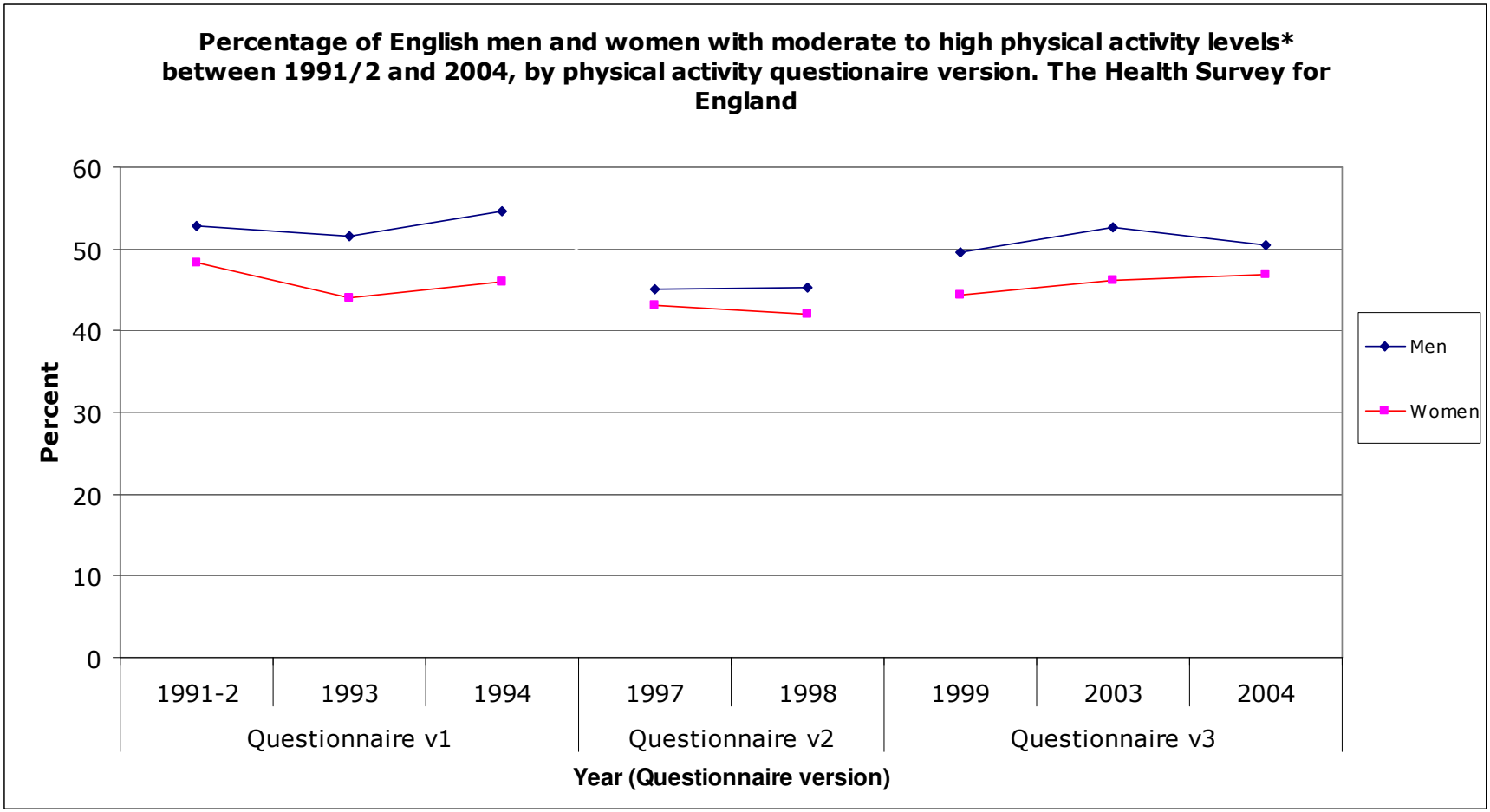
Overall effect of changing distribution of activities and energy cost



Source: Back of envelope

Percentage of people by activity level in US Behavioural Risk Factor Surveillance System





Source: Stamatakis et al, Preventive Medicine 2007

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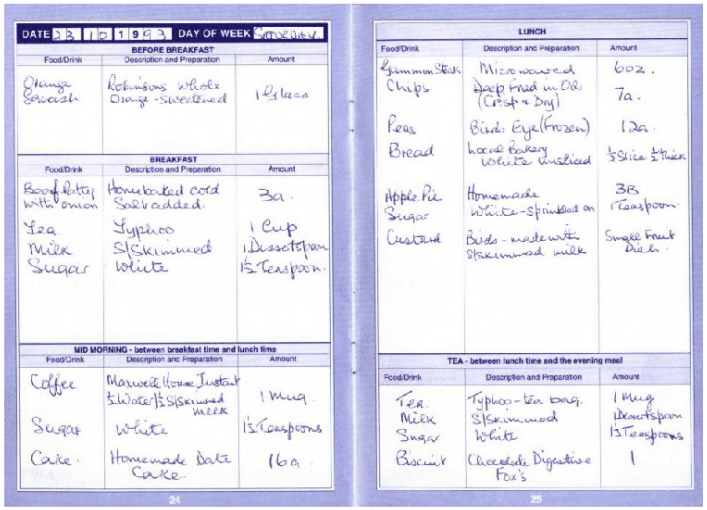
- Strong evidence from epidemiological studies √
- Consistent, biologically plausible, supported by evidence from intervention studies √
- Dose-response ?
- Type of activity ?
- Effect modification ?

- Diaries / logs
- High researcher burden
- Dependent upon accuracy of compendia of energy costs of activities
- Only focus on this dimension of activity
- High participant burden



DAY_____DATE_____

Minute / Hour	0-15	16-30	31-45	46-60
8 am				
9 am				
10 am				
11 am				
12 pm				
1 pm				
2 pm				
3 pm				
4 pm				
5 pm				
6 pm				
7 pm				
8 pm				
9 pm				
10 pm				
11 pm				
12 am				
1 am				
2 am				
3 am				
4 am				
5 am				
6 am				
7 am				

Was this a typical day in terms of activity (more intense, less intense)?_____

What sport activities (if any) did you participate in?_____

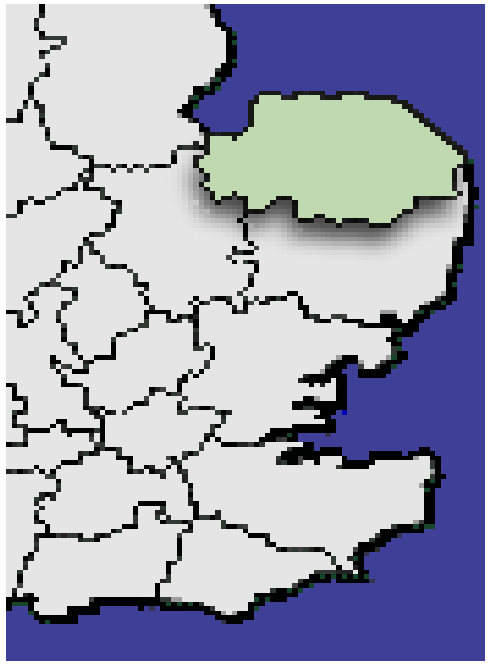
PAQs used in the general population

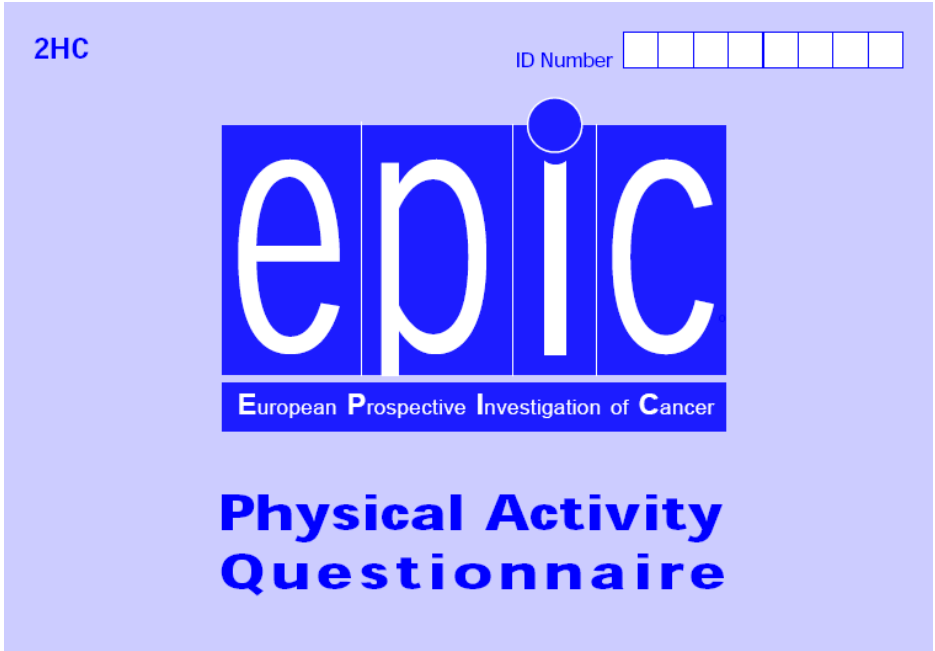
Aerobic Center Longitudinal Study PAQ
Baecke
Bouchard 3-day physical activity record
CARDIA physical activity history
Framingham Physical activity index
Godin Leisure-time exercise questionnaire
HIP activity questionnaire
Historical leisure activity questionnaire
Kuopio Ischemic Heart Disease Study Q's
Lipid research clinics questionnaire
Minnesota Leisure-time PAQ
Modifiable Activity Questionnaire
Paffenbarger Physical Activity Questionnaire
Seven-Day Physical Activity Recall
Stanford Usual Activity Questionnaire
Tecumseh Occupational PAQ

Source: Med Sci Sports Exercise 1997;29 (supplement)

EPAQ2 – an exemplar

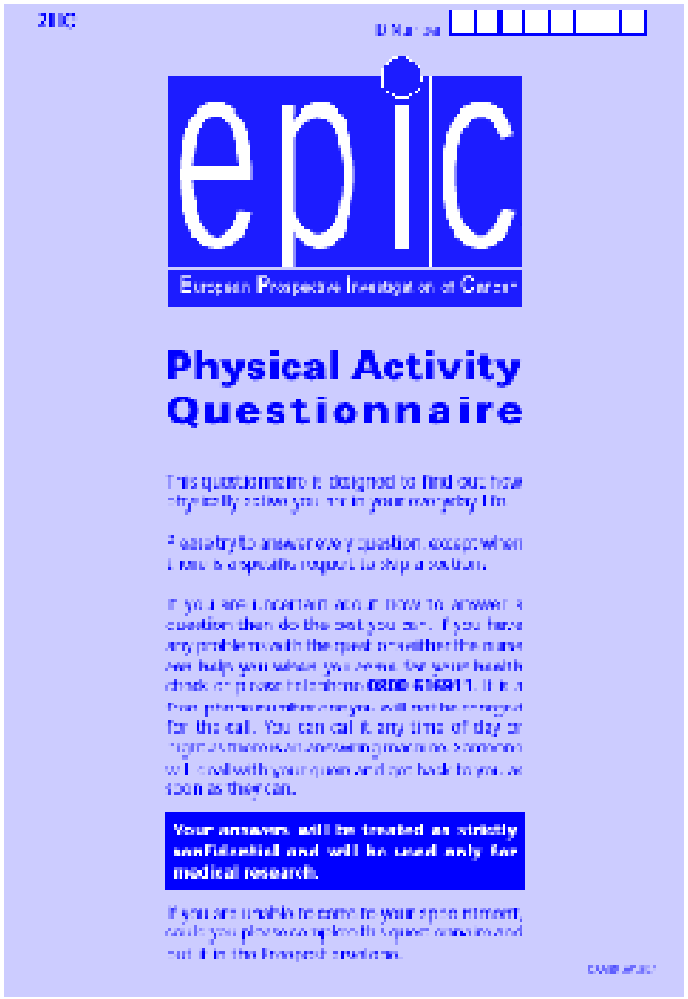
Information collected in disaggregated form related to different domains of life





Domestic
Occupational
Travel
Recreational

Source: Wareham et al. Int J Epid 2002



epic

European Prospective Investigation into Cancer

Physical Activity Questionnaire

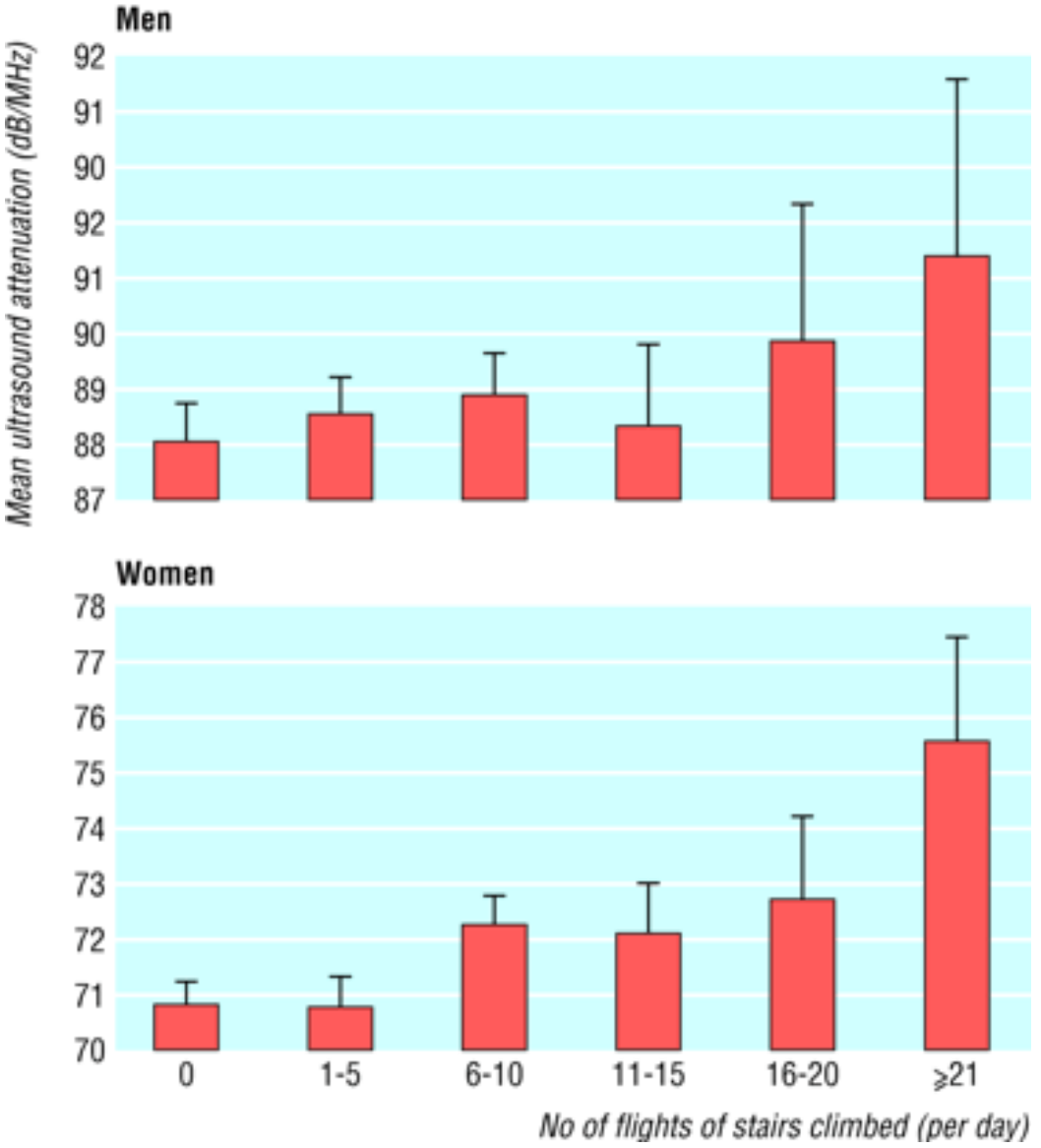
This questionnaire is designed to find out how physically active you are in your everyday life.

Please try to answer every question, except when it says a specific request to skip a section.

If you are uncertain about how to answer a question then do the best you can. If you have any problems with the questionnaire then please ask for help. We will help you when you arrive for your health check or please telephone [illegible]. If we [illegible] for this call. You can call it any time of day or night [illegible] will deal with your query and get back to you as soon as they can.

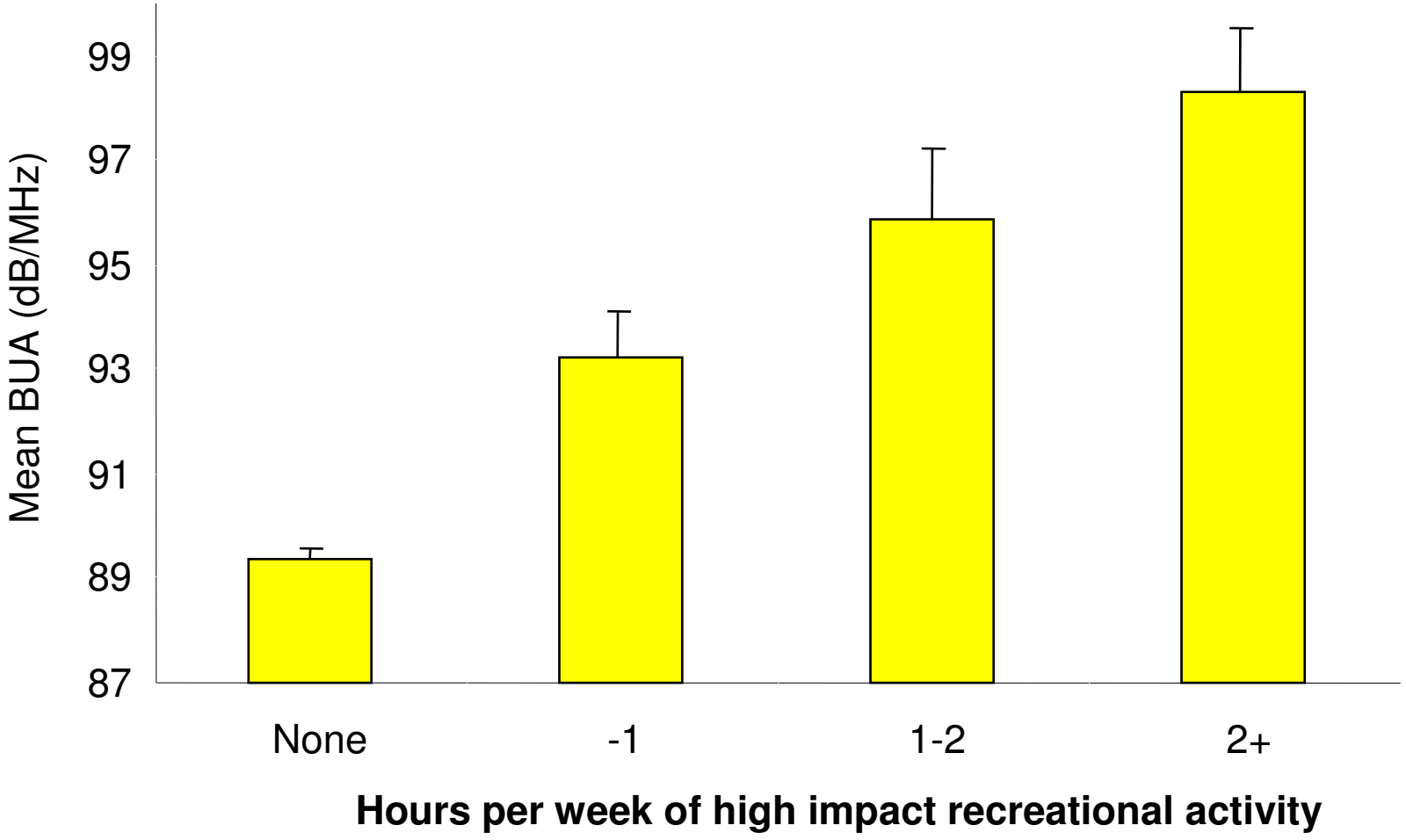
Your answers will be treated as strictly confidential and will be used only for medical research.

If you are unable to come to your appointment, could you please complete this questionnaire and return it in the [illegible]



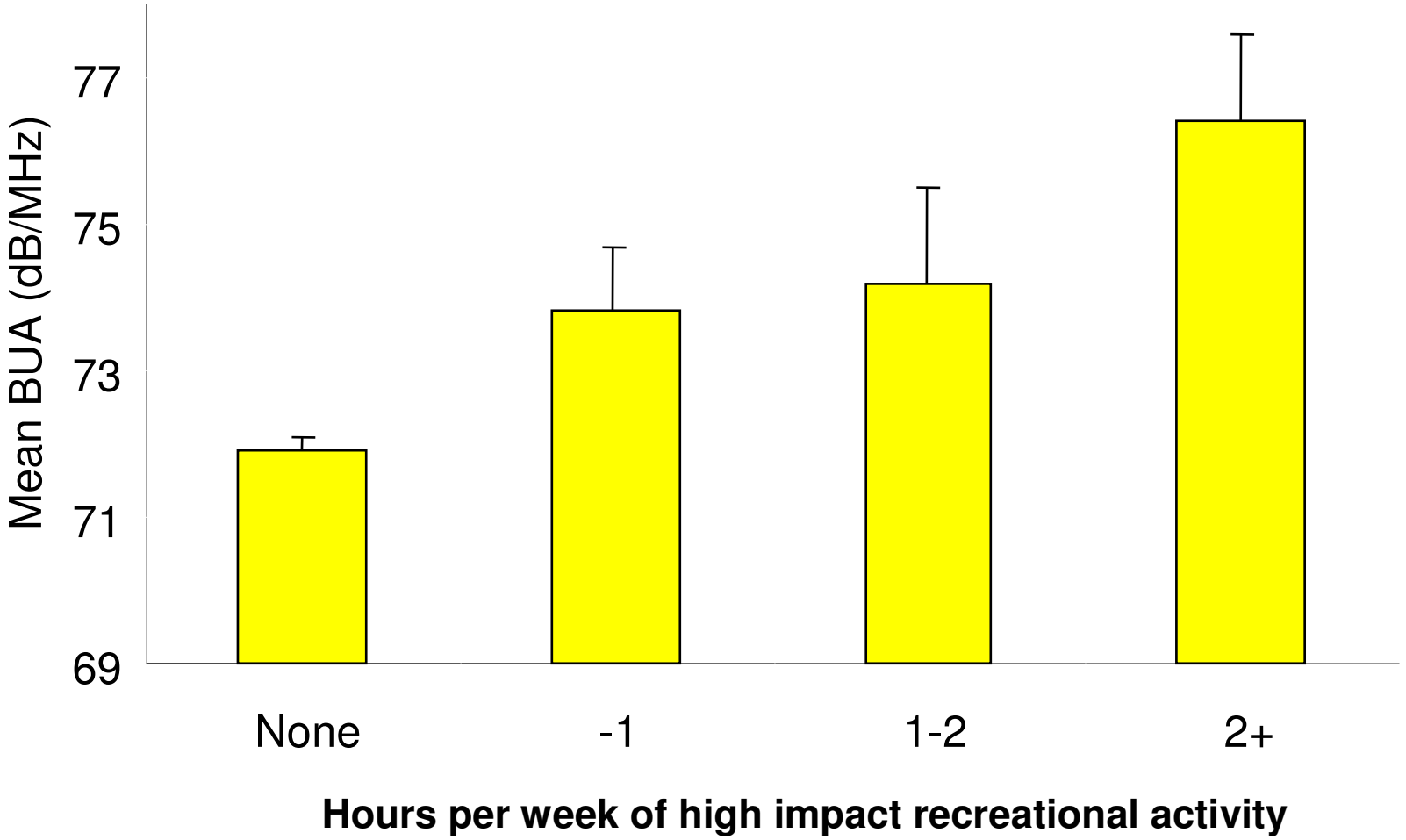
Source: Jakes et al, BMJ 2001

Men



Source: Jakes et al, BMJ 2001

Women



Source: Jakes et al, BMJ 2001

From reported activity to total energy expenditure

Please give an answer for the AVERAGE TIME you spent on each activity and the NUMBER OF TIMES you did that activity in the past year

	Average Time per episode		Number of times you did the activity in the past year							
	Hours	Mins	None	Less than once a month	Once a month	2 to 3 times a month	Once a week	2 to 3 times a week	4 to 5 times a week	Every day
Swimming — competitive or laps										
Swimming — leisurely not laps										
Backpacking or mountain climbing										
Walking for pleasure — you should not include walking as a means of transportation as this was included in Sections A & B										
Racing or rough terrain cycling										
Cycling for pleasure — you should not include cycling as a means of transportation										

Computation

Frequency
Duration
Intensity – energy cost

Different precision of recall by activity

Each visit.....
Height / Weight / BMI
Fat % by impedance
PAL by 4 days of HRM
VO_{2max} per kg

Month 12....
Questionnaires

Reliability

	Men (n=187)	**Women** (n=212)
TV time (hr/wk)	0.75	0.78
Activity at home (MET.hr/wk)	0.77	0.74
Activity at work (MET.hr/wk)	0.57	0.37
Recreational activity (MET.hr/wk)	0.69	0.64
Vigorous activity (hr/wk)	0.75	0.41
Self-reported physical activity index (MET hr/wk)	0.74	0.72

Source: Wareham et al. Int J Epid 2002

Validity

	Mean Daytime Energy Expenditure (kJ/hr)	**Mean VO_{2max}** (ml/min/kg)	**Physical Activity Ratio ≥5** (%)
TV viewing (hr/wk)	-0.07	-0.19‡	0.02
Activity at home (MET.hr/wk)	-0.04	-0.09	-0.12
Activity at work (MET.hr/wk)	0.17‡	0.01	-0.07
Recreational activity (MET.hr/wk)	0.13	0.16‡	0.20†
Vigorous activity (hr/wk)	0.01	0.16‡	0.17‡
Self-reported physical activity index (MET.hr/wk)	0.28§	0.15‡	0.05

Source: Wareham et al. Int J Epid 2002

Reliability and Validity of the Past Year Total Physical Activity Questionnaire

Christine M. Friedenreich[1], Kerry S. Courneya[2], Heather K. Neilson[1], Charles E. Matthews[3], Gordon Willis[4], Melinda Irwin[5], Richard Troiano[4], and Rachel Ballard-Barbash[4]

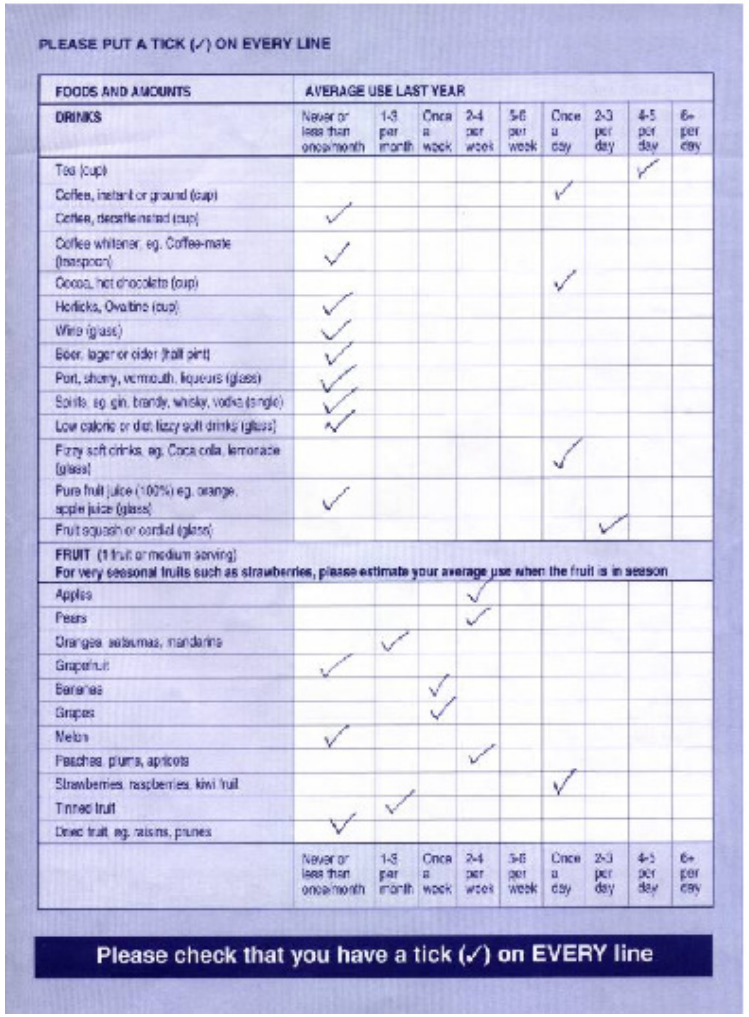
Total physical activity

Reliability	0.64
Validity	
vs Physical activity log	0.41
vs Accelerometer	0.26

Source: Friedenreich et al, Am J Epid 2005

From reported activity to total energy expenditure: a step too far ?

- Duration x frequency x intensity
- Not the same degree of precision for all activities
- Maybe use different approaches for different aspects of activity
- Careful qualification of what has been measured and what has been estimated
- Limit to description of self-reported participation in activity rather than attempt overall summary estimation of total energy expenditure
- Appearance of spurious precision by attribution of units of energy expenditure



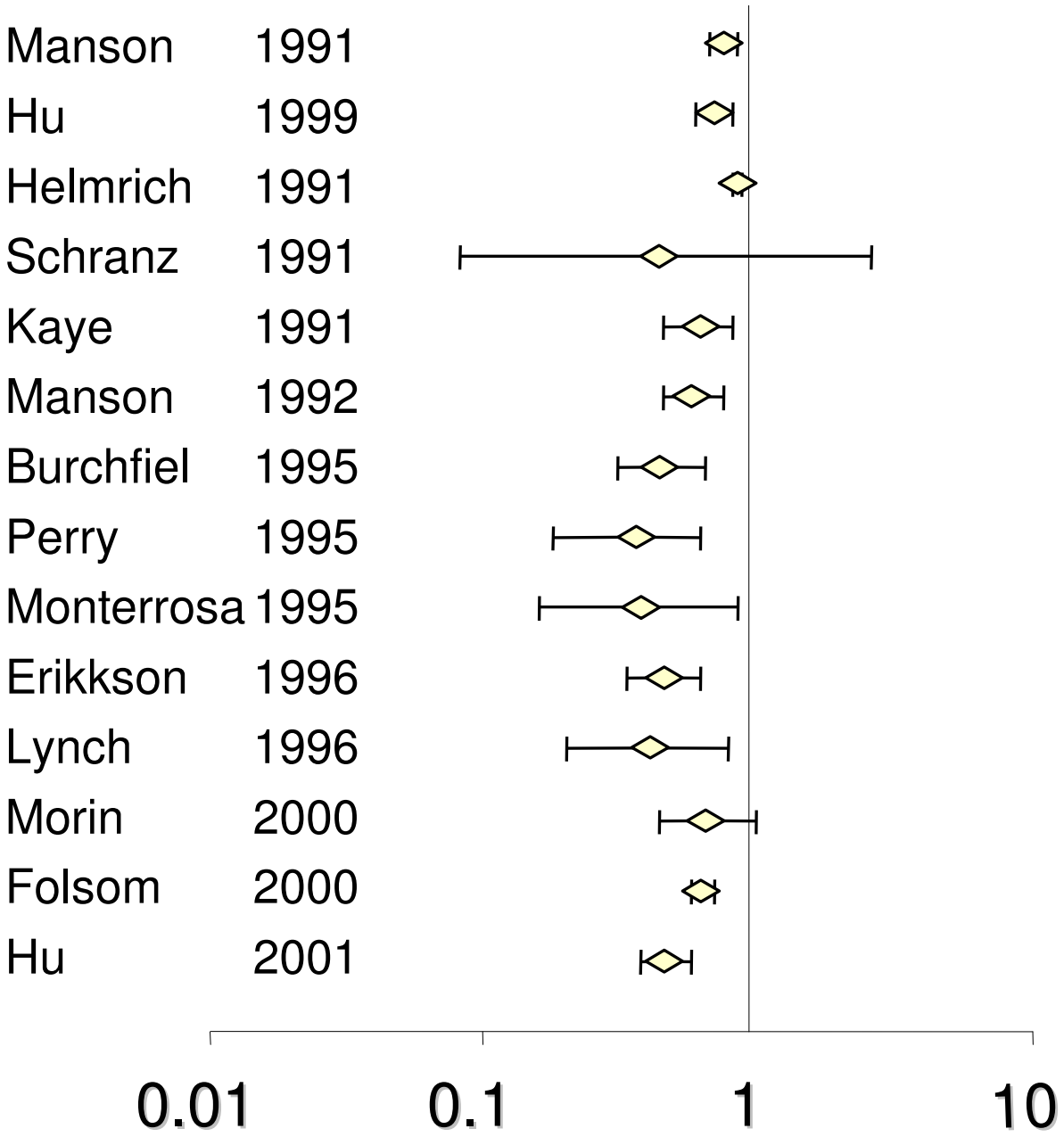
PLEASE PUT A TICK (✓) ON EVERY LINE

FOODS AND AMOUNTS	AVERAGE USE LAST YEAR								
DRINKS	Never or less than once/month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
Tea (cup)								✓	
Coffee, instant or ground (cup)						✓			
Coffee, decaffeinated (cup)	✓								
Coffee whitener, eg. Coffee-mate (teaspoon)	✓								
Cocoa, hot chocolate (cup)						✓			
Horlicks, Ovaltine (cup)	✓								
Wine (glass)	✓								
Beer, lager or cider (half pint)	✓								
Port, sherry, vermouth, liqueurs (glass)	✓								
Spirits, eg. gin, brandy, whisky, vodka (single)	✓								
Low calorie or diet fizzy soft drinks (glass)	✓								
Fizzy soft drinks, eg. Coca-cola, lemonade (glass)						✓			
Pure fruit juice (100%) eg. orange, apple juice (glass)	✓								
Fruit squash or cordial (glass)							✓		
FRUIT (1 fruit or medium serving) For very seasonal fruits such as strawberries, please estimate your average use when the fruit is in season									
Apples				✓					
Pears				✓					
Oranges, satsumas, mandarins		✓							
Grapefruit	✓								
Bananas			✓						
Grapes			✓						
Melon	✓								
Peaches, plums, apricots				✓					
Strawberries, raspberries, kiwi fruit						✓			
Tinned fruit		✓							
Dried fruit, eg. raisins, prunes	✓								
	Never or less than once/month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day

Please check that you have a tick (✓) on EVERY line

Dose-response
Type of activity

How much is enough for prevention ?

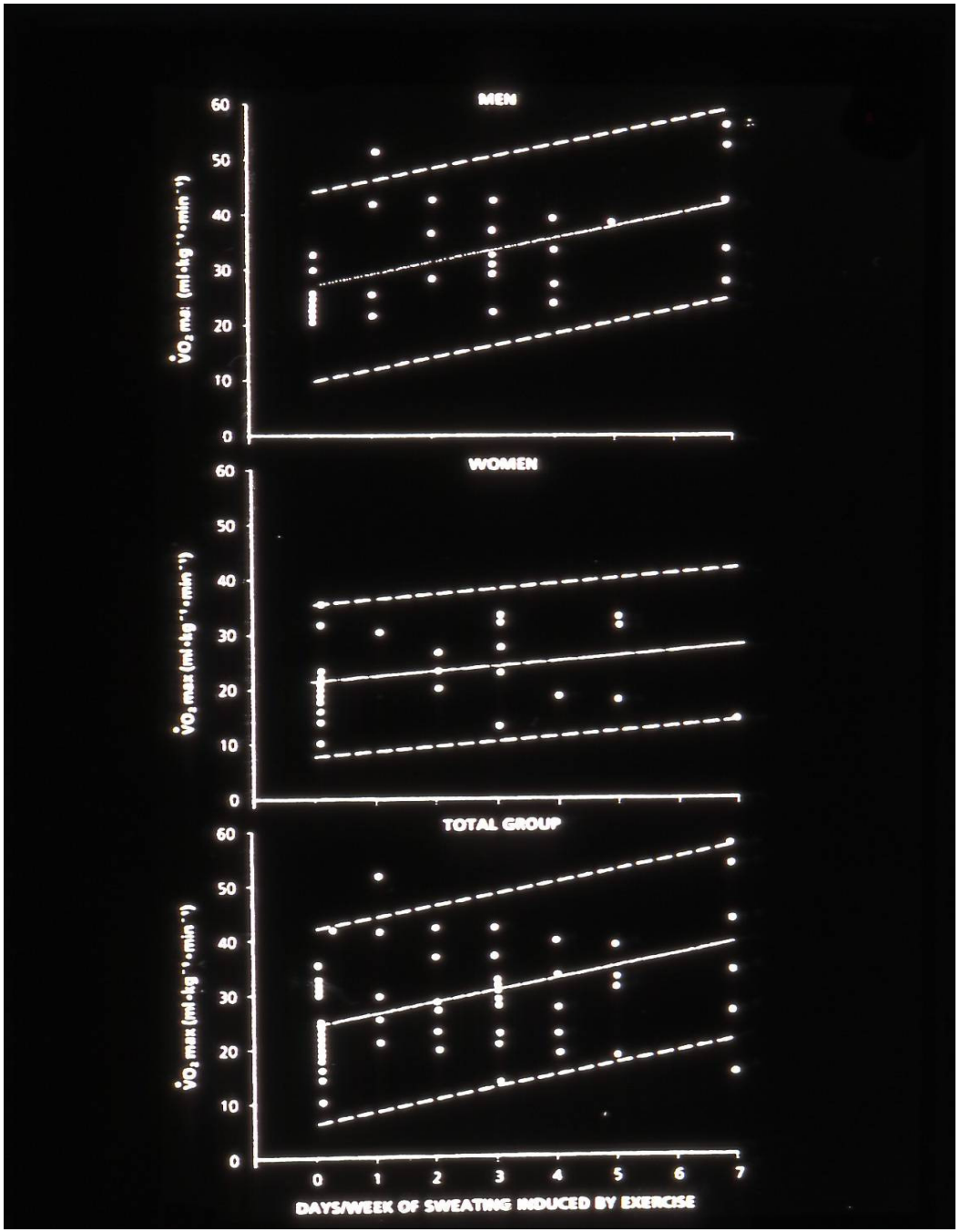


Source: Williams et al. The Evidence base for diabetes care. J Wiley 2002

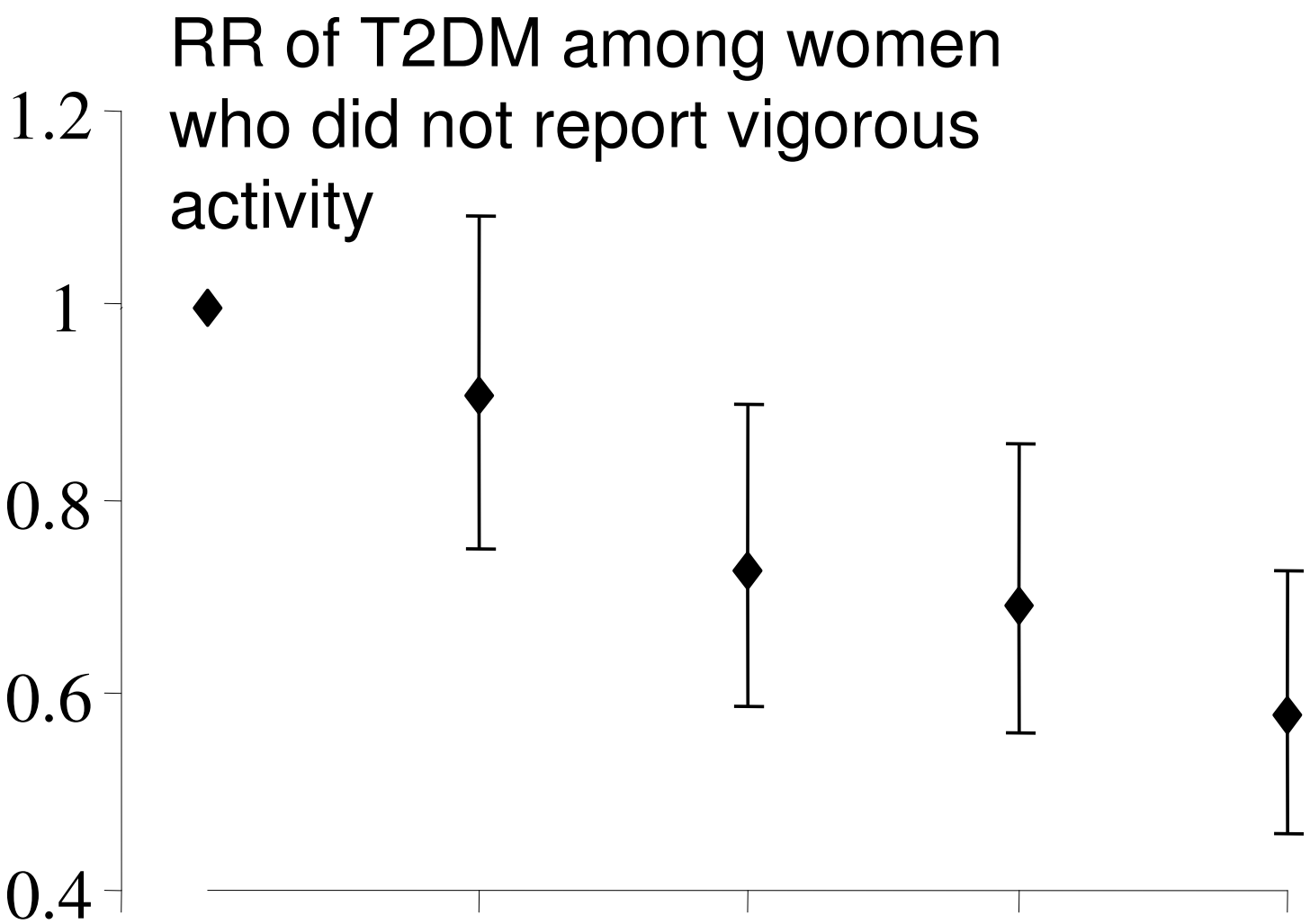
Physical activity and incidence of NIDDM Nurses' Health Study

Vigorous activity	RR age adjusted	RR age & BMI adjusted
0	1.00	1.00
1	0.74 (0.60-0.91)	0.89 (0.72-1.11)
2	0.55 (0.44-0.68)	0.71 (0.56-0.89)
3	0.73 (0.59-0.90)	0.93 (0.73-1.16)
4+	0.63 (0.53-0.75)	0.86 (0.71-1.04)
at least once weekly	0.67 (0.60-0.75)	0.84 (0.75-0.95)

Source: Manson et al. Lancet 1991;338:774-8

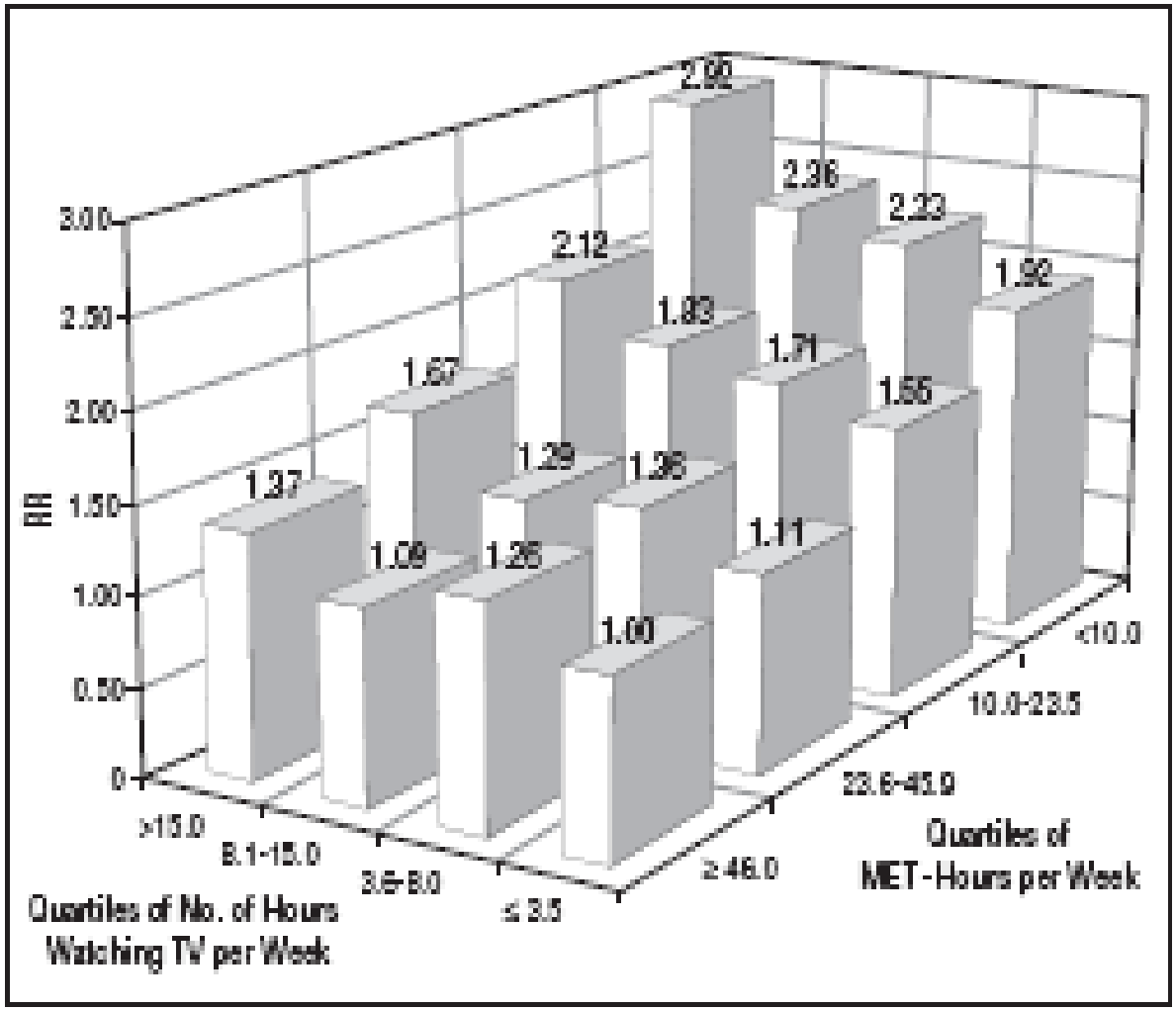


Source: Siconlofi et al



Source: Hu et al JAMA 1999

Relative risk of developing type 2 diabetes by physical activity level and time spent watching TV



Source: Hu et al, Arch Int Med 2001

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Pragmatic risk prediction for clinical stratification

NATIONAL CHOLESTEROL EDUCATION PROGRAM
Third Report of the Expert Panel on
Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel

Risk Assessment Tool for Estimating 10-year Risk of Developing Hard CHD (Myocardial Infarction and Coronary Death)

The risk assessment tool below uses recent data from the Framingham Heart Study to estimate 10-year risk for "hard" coronary heart disease outcomes (myocardial infarction and coronary death). This tool is designed to estimate risk in adults aged 20 and older who do not have heart disease or diabetes. Use the calculator below to estimate 10-year risk.

Age:	☐ years
Gender:	○ Female ○ Male
Total Cholesterol:	☐ mg/dL
HDL Cholesterol:	☐ mg/dL
Smoker:	○ No ○ Yes
Systolic Blood Pressure:	☐ mm/Hg
Currently on any medication to treat high blood pressure.	○ No ○ Yes

Calculate 10-Year Risk

Quick and easy to compete
High face validity
Very simple to compute
High reliability / validity
Predictive of risk

Baseline EPIC Physical activity questionnaire

Postal, self-administered, frame of reference - past year

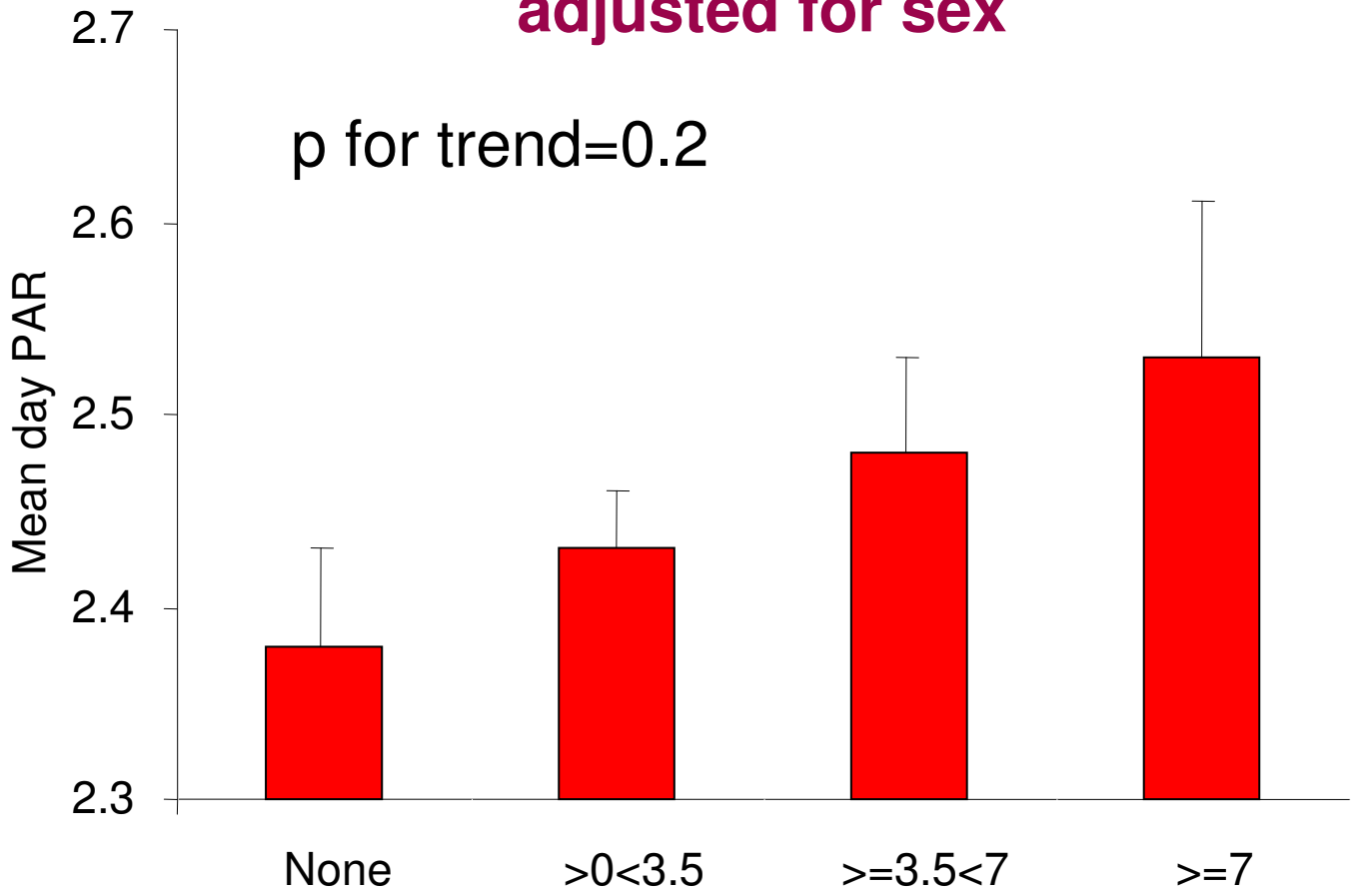
Work category

Sedentary, Standing, Manual, Heavy manual

Hours per week ...

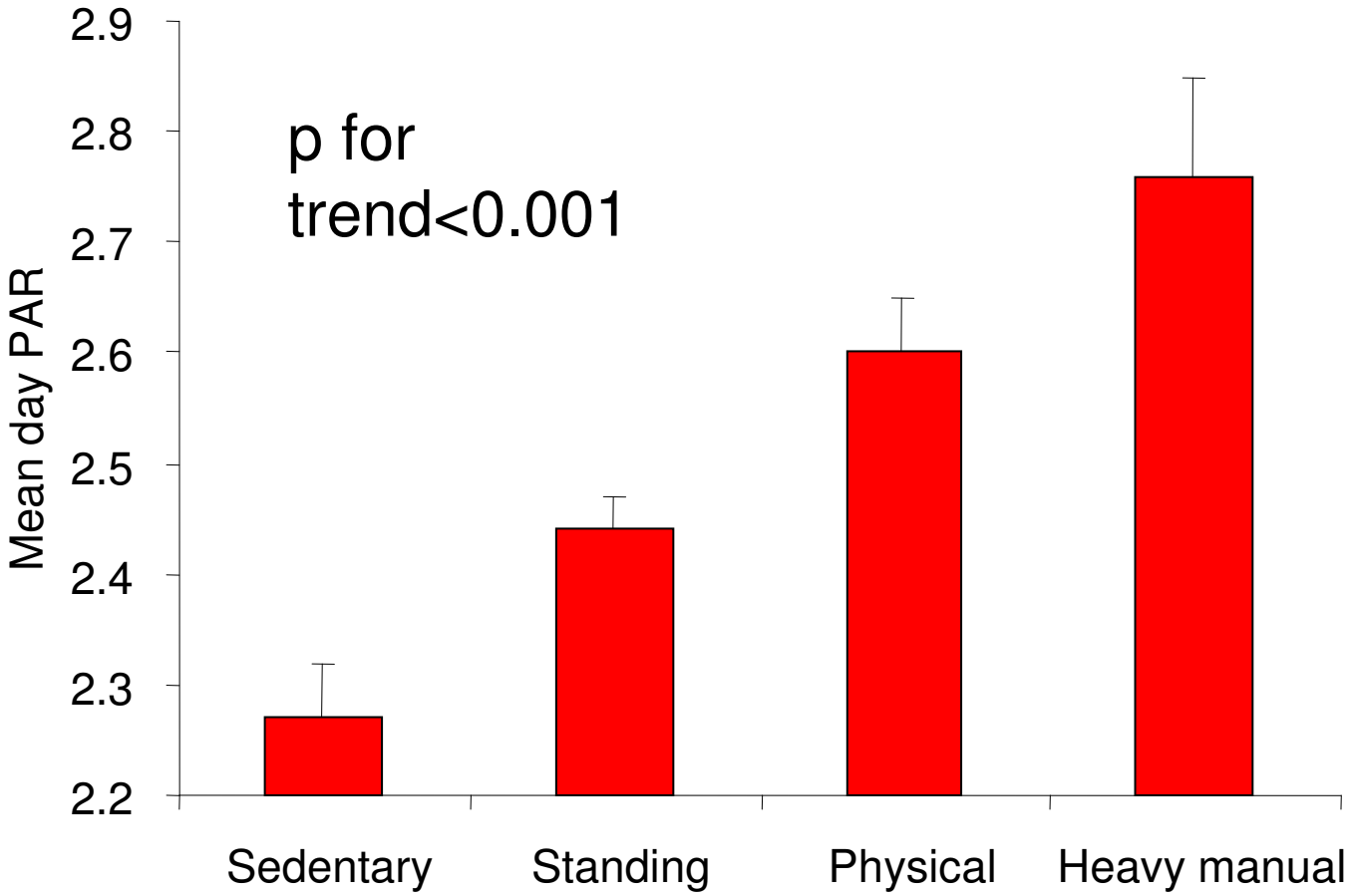
Cycling, Physical exercise

Mean day PAR by self-reported participation in cycling and sports adjusted for sex



Source: Wareham et al Public Health Nutrition 2003

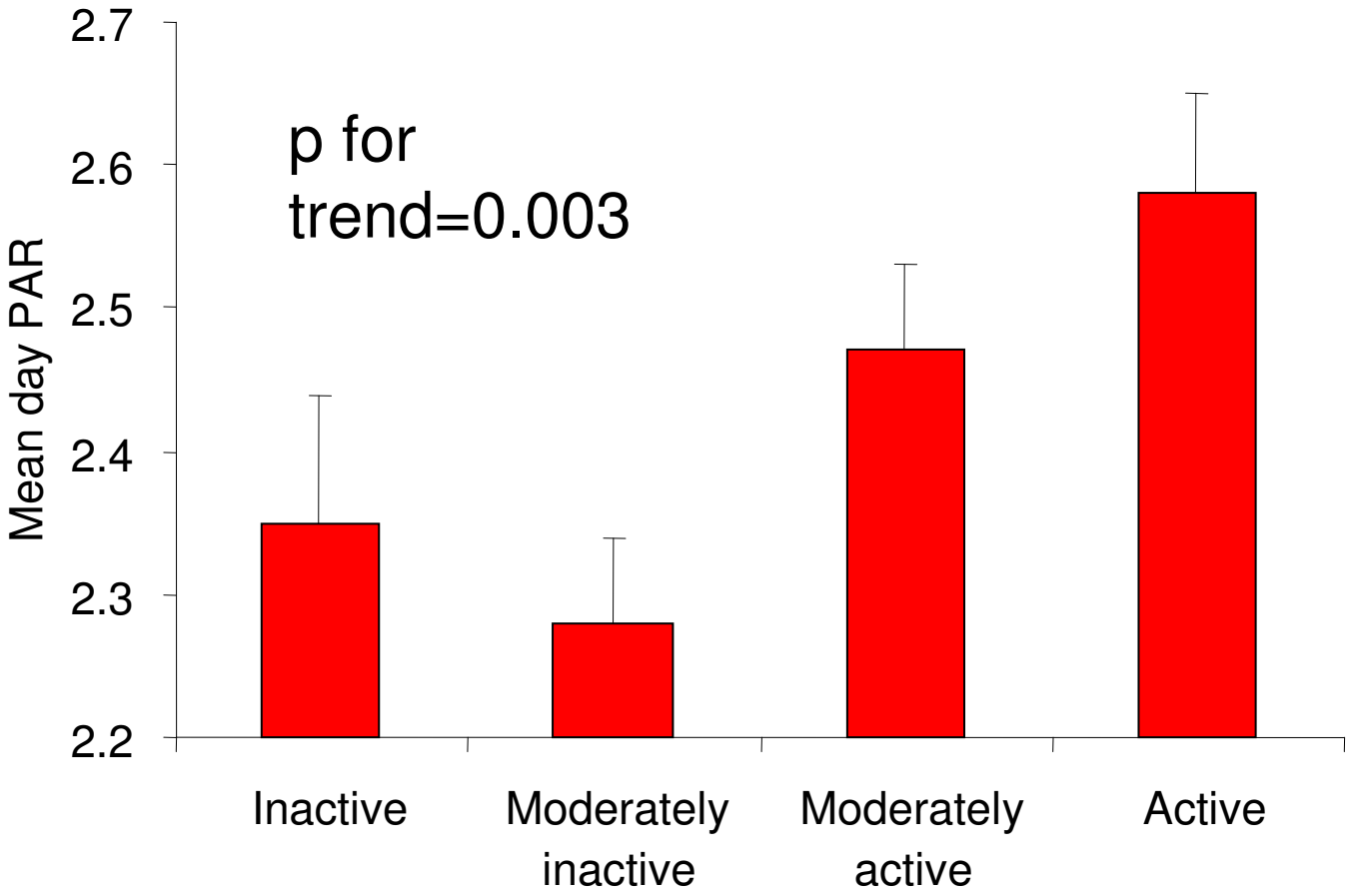
Mean day PAR by occupational physical activity adjusted for sex



Source: Wareham et al Public Health Nutrition 2003

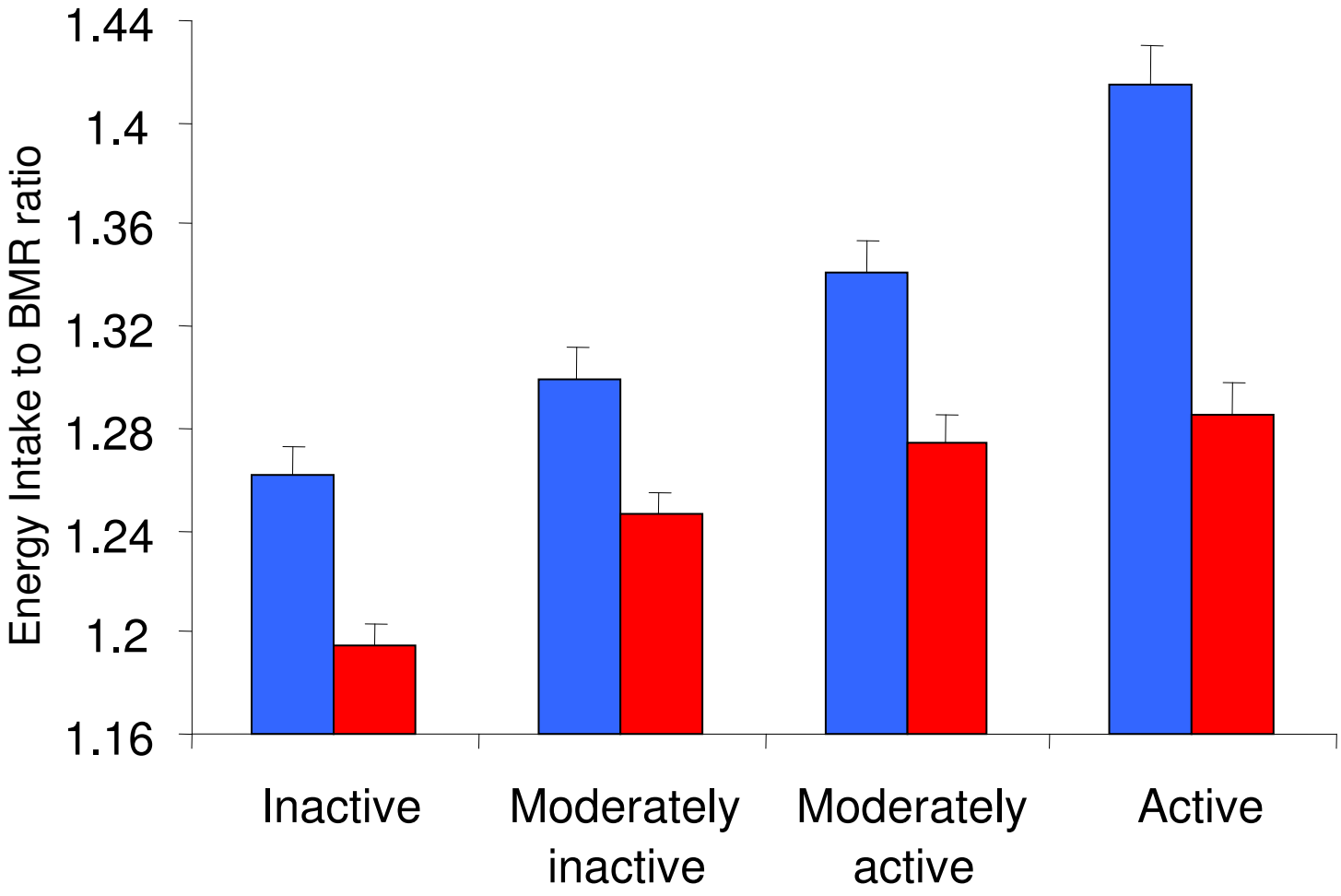
	Occupation category			
	Sedentary	Standing	Physical	Heavy
Leisure activity (hours per week)				
0	1	2	3	4
-3.5	2	3	4	4
3.5-7	3	4	4	4
>=7	4	4	4	4

Mean day PAR by physical activity index

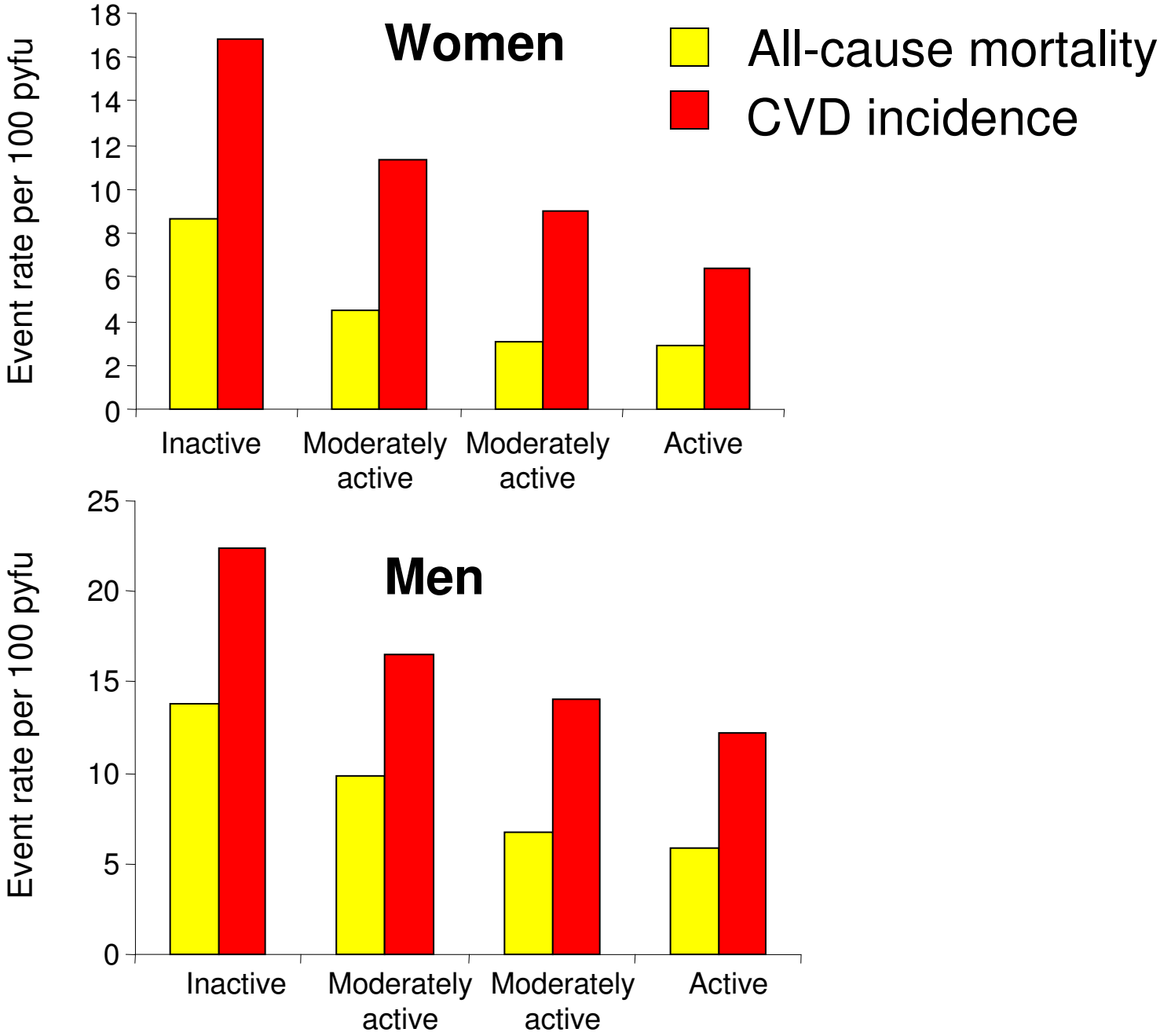


Source: Wareham et al Public Health Nutrition 2003

Ratio of energy intake, from 7-day food diary, to predicted BMR by physical activity index (n=5,847)



Source: Wareham et al Public Health Nutrition 2003



Source: Khaw et al, Int J Epid 2006

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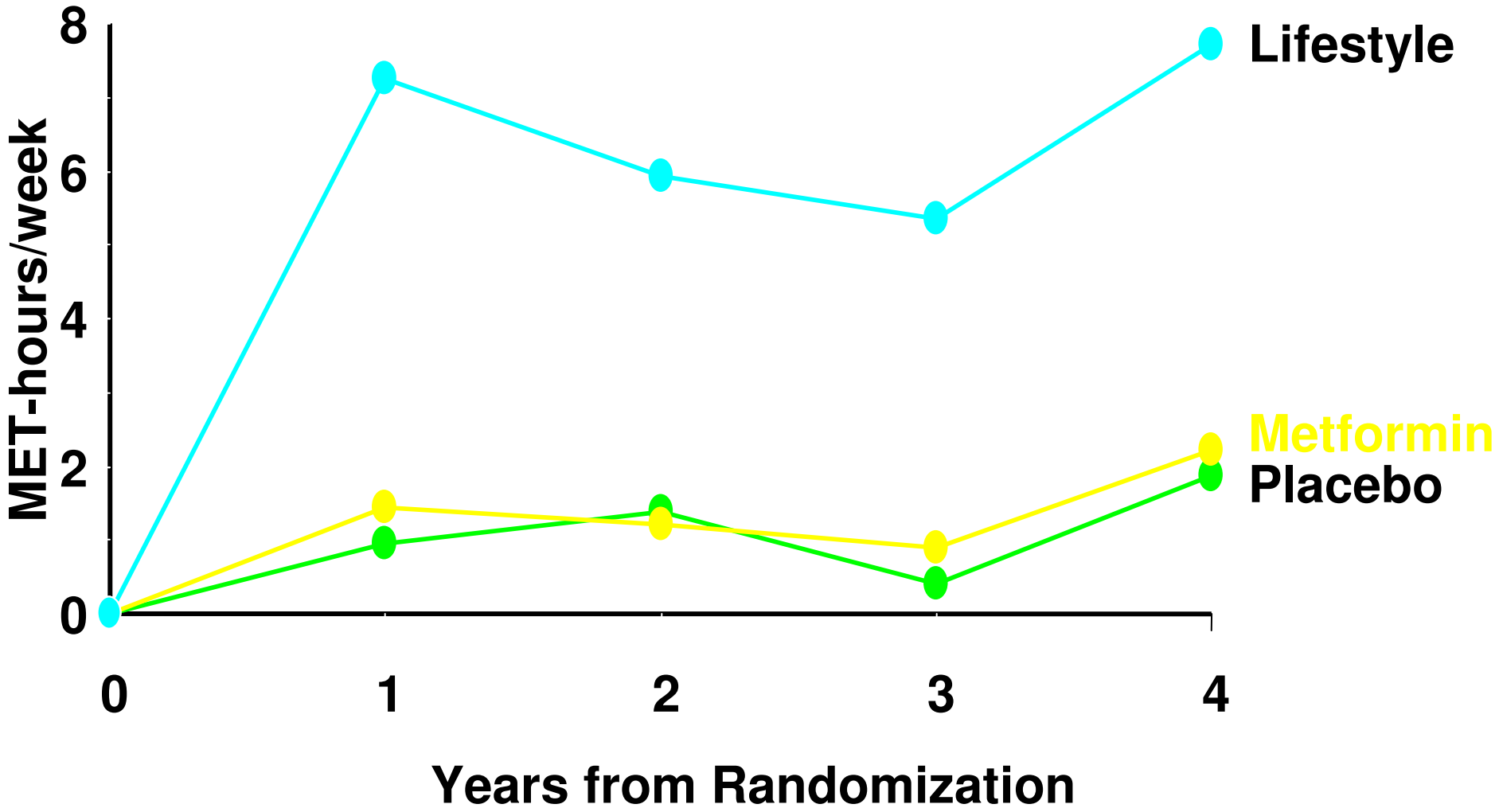
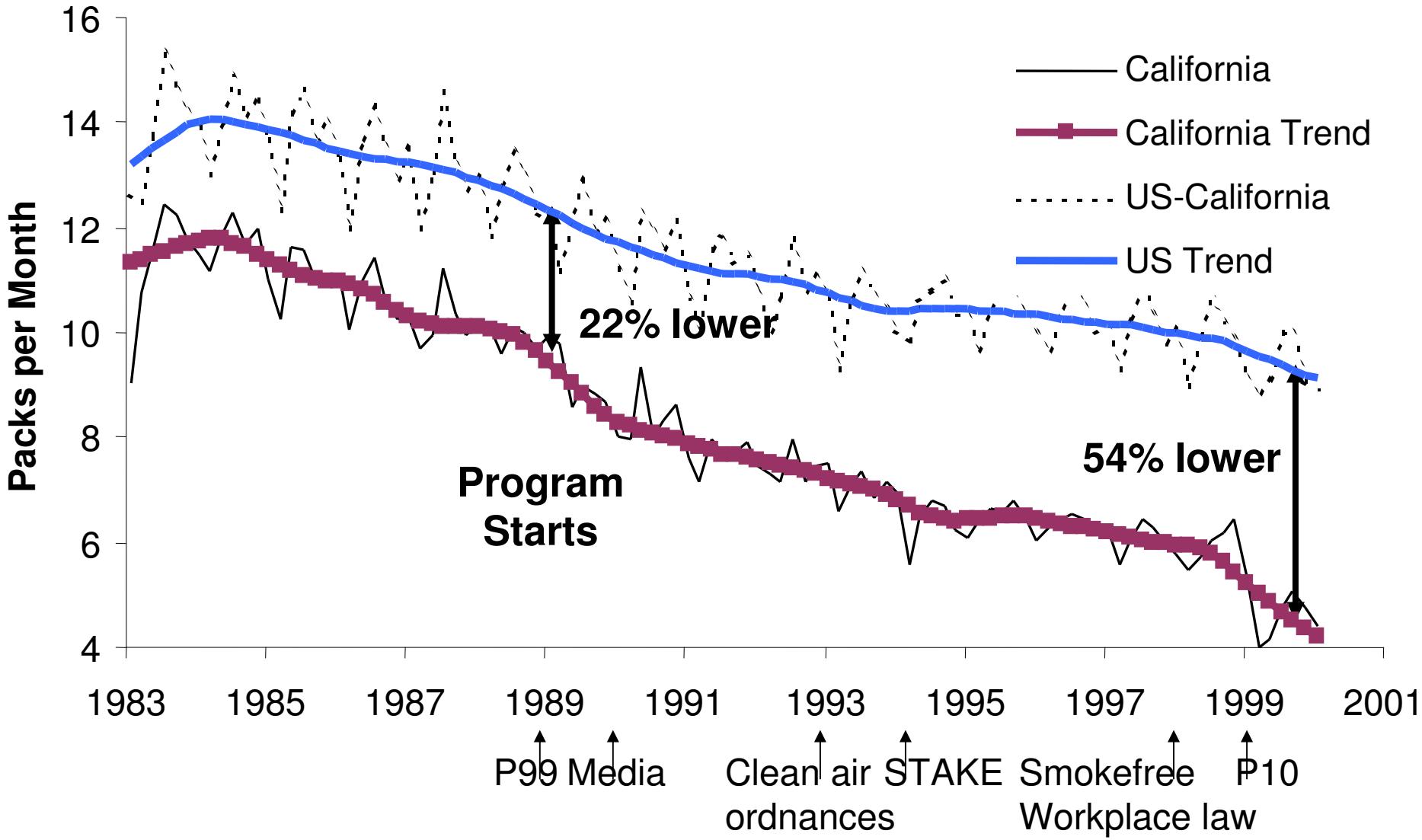
Mean Change in Leisure Physical Activity



Source: The DPP Research Group, *NEJM 346*:393-403, 2002

Seasonally Adjusted Trend of Per Capita Consumption for Cigarettes, California vs. U.S.



Source: Tobacco Institute; Orzechowski & Walker; U.S. Bureau of Census

Elizabeth A. Gilpin, http://ssdc.ucsd.edu

Congestion charging...

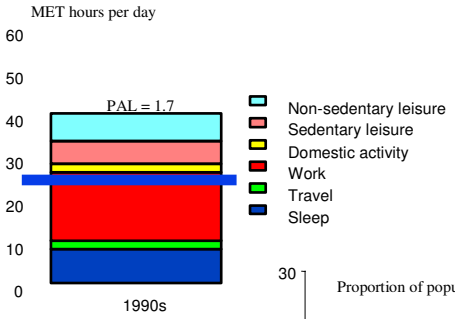
Intervention

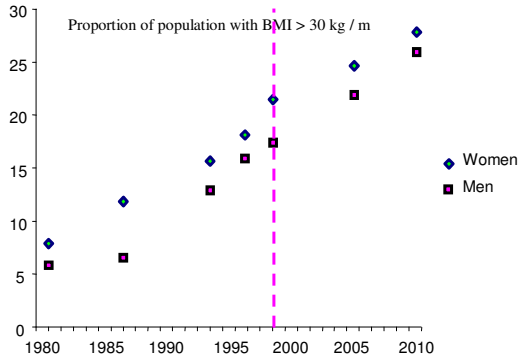
Closely related behaviours

Associated behaviours

Sum of all activities

Obesity prevalence





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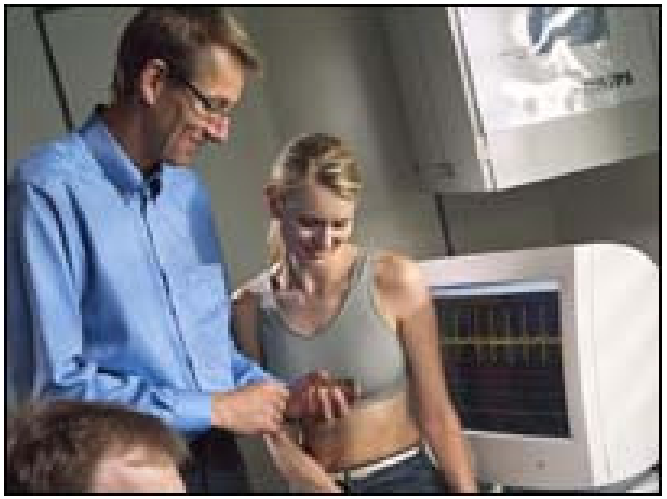
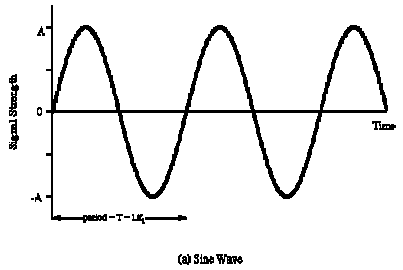


Objective assessment of physical activity

Actigraph acceleration response



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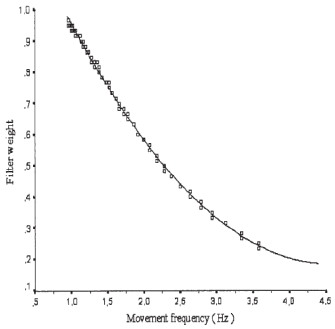

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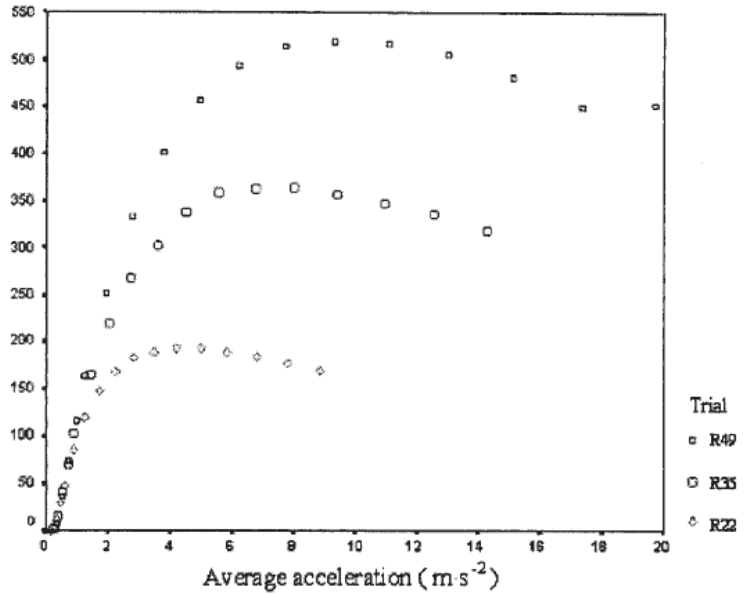
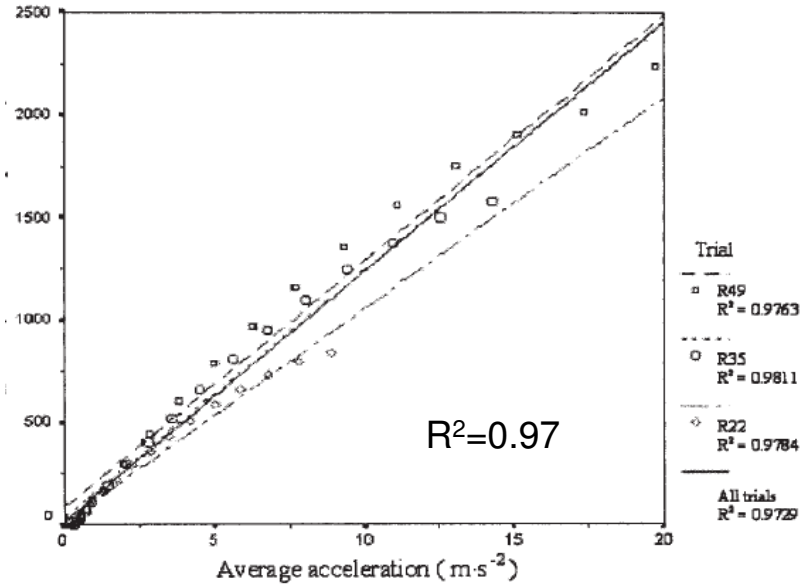
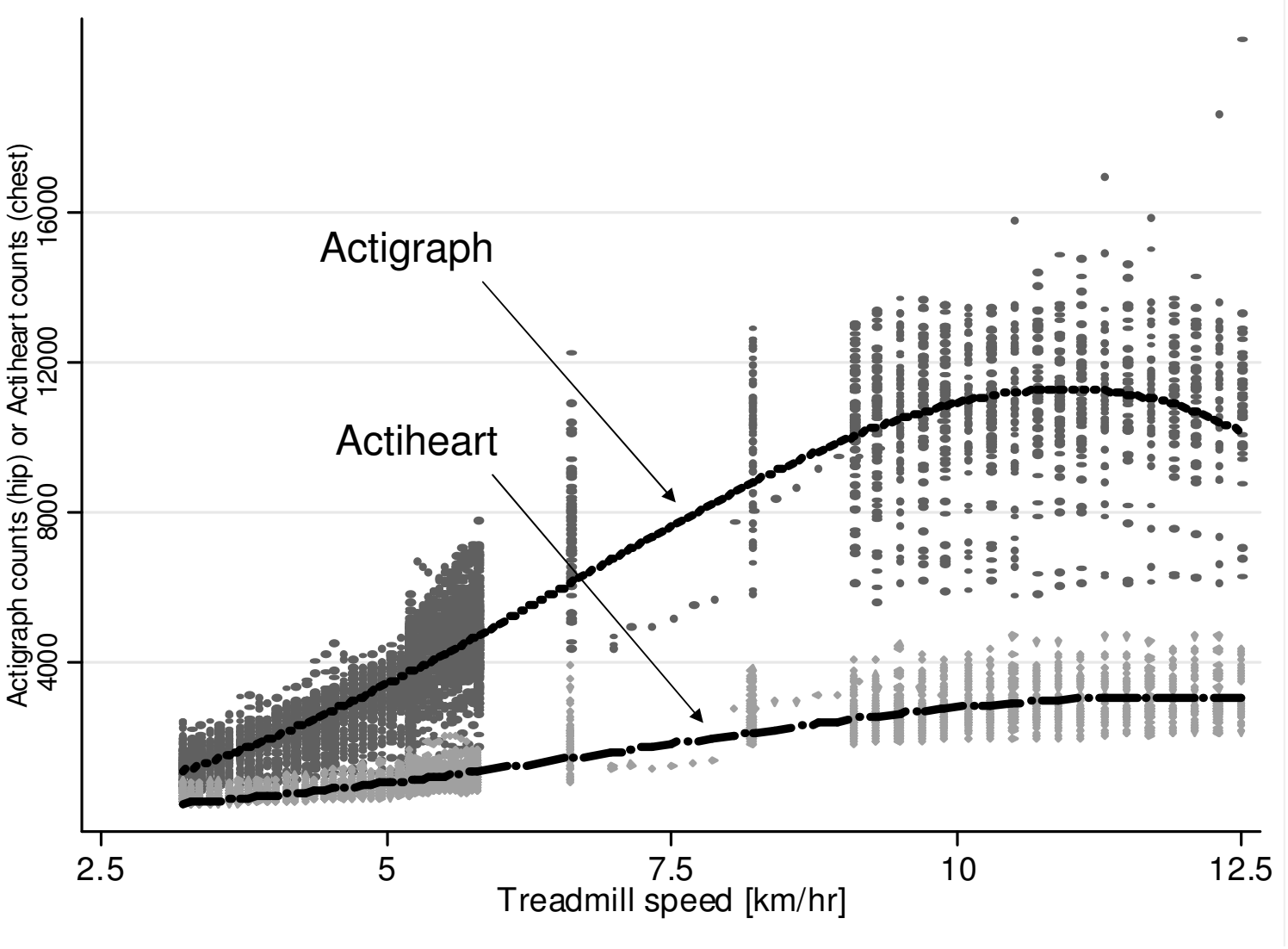
Actigraph counts vs acceleration



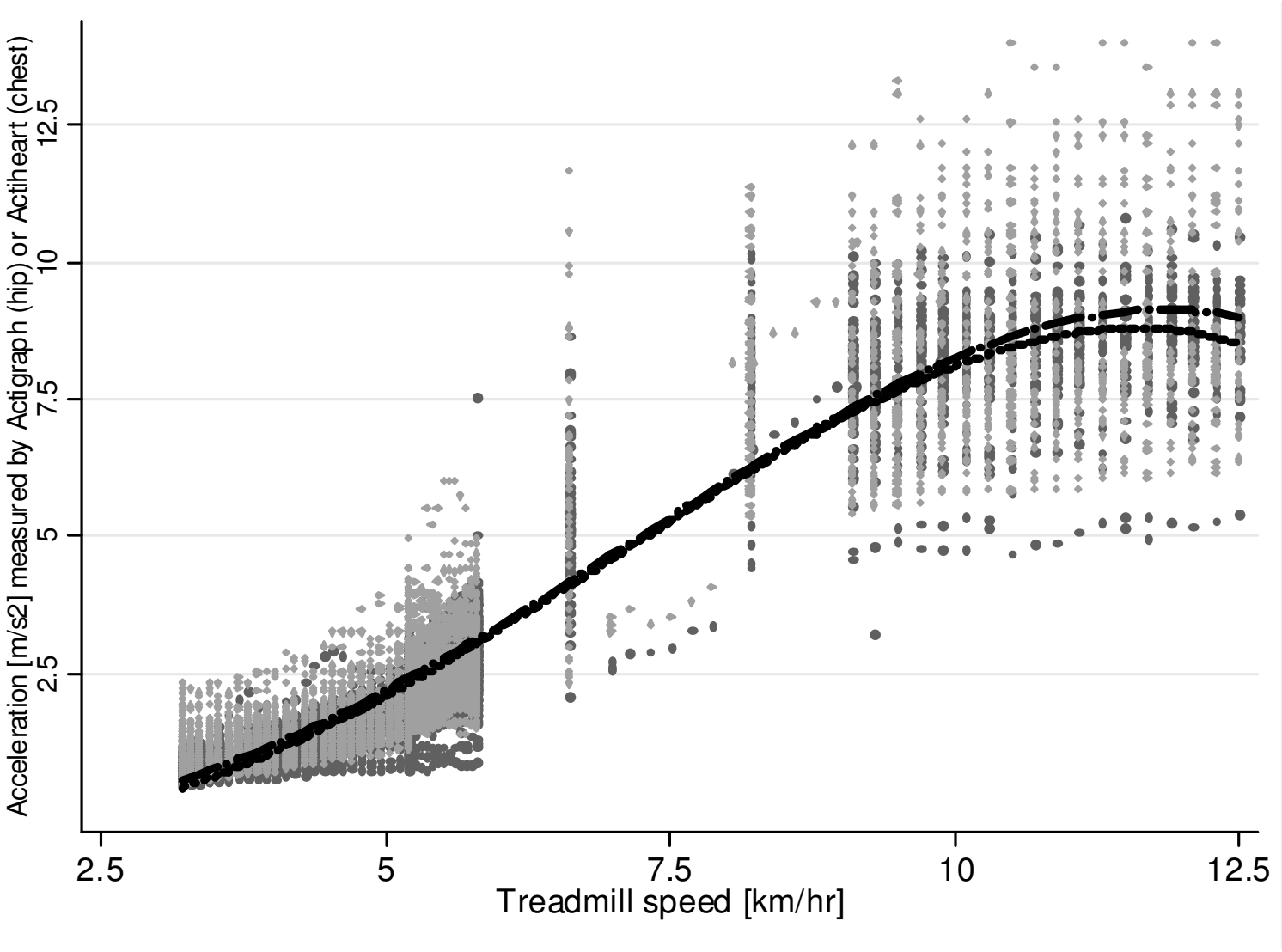
Filter-corrected counts vs acceleration



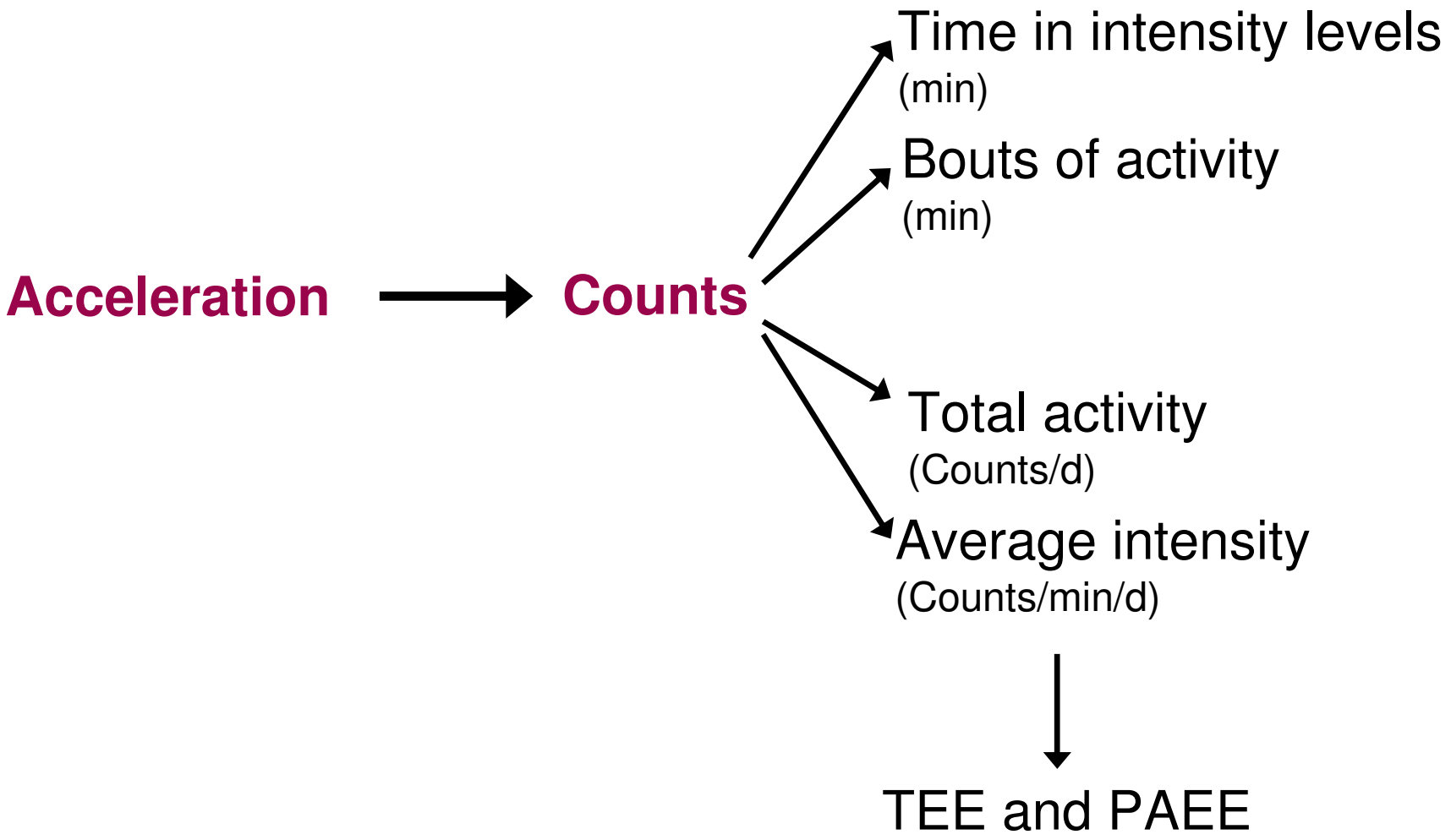
Accelerometry output in “counts per min”



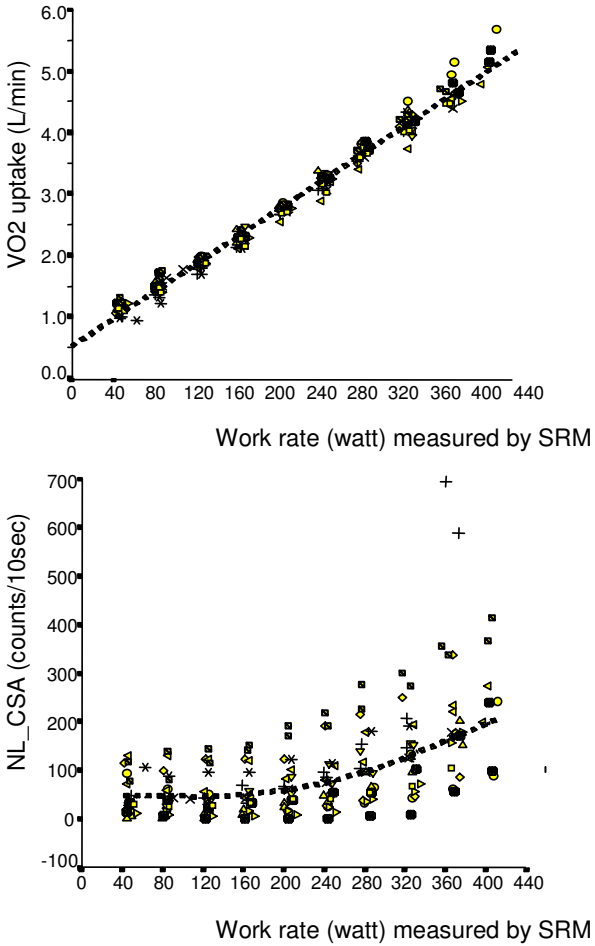
Accelerometry output expressed in m/s^2



Computing summary variables

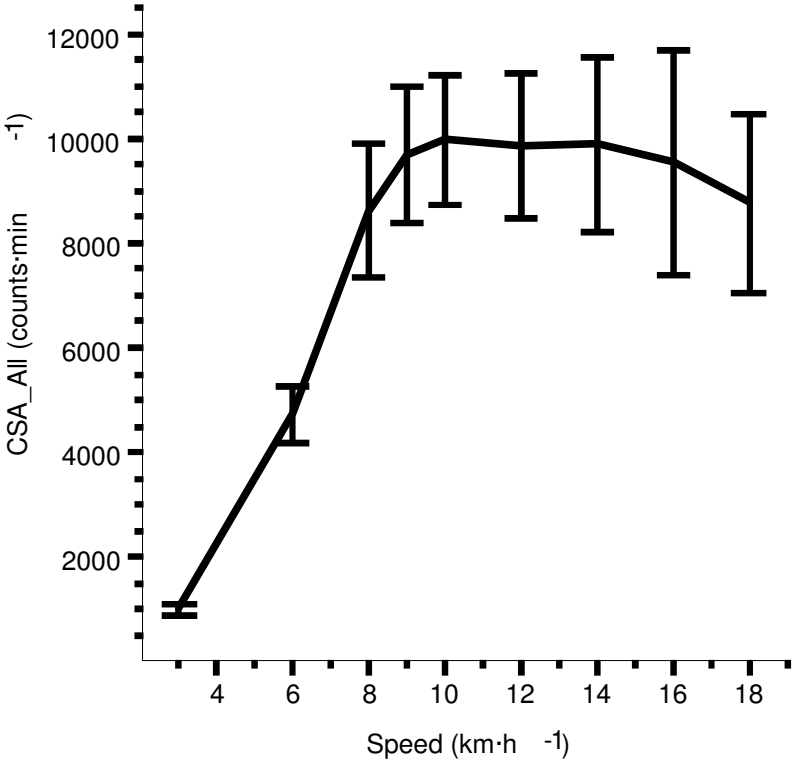


cycling



Source: Brage et al, 2003

non-linearity with speed

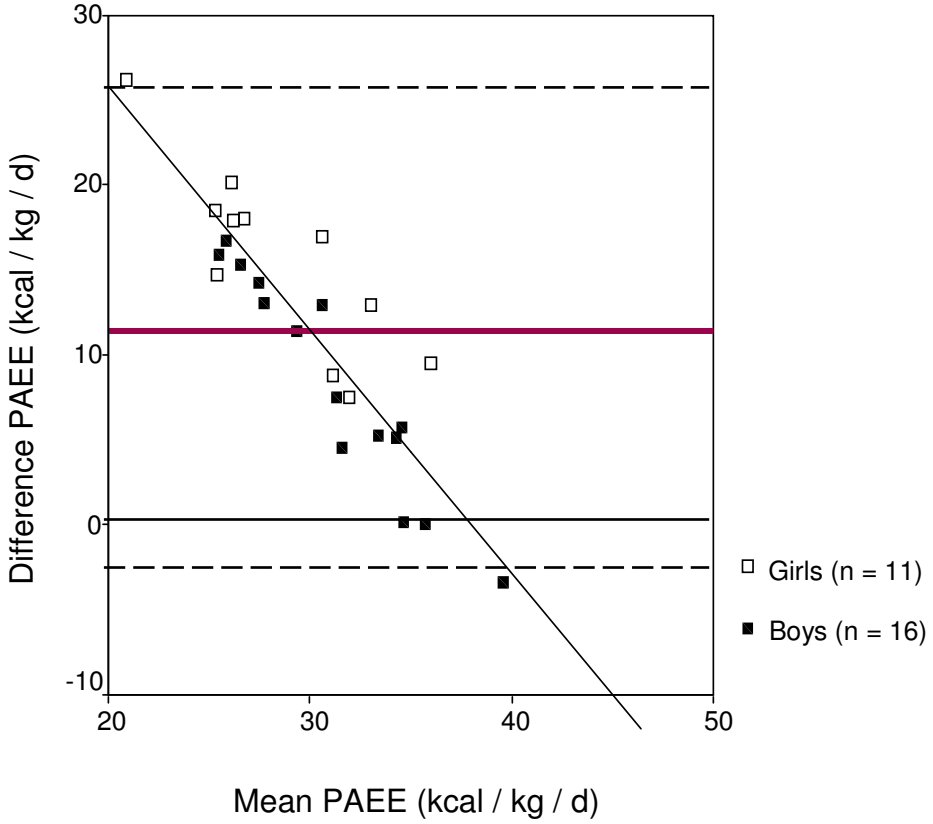


Source: Brage et al, MSSE 2003

Predicting PAEE from laboratory based activity counts introduce systematic bias

- 26 children (9-10 y), simultaneous measurements of TEE by DLW and body movement by accelerometry
- Mean difference: 11.4 ±7.0 kcal·kg^{-1}·d^{-1} (P < 0.0001)
- Limits of agreement: + 25.4 and –2.6 kcal·kg^{-1}·d^{-1}
- *r* = -0.90 (P < 0.0001)

- The laboratory derived PAEE equation overestimated free-living PAEE by ~47%



Ekelund *et al*. Lancet, 2004;363:1163

Criterion validity of accelerometers and pedometers to assess free-living physical activity

Accelerometers and pedometers: methodology and clinical application
Kirsten Corder, Søren Brage and Ulf Ekelund

DLW studies

Adults	6 studies	R^2 0.13 – 0.81
Children	7 studies	R^2 0.13 – 0.81

Source: Current opinion in clinical nutrition and metabolic care 2007

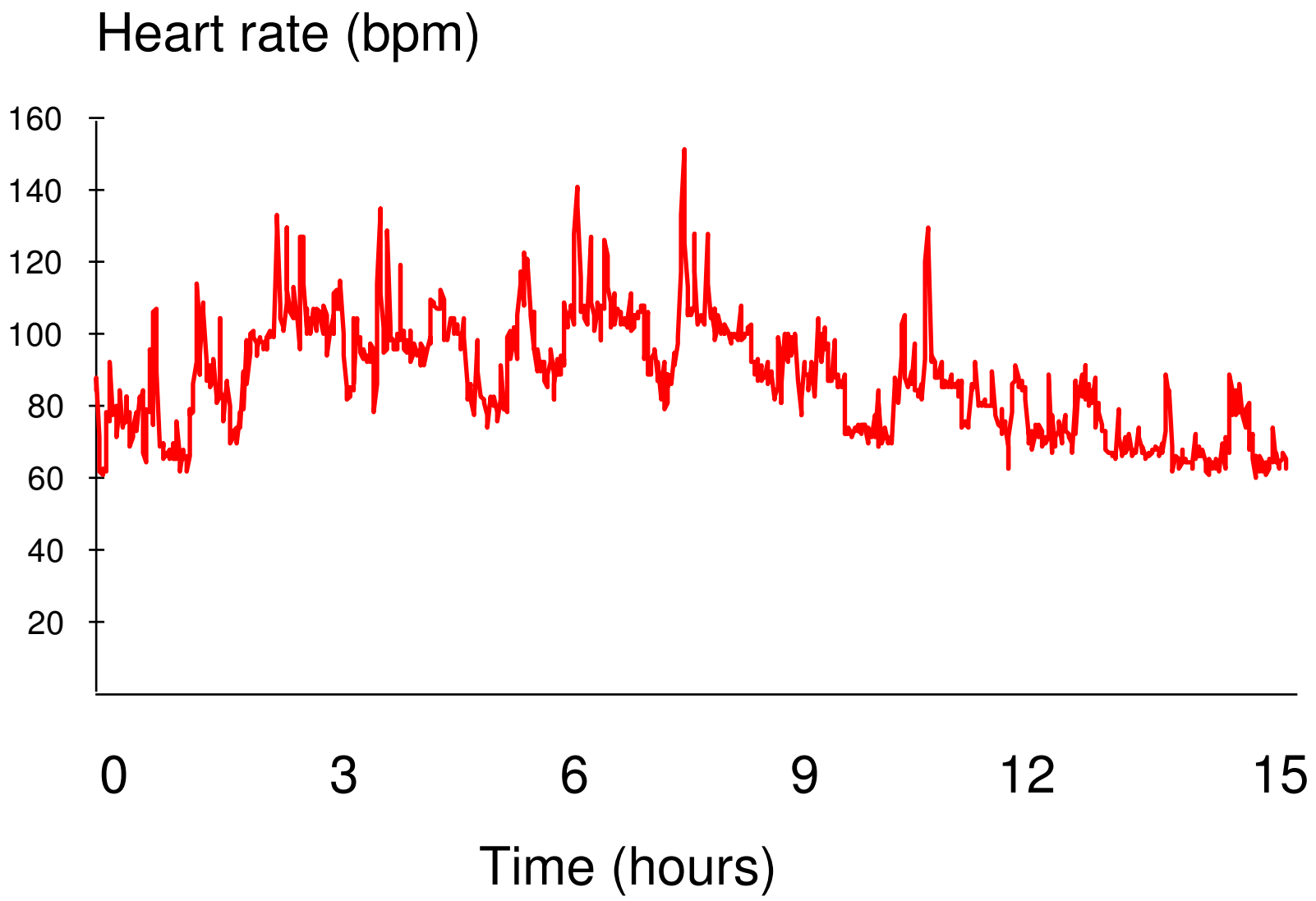
Movement sensors

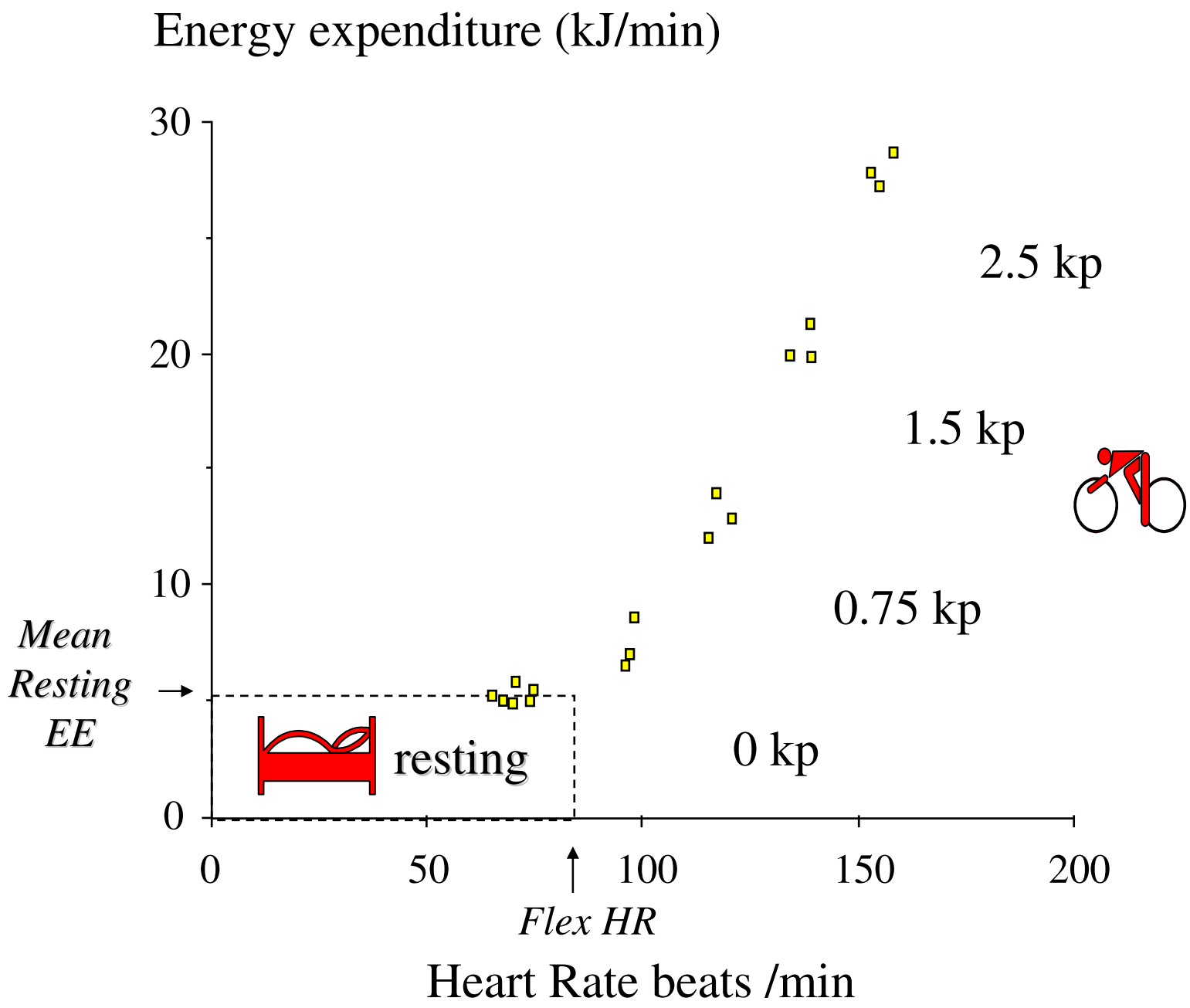
Advantages

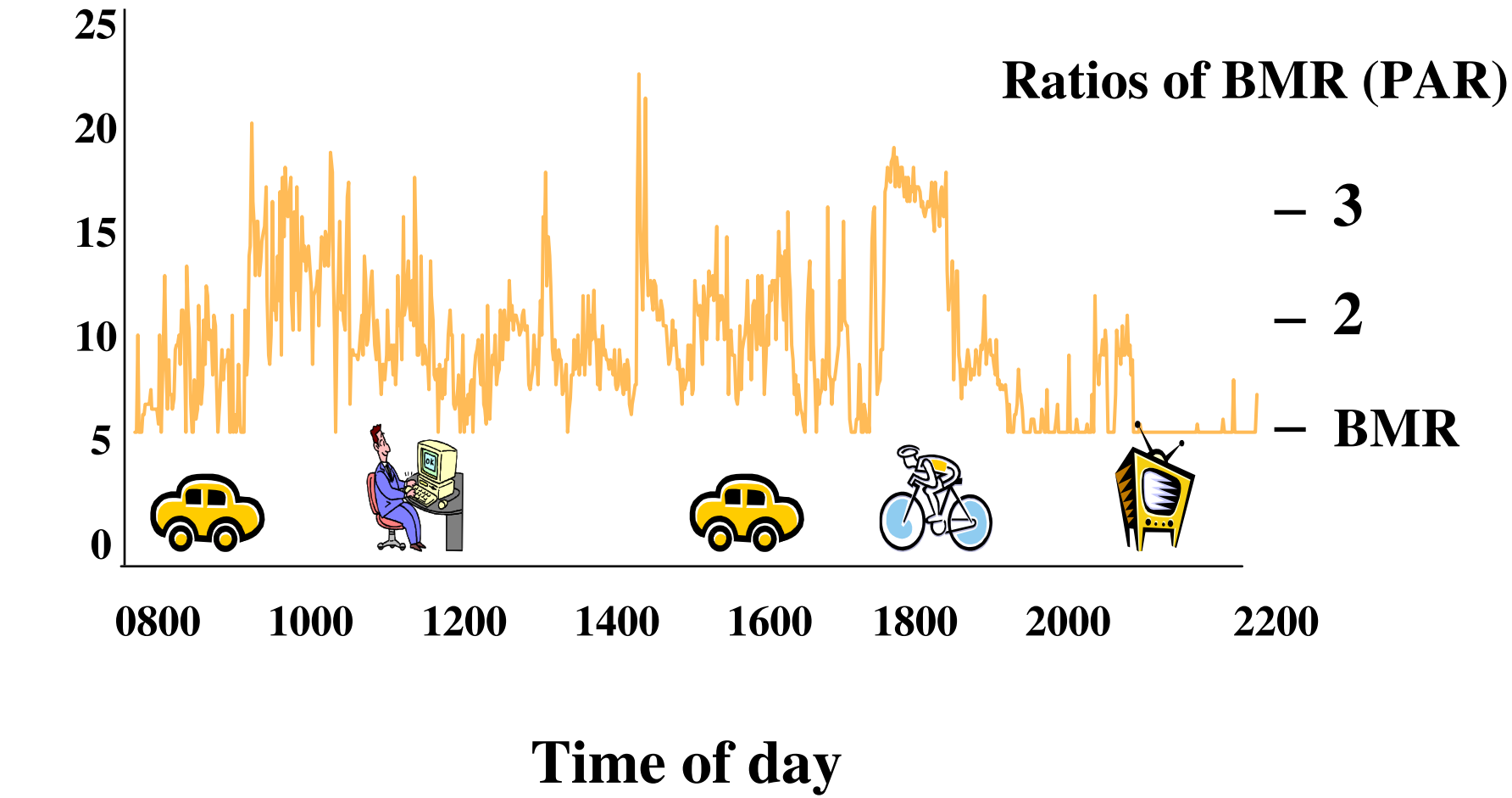
- Measures body movement
- Measures inactivity perfectly
- Relatively good correlations with PAI during walking and jogging on the flat

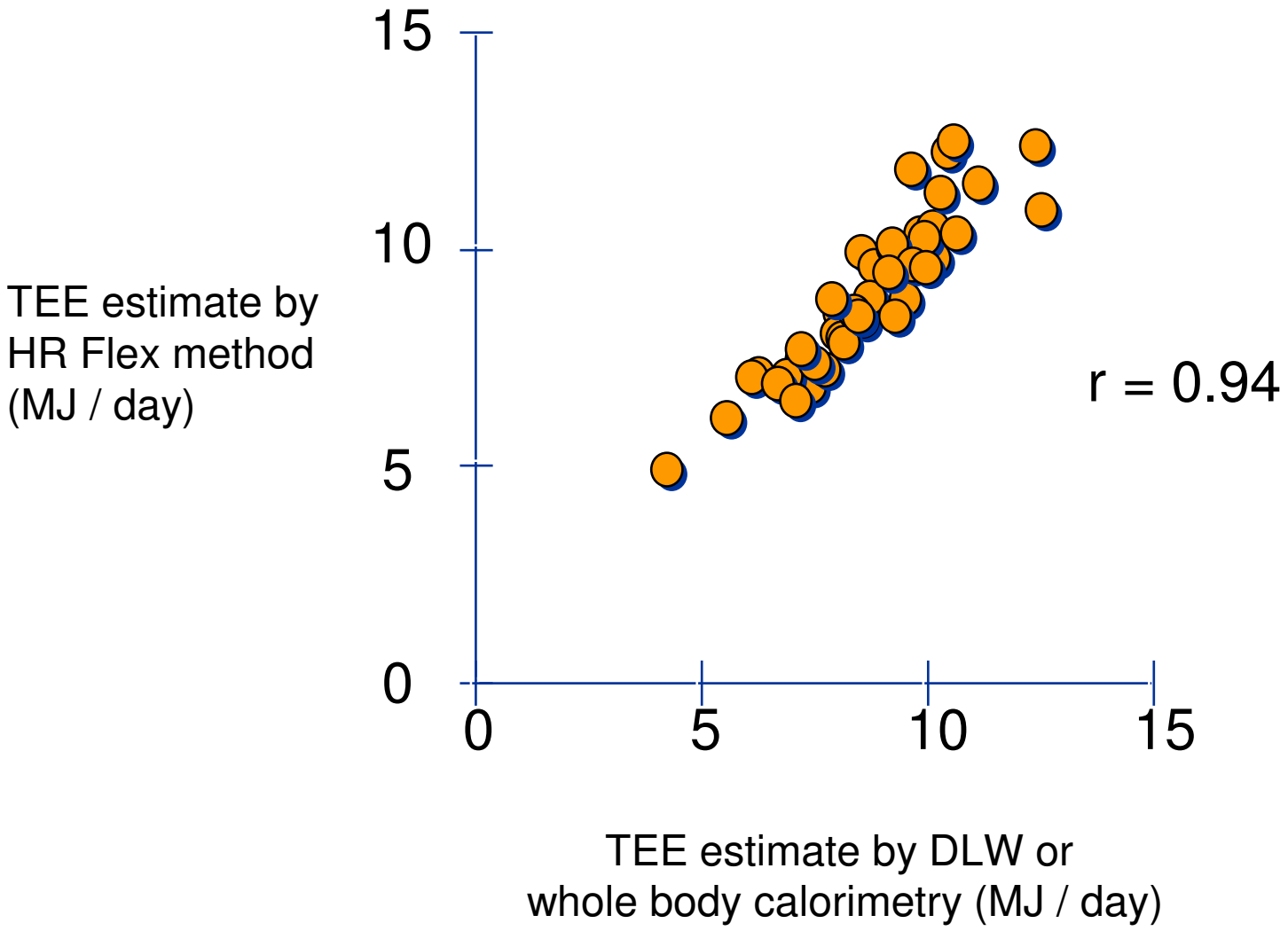
Disadvantages

- 'Counts' are not easy to relate to
- Not universal relationship between counts and PAI across activity types
- Cycling, swimming, carrying weights, walking uphill, ≥ moderate speed running underestimated with most equations
- Most monitors not waterproof
- Belt may cause discomfort or be forgotten when taken off
- 'Monitor not worn' periods hard to identify
- MTI Actigraph: Movement frequency-dependent filtering


Heart rate (bpm)
160
140
120
100
80
60
40
20
0
3
6
9
12
15
Time (hours)


Energy expenditure (kJ/min)
30
20
10
0
Mean
Resting
EE
2.5 kp
1.5 kp
0.75 kp
0 kp
resting
0
50
100
150
200
Flex HR
Heart Rate beats /min


Energy Expenditure (kJ/min)
25
20
15
10
5
0
Ratios of BMR (PAR)
– 3
– 2
– BMR
0800
1000
1200
1400
1600
1800
2000
2200
Time of day



Source: Ceesay et al. Brit. J Nut. 1988

HR monitoring

Advantages

- Well-established physiological concept
- Highly linear relationship between HR and PAI during moderate-to-high intensities
- No need to take off if waterproof
- Monitor not worn' time segments easily identified

Disadvantages

- Relationship between HR and PAI questionable at low intensity levels, e.g. during psychological stress.
- Requires some level of individual calibration
- Not always easy to pick up HR (noise)
- Interference for telemetry systems (more noise)
- Electrodes / chest strap may cause discomfort

Combined monitoring studies

Almost all studies report improvement in precision (typically R^2 values)

First study was done in Cambridge (Avons et al, 1988)

Other important combined monitoring studies using regression include Haskell et al (1993) and Moon et al (1996)

Progress towards wider use of objective monitoring

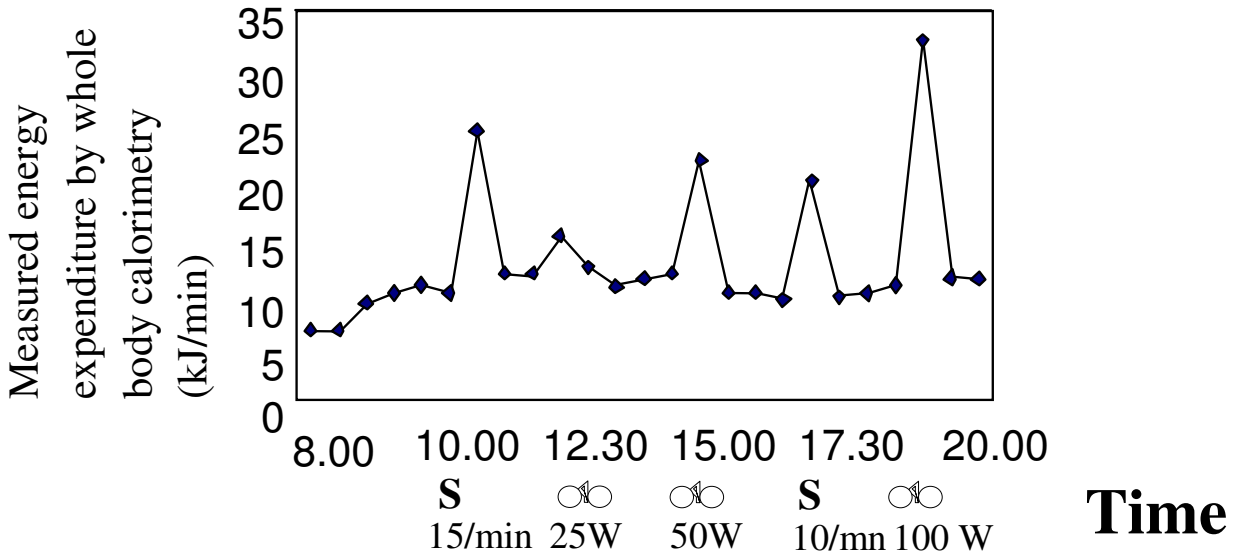
- More practical monitors incorporating combined sensing

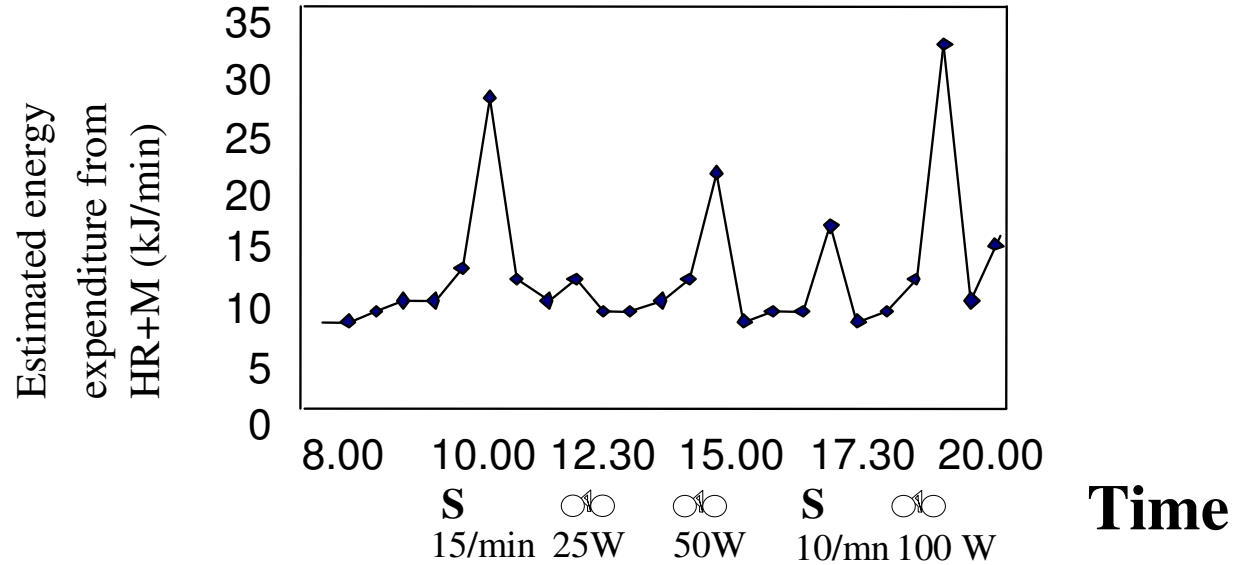
- Removal of need for individual calibration if possible

- Simpler individual calibration without requirement for expensive laboratory equipment

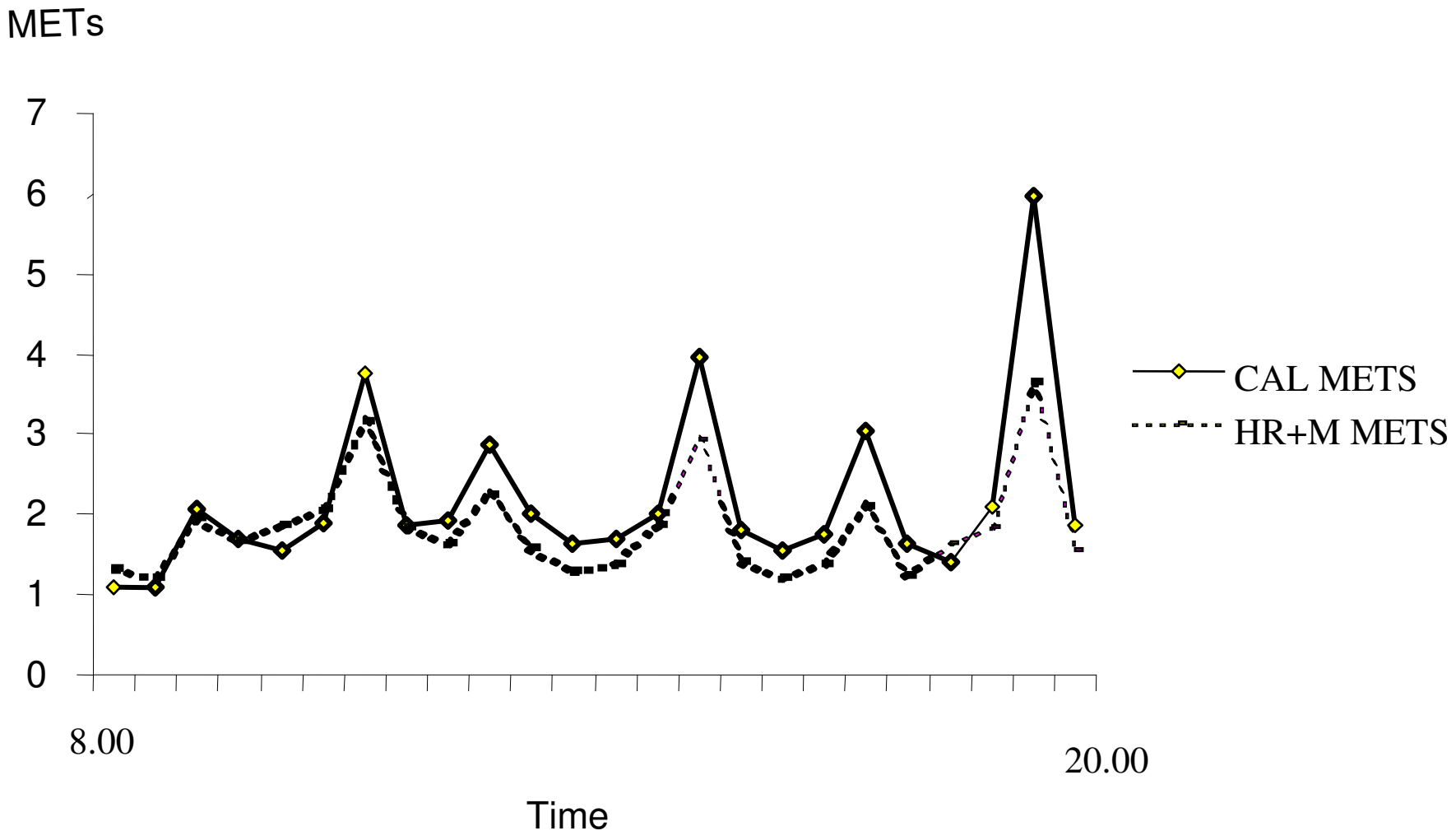
Combined heart rate and movement sensing

- Single piece
- Small, light, waterproof
- Starts and stops automatically
- Tamperproof
- No visible feedback to volunteer
- Easy to download data
- Automated data processing

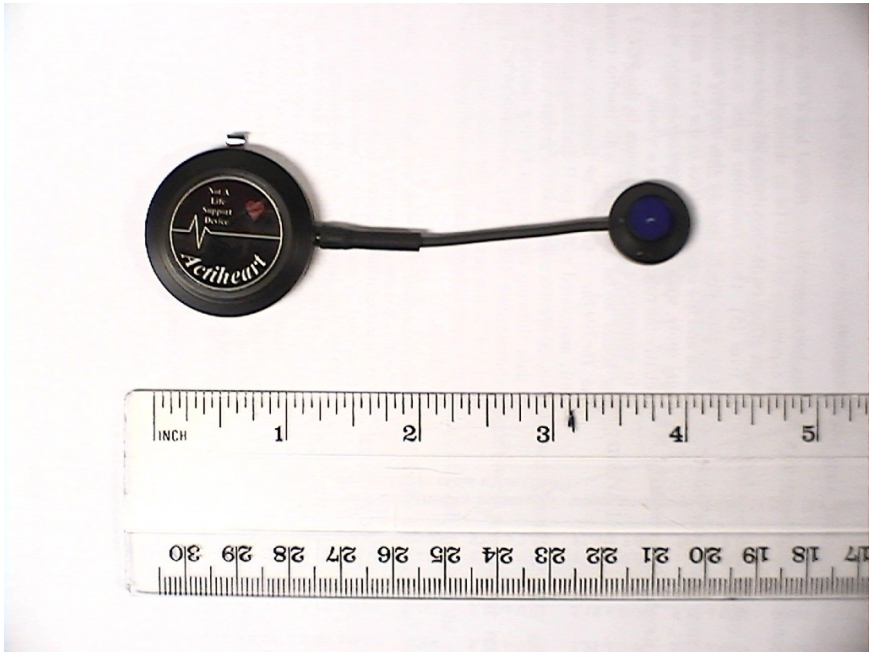


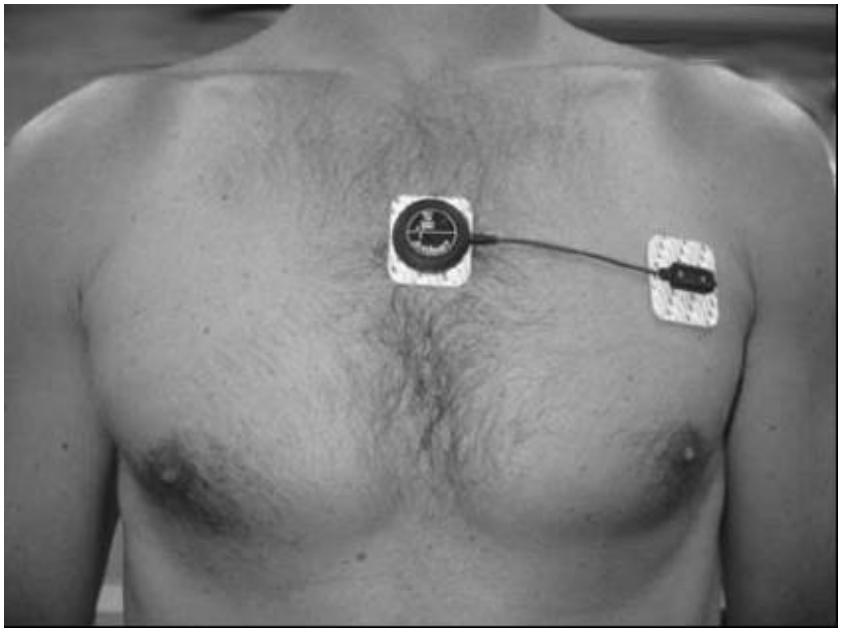


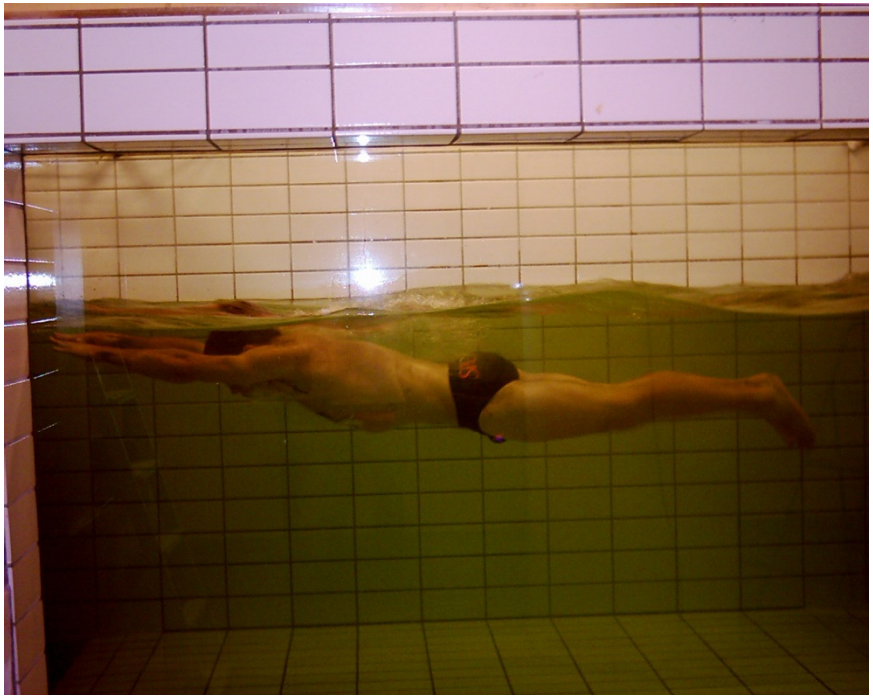
Source: Rennie et al, Eur J Clin Nutr 2001

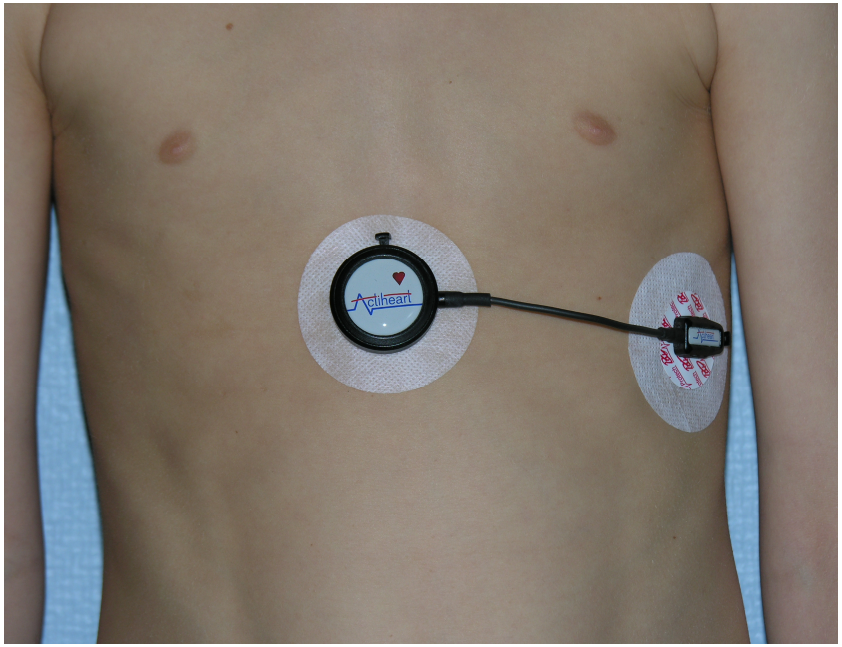


Source: Rennie et al, Eur J Clin Nutr 2000


Actiheart
INCH
1
2
3
4
5






Actiheart

Combined ACC and HR monitor

European Journal of Clinical Nutrition (2005) 59, 561–570
© 2005 Nature Publishing Group All rights reserved 0954-3007/05 $30.00
www.nature.com/ejcn

ORIGINAL COMMUNICATION

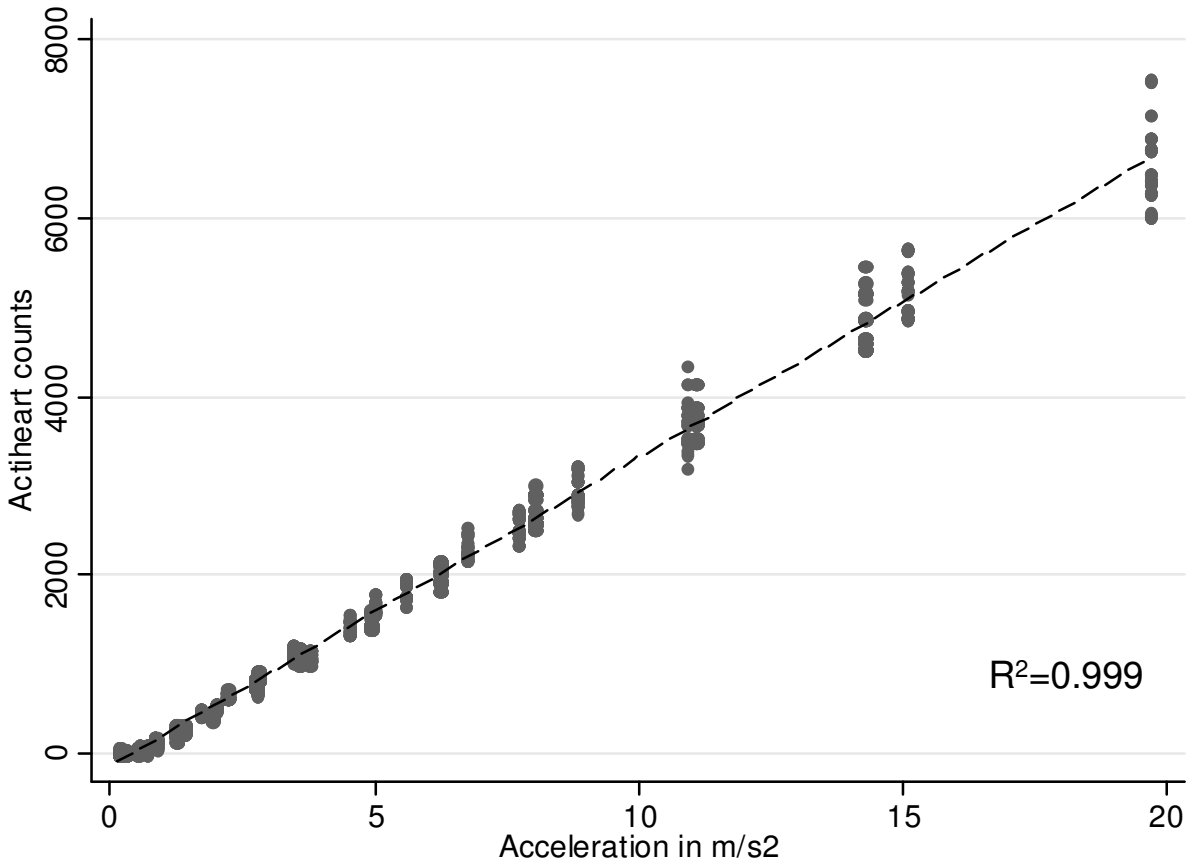
Reliability and validity of the combined heart rate and movement sensor Actiheart

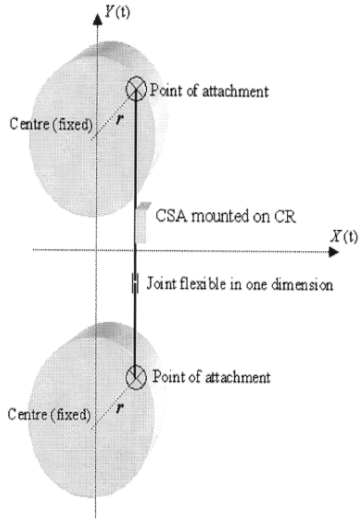
S Brage[1]*, N Brage[2], PW Franks[1], U Ekelund[1] and NJ Wareham[1]

[1]*MRC Epidemiology Unit, Institute of Public Health, University of Cambridge, UK; and* [2]*Institute of Sports Science and Clinical Biomechanics, University of Southern Denmark, Odense, Denmark*

Eur J Clin Nutr 59, 561-70, 2005

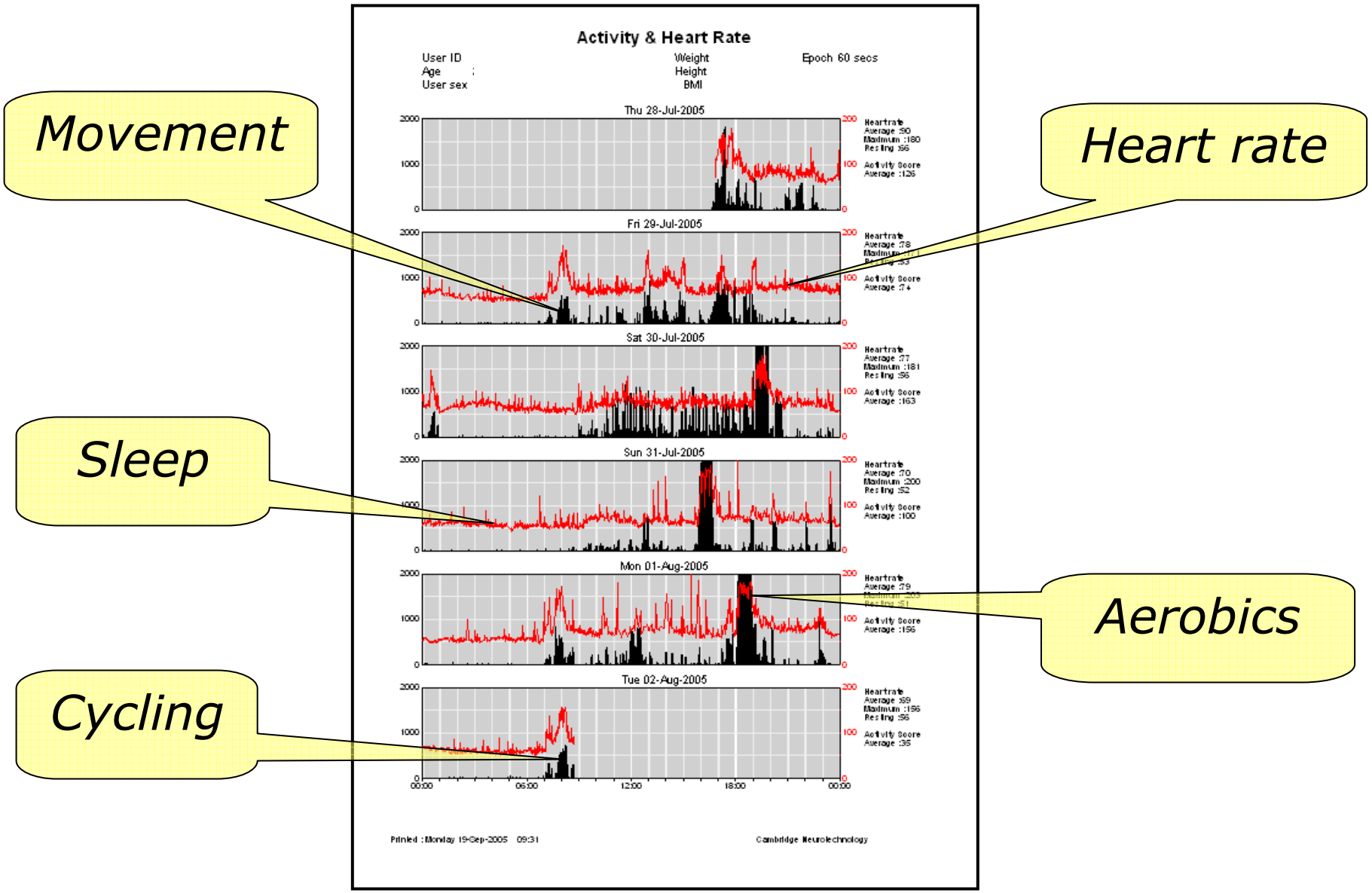
Actiheart acceleration response



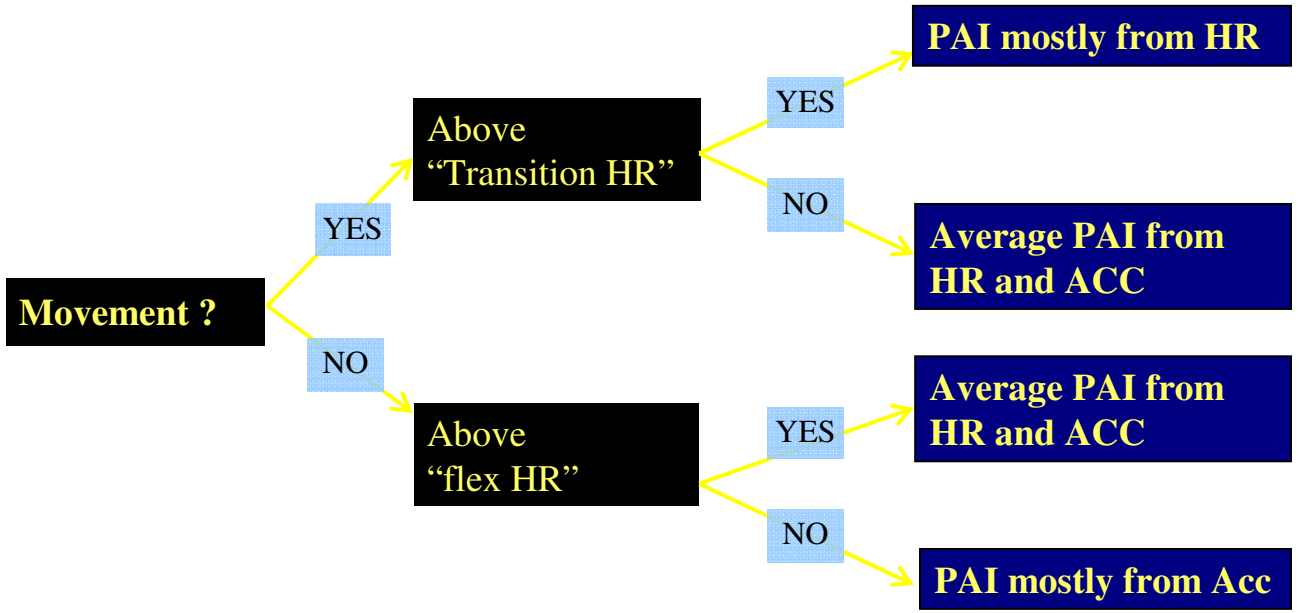


Brage et al, EJCN 2005

HR and Movement

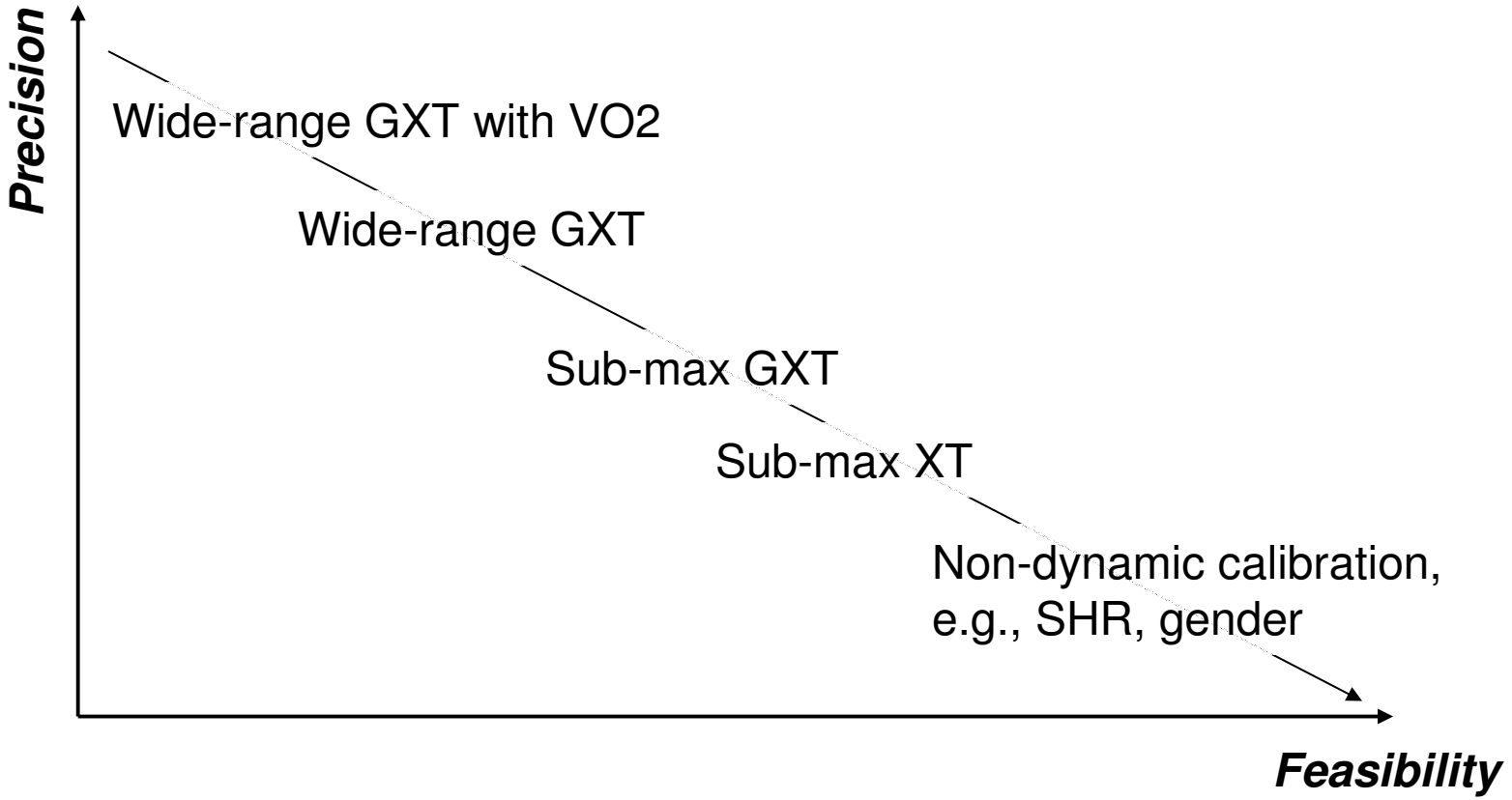


Branched equation modeling



Source: Brage et al, JAP 2004

Individual calibration



Brage et al, JAP 2007

Results from the laboratory validation in children

- The combined Actiheart model

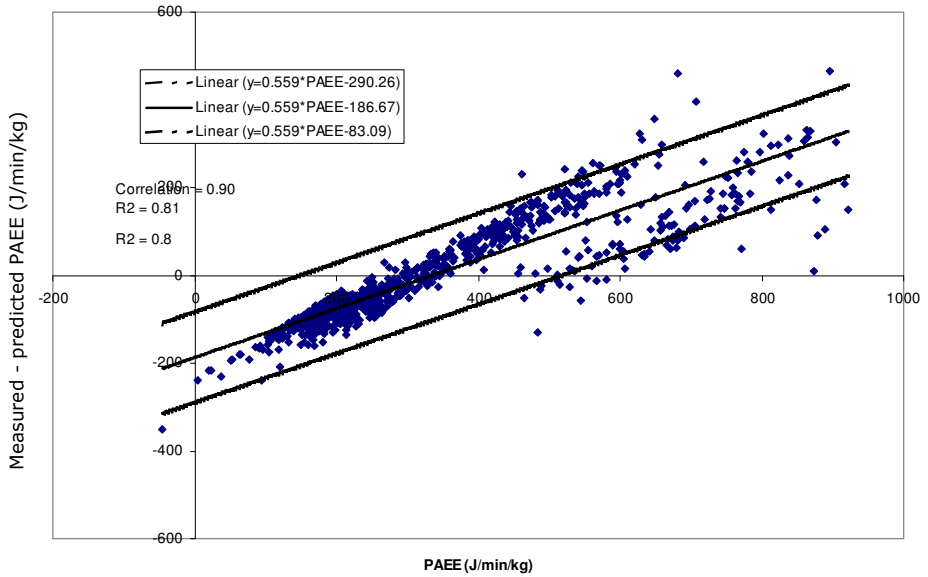
  $R^2 = 0.86$
- Heart rate model

  $R^2 = 0.84$
- Activity monitor models

  $R^2 = 0.37$ to 0.69

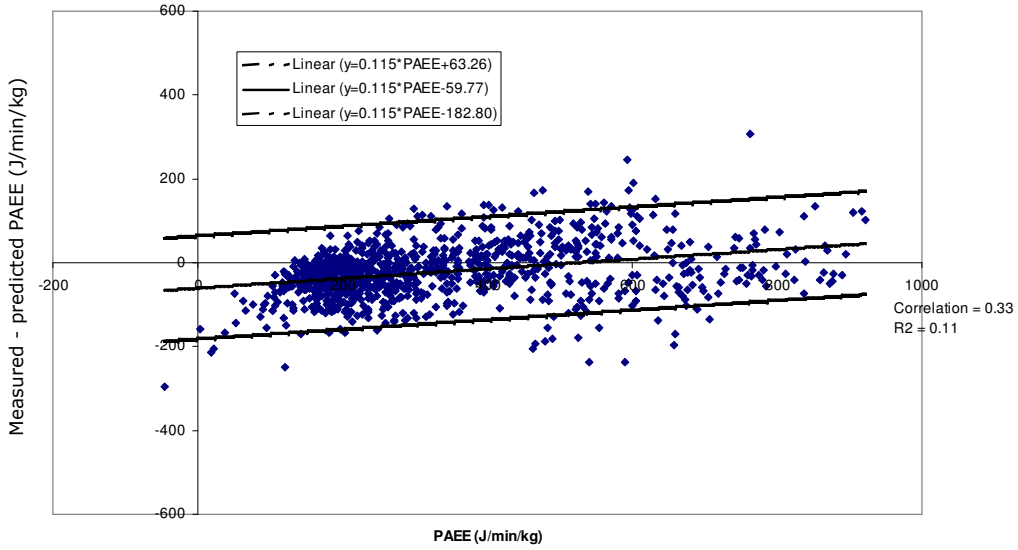
Source: Corder et al, MSSE 2005

Difference between the predicted PAEE from the hip MTI model and the criterion plotted against the criterion



Hip MTI

Difference between the predicition of PAEE using the Combined Actiheart model and the criterion plotted against the criterion



Combined Actiheart model

Source: Corder et al, MSSE 2005

- Theoretical advantages of combined HR and movement sensing

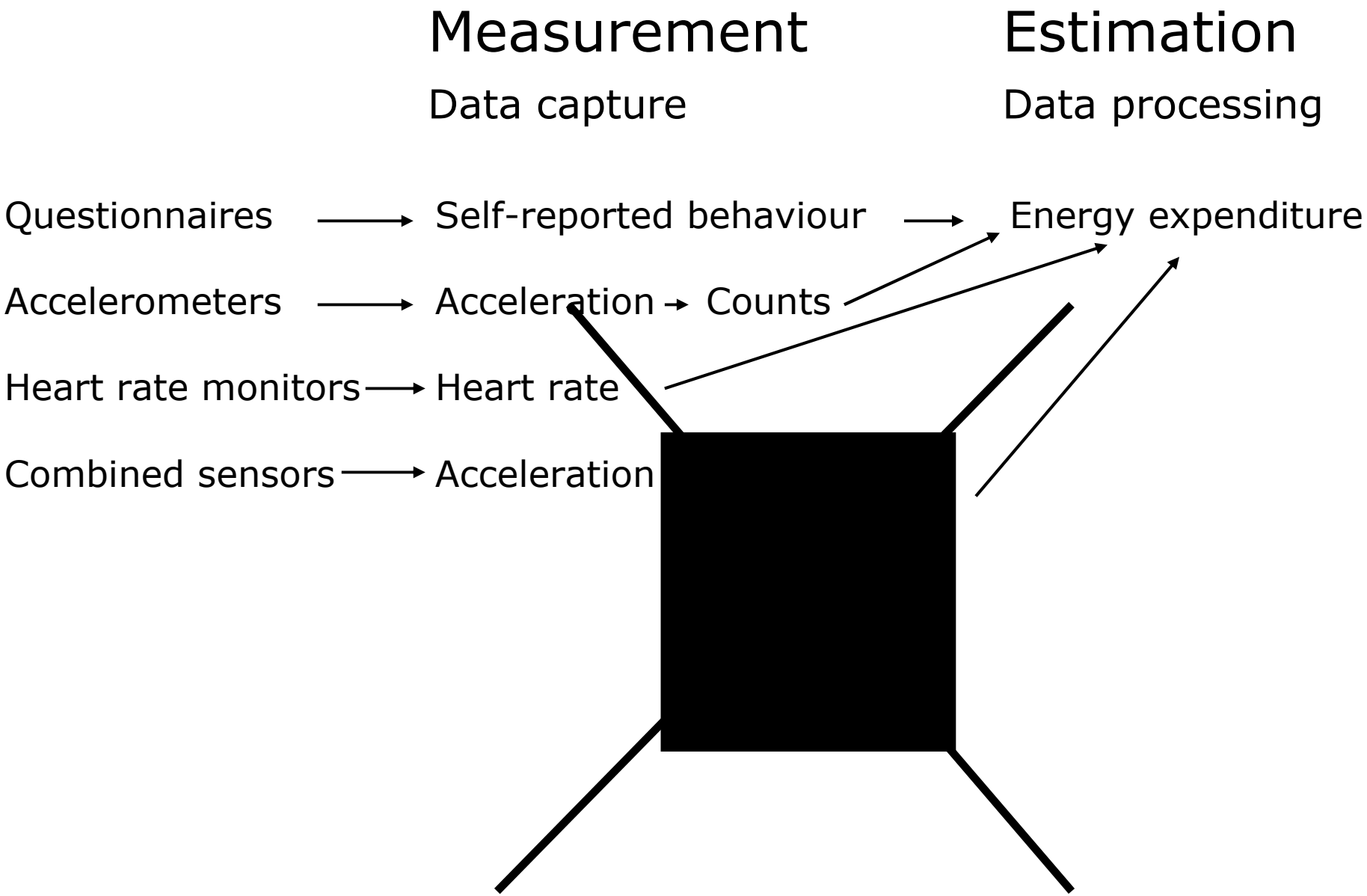
- Advances in technology have now made it feasible

- Instrument is technically valid and reliable

- Using appropriate prediction equations, can accurately predict energy expenditure

- Can be used with different degrees of individual calibration

- Method is acceptable in populations of different ages, degrees of overweight and in diverse cultural and climatic situations


Measurement
Data capture
Estimation
Data processing
Questionnaires
Self-reported behaviour
Energy expenditure
Accelerometers
Acceleration
Counts
Heart rate monitors
Heart rate
Combined sensors
Acceleration

Descriptive

- assessing prevalence differences between populations
- monitoring temporal trends within populations

Aetiological

- quantifying the effect size of an association
- specifying which dimension of physical activity is of most importance for a particular health outcome

Predictive

- stratifying populations to target interventions on inactive individuals who are “at risk”

Evaluative

- detecting physical activity response to an intervention

Conclusions

- Choose a PA assessment instrument “fit for purpose”
- This presupposes that “purpose” is predetermined
- There is no “all purpose” method
- Take care when assessing validity of a self-report measure and when describing what it is that the method measures
- “Validation” against a criterion method of the same fundamental type may reflect correlated error
- PAQs measure self-reported physical activity behaviour. Output should be described in this way and one should be cautious about computation of quantitative physiological measures.

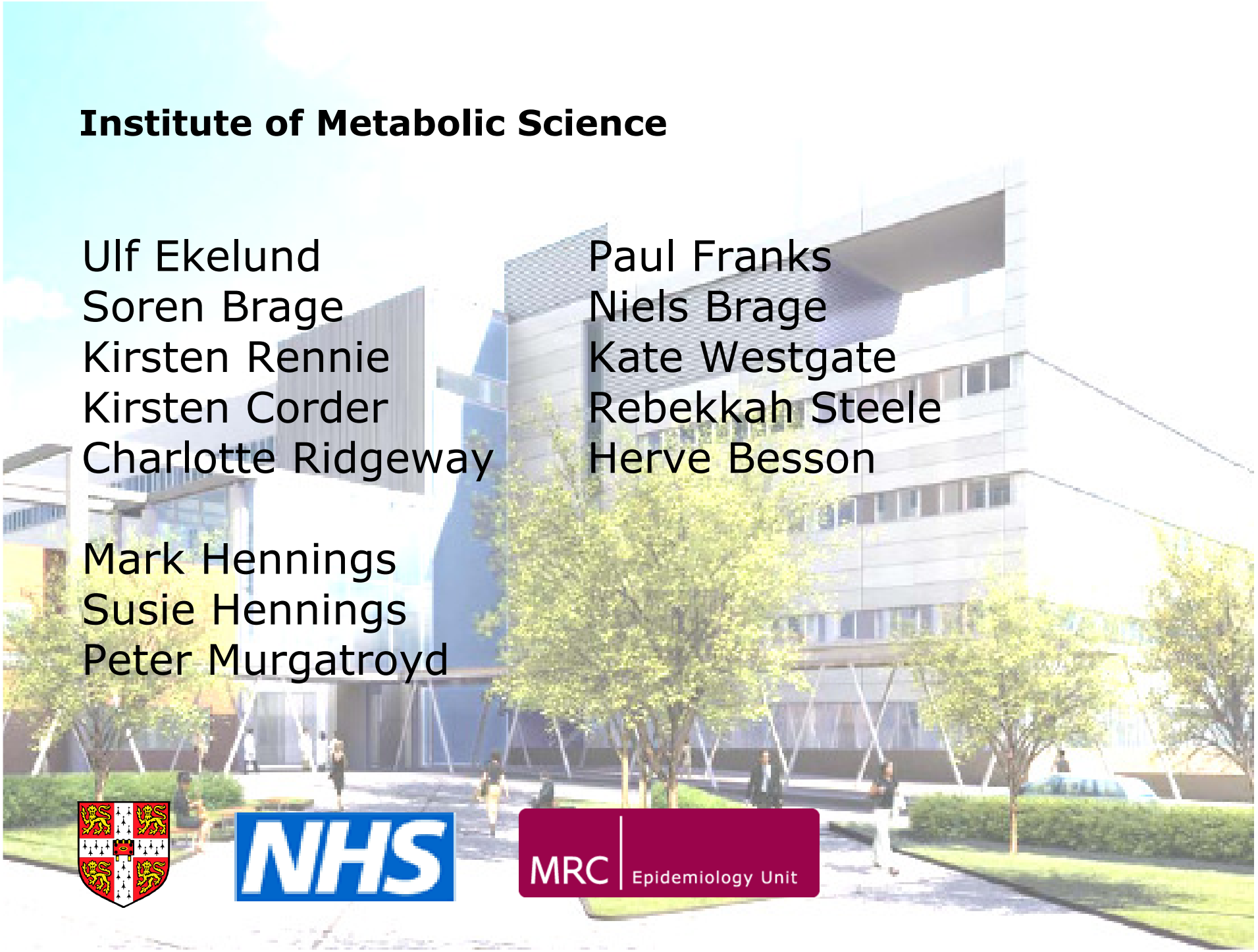
- Objective measurement of PA does not remove the need for questionnaire assessment of self-reported behaviour

- For every objective measurement device one needs technical validity studies to determine that it measures what it is supposed to measure

- For accelerometers, that should be acceleration

- A separation is required between the validation of the measurement and that of the prediction of a more distal physiological phenomenon

- There should be no black box computation



Institute of Metabolic Science

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Niels Brage
Kate Westgate
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Mark Hennings
Susie Hennings
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