UNIVERSITY OF CAMBRIDGE

MRC Epidemiology Unit

Harmonisation of physical activity data

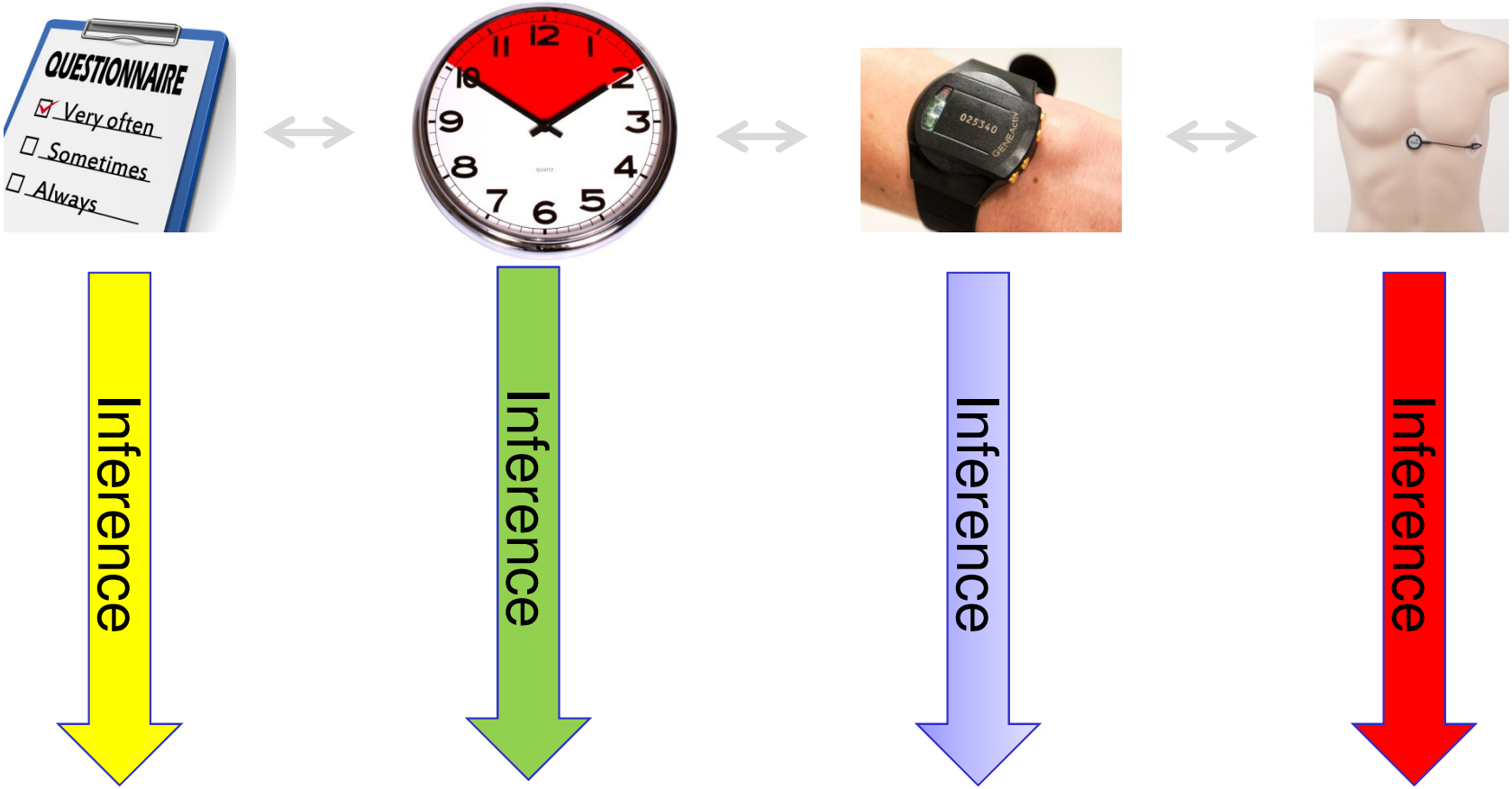
Methodological challenges and potential solutions

Søren Brage

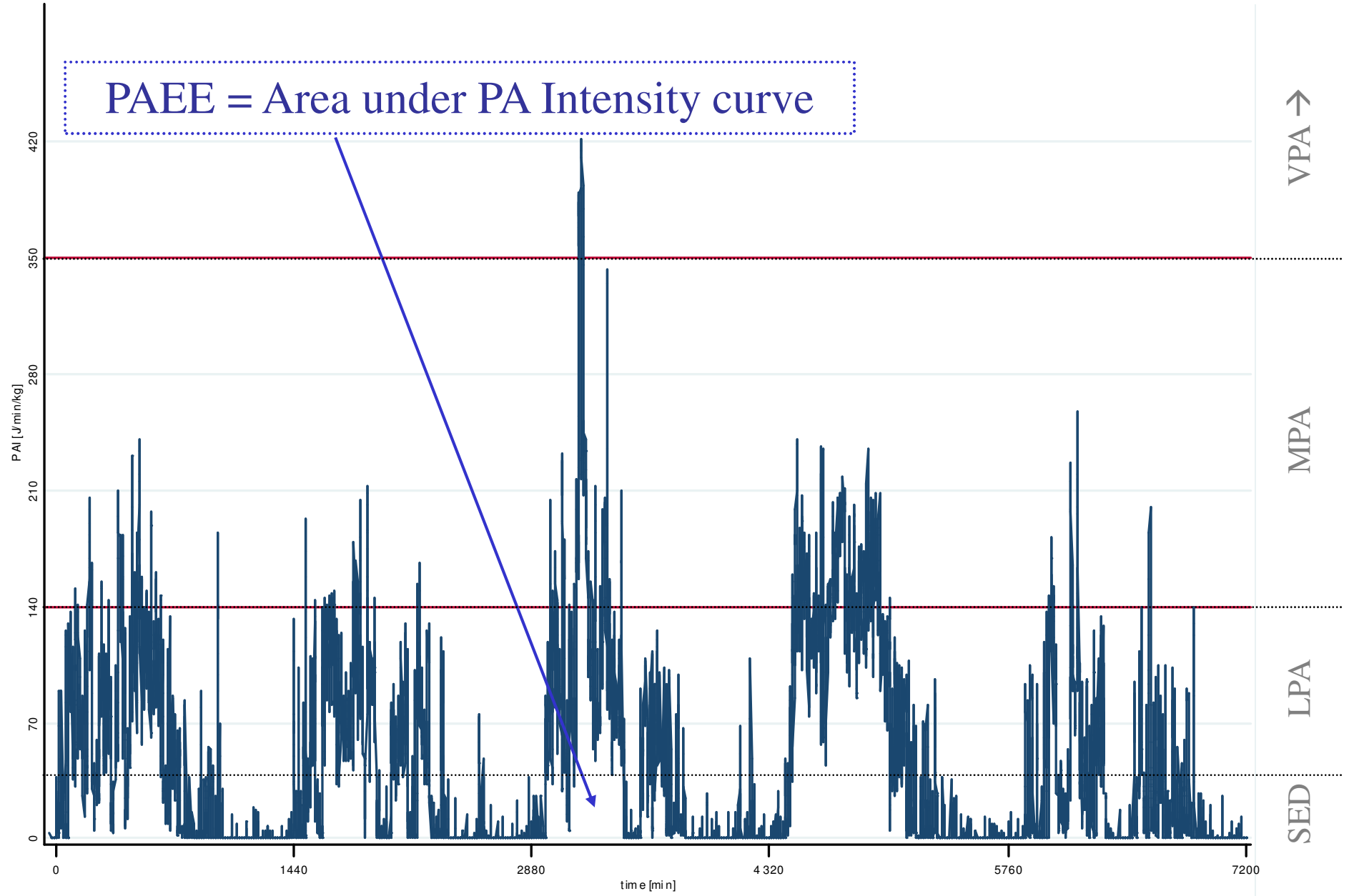
ISPAH Data Harmonisation Satelite meeting, Cambridge

18th October 2018

Different measurements, same underlying target



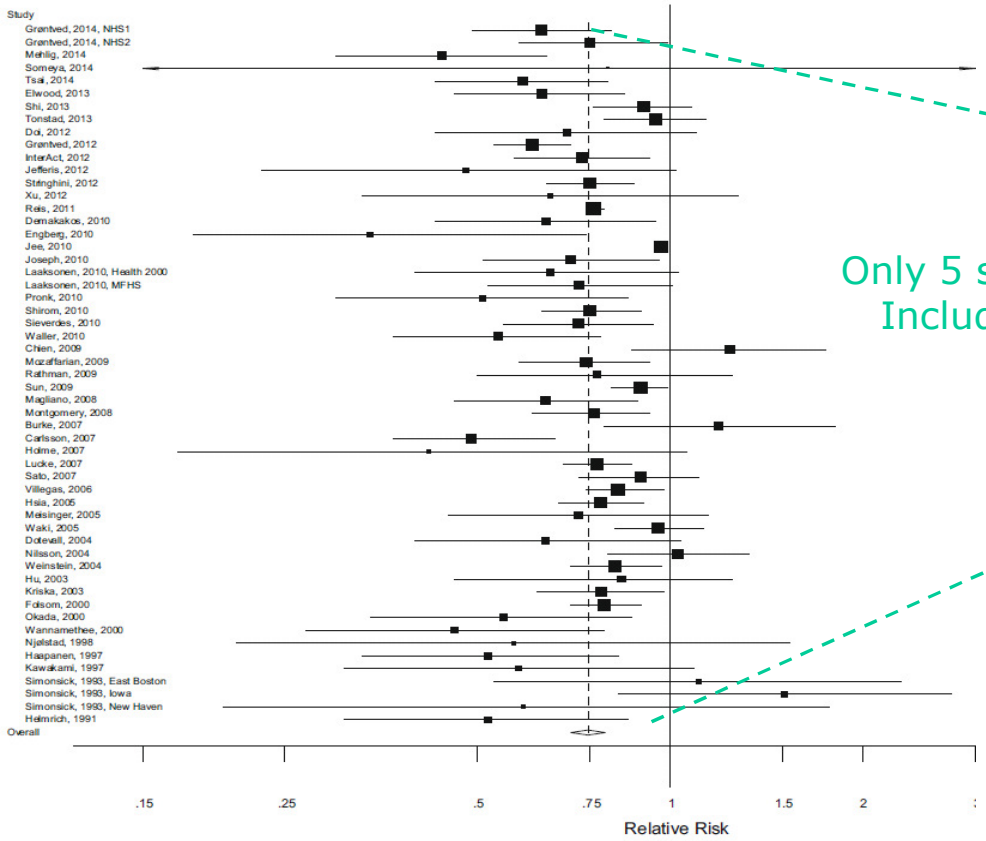
Physical Activity intensity time-series during free-living



Total vs actioned evidence base…

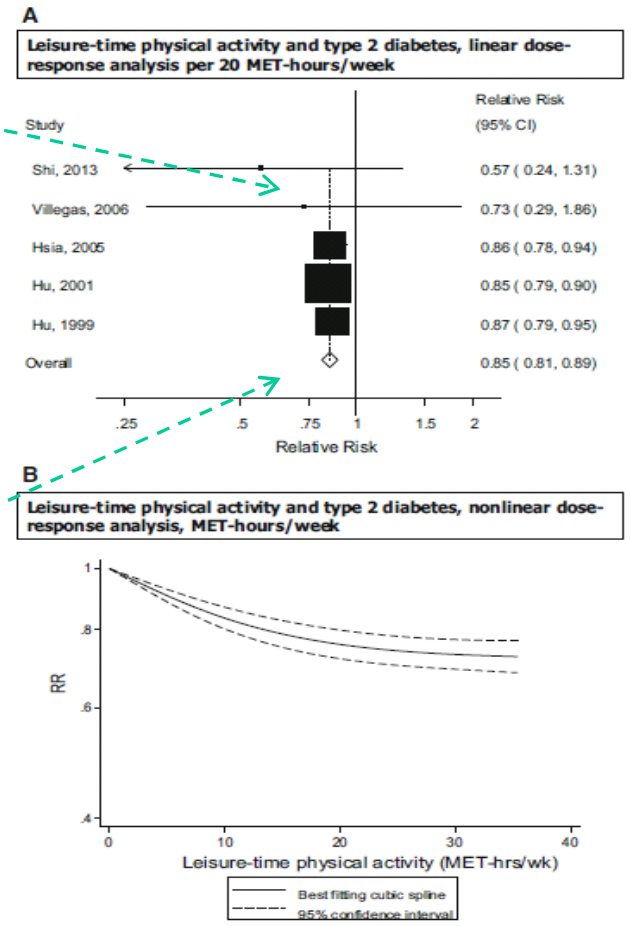
A typical meta-analysis…

Usual: LTPA (high vs low)



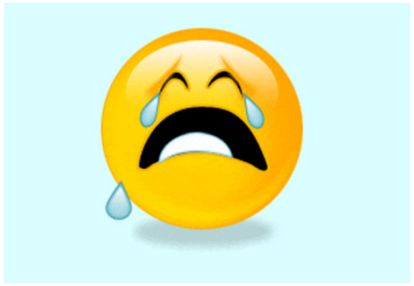
Only 5 studies Included !

Dose response : LTPA (MET-hrs/wk)



(Aune et al. 2015)

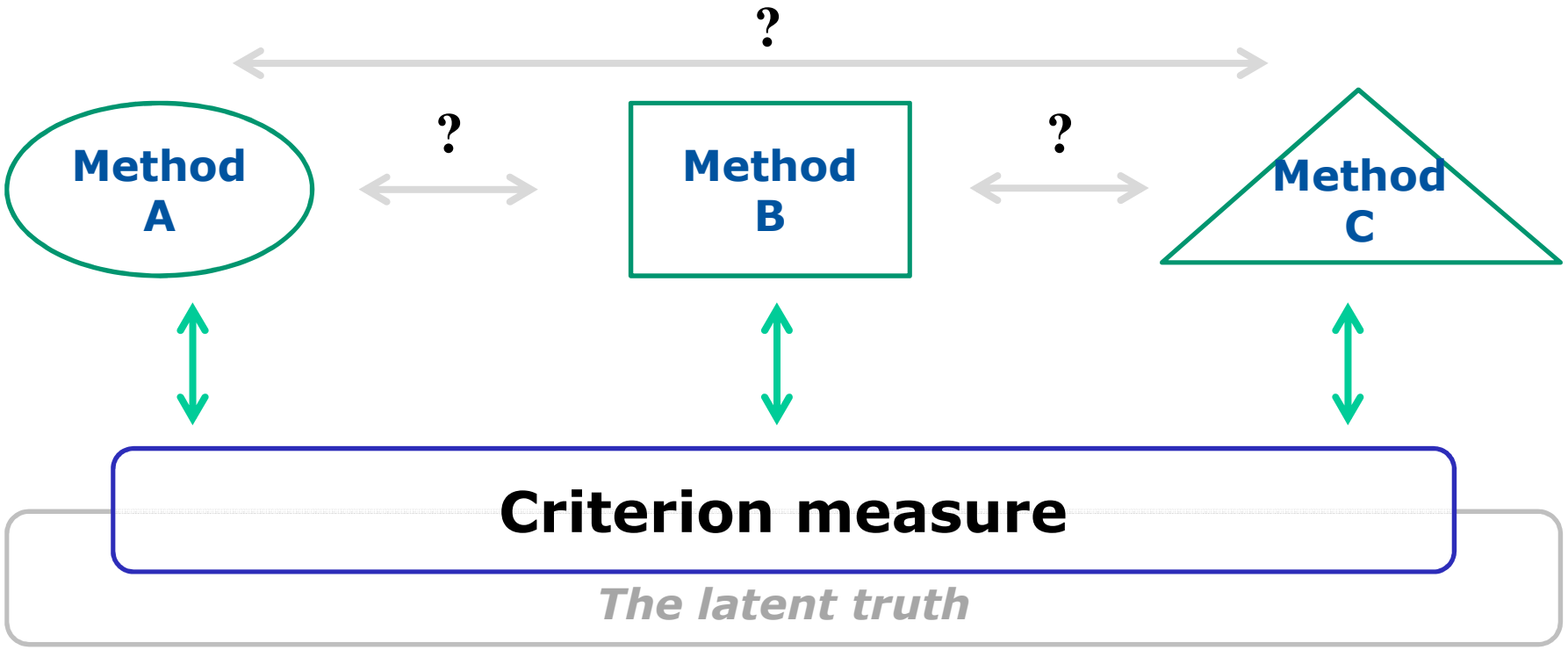
Can we **bring harmony** to the un-harmonisable ("harmomiserable")?



Some options

1. **Be bold! Make assumptions** (and test them!)
2. **Bring more data into the mix**
   - Harmonisation using validation data
   - Validation and Marginalisation
   - Harmonisation using indirect validation
   - Measurement error correction methodology

Chasing the truth…

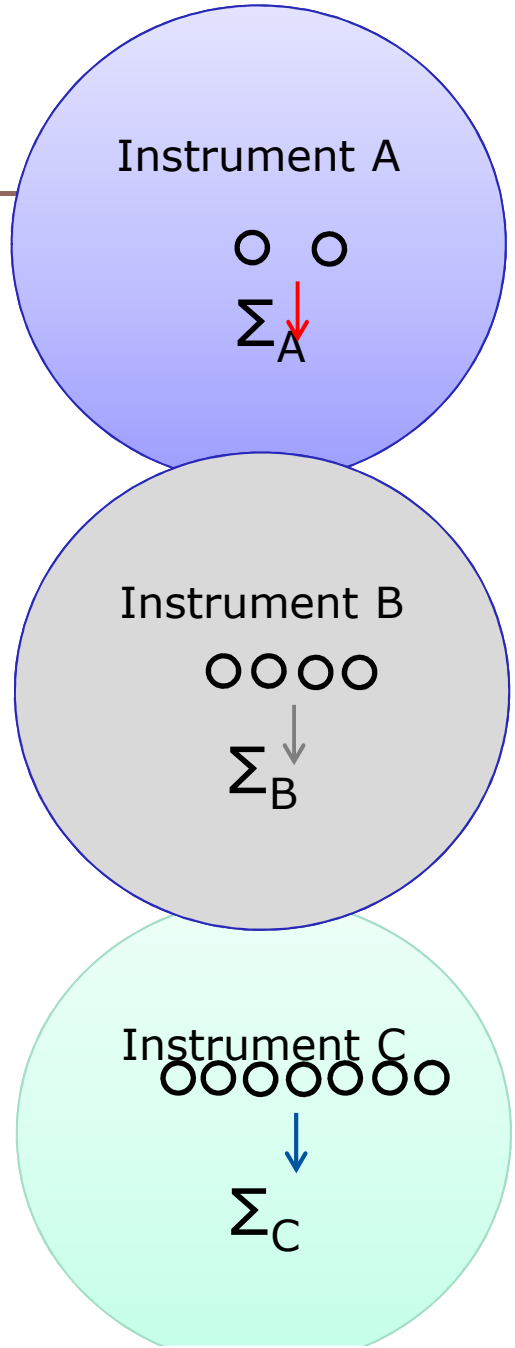


Measurements, inferences, truth…

Possible target variables

Volume
Frequency
Duration
Intensity
Energy Expenditure
Type
Domain
Meeting guideline

$transform_i$, ε_i



Harmonisation transforms

The transforms have two key characteristics:

1. **Mapping**: Method X values to target values

2. **Uncertainty** estimator of the mapping

Dose-response Meta-analysis - Motivating Example

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Dose-response Meta-analysis - Motivating Example

Exposure Harmonisation: Meta-data

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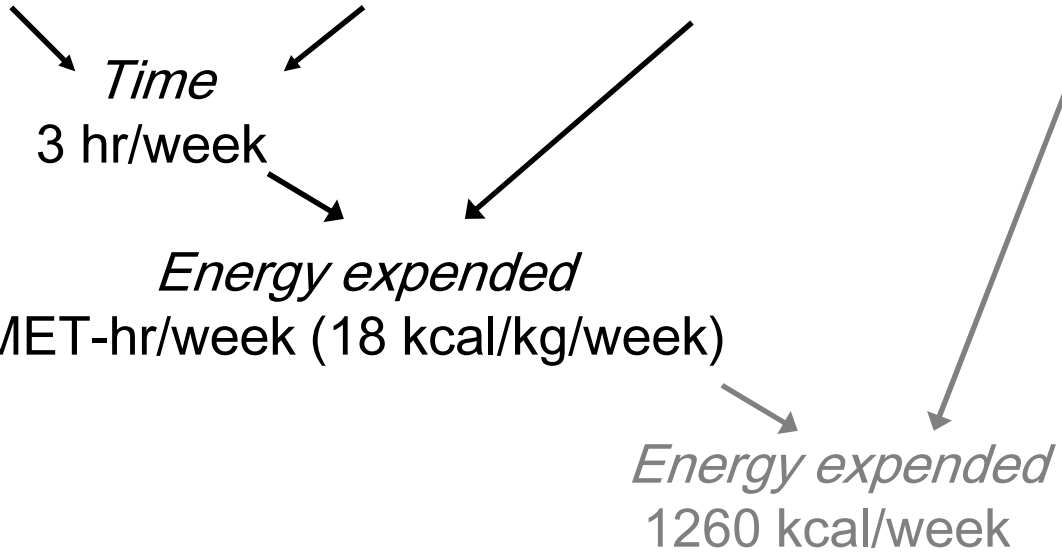
Target variable: "**LT" PAEE** (Marginal-MET.hrs/wk)

Computation of estimates of physical activity EE from questionnaires

Frequency x Duration x Intensity x Body weight

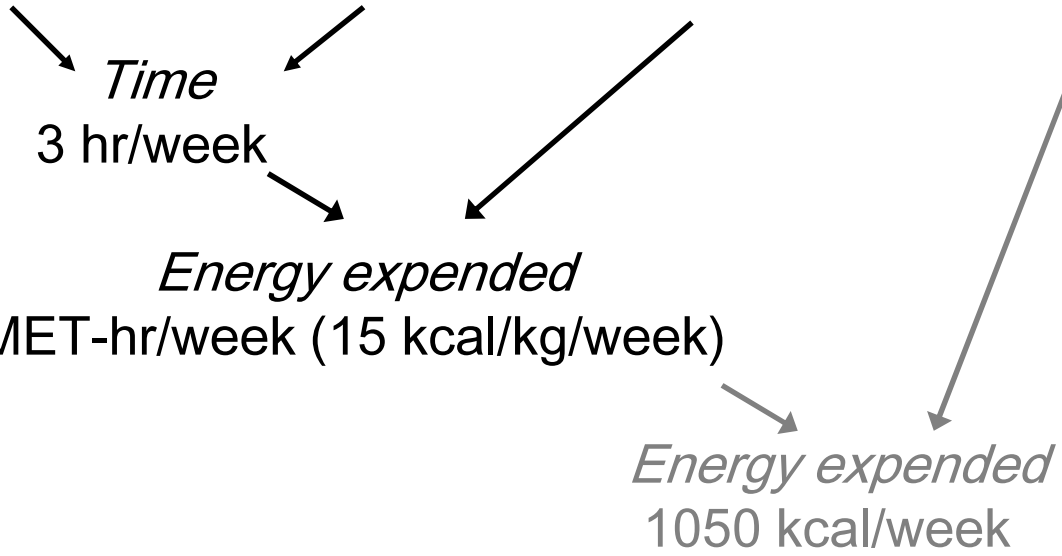
Example: 2 events/week x 1.5 hr/event x 6 METs x 70 kg



Computation of estimates of physical activity EE from questionnaires

Frequency x Duration x Intensity x Body weight

Example: 2 events/week x 1.5 hr/event x 5 MMETs x 70 kg



Can we work this out from aggregate data?

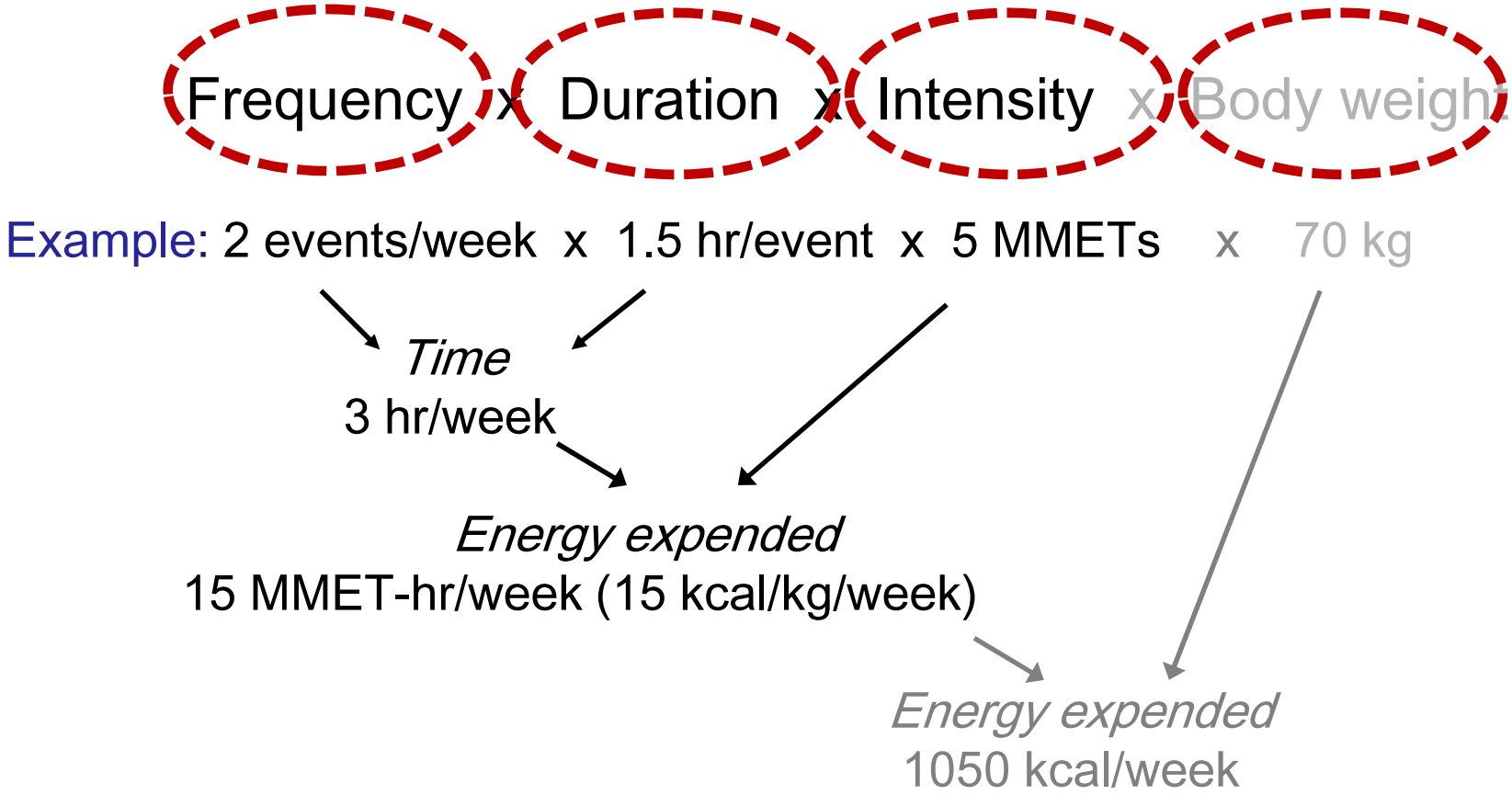
Mapping aggregate MET.hours to MMET.hours

- Mean MET.hrs by exposure group
- REE component is 1 MET per reported hour

- Is mean duration reported by exposure group?
  - **MMET.hrs = MET.hrs – 1 MET x duration (hrs)**

- Mean duration not available?
  - Make assumption about duration
  - Use relationship between MMET.hrs and MET.hrs in other selfreport data where it both are available
    - e.g. MMET.hrs = b_1* MET.hrs + b_2 * MET.hrs^2

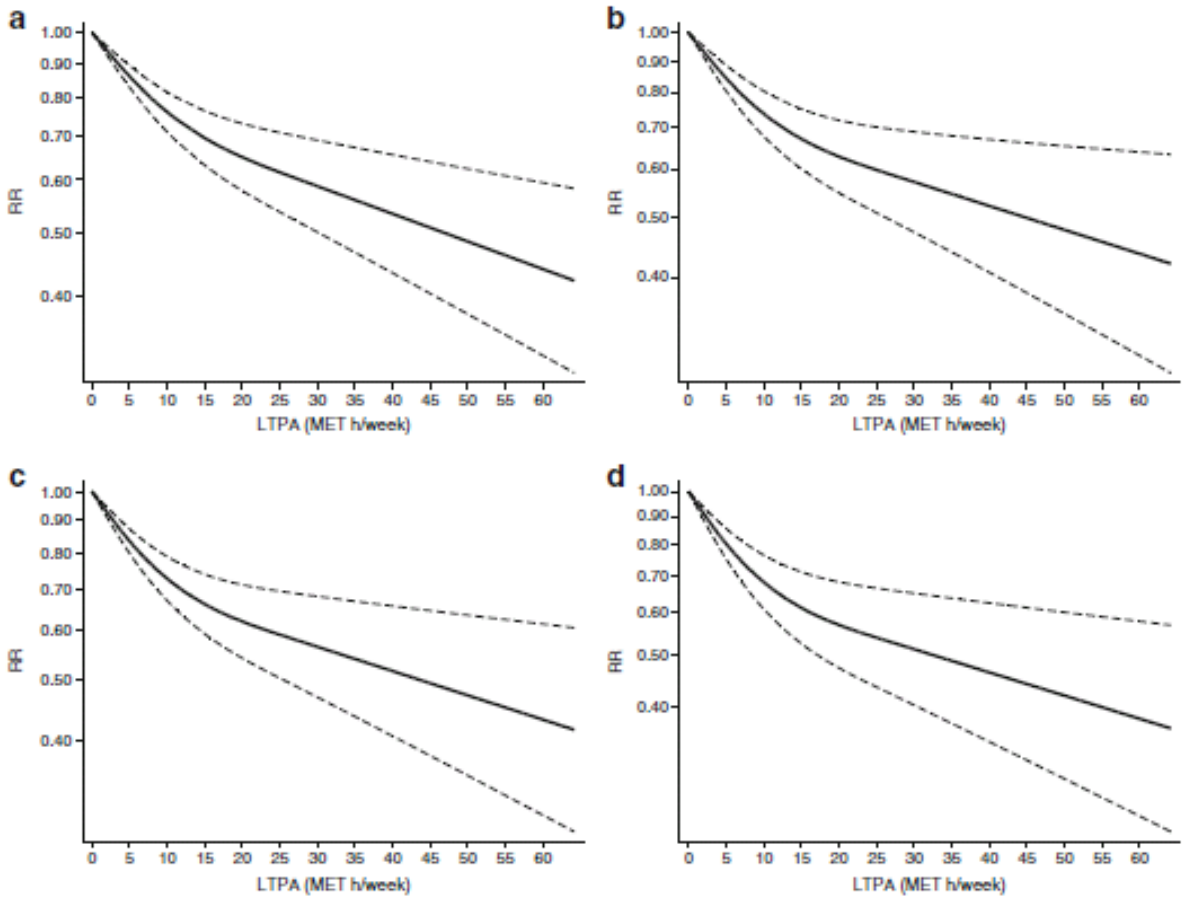
Any of these not measured (reported)?



Testing impact of assumptions

Intensity assumption (n=15/27)

3.5 MET vs 4.5 MET



Duration assumption → ***45 min*** ***vs*** ***30 min*** *per session (n=9/27)*

Smith et al, 2016

Categorical data

MRC | Epidemiology Unit

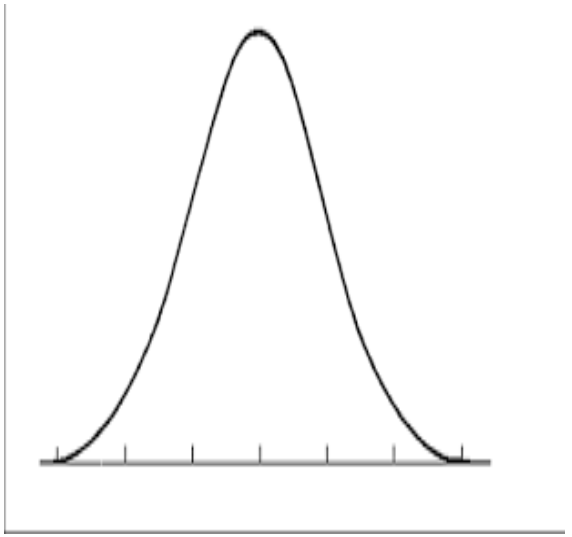
Work activity	Leisure time physical activity (Duration of sport and cycling in hrs/wk)			
	No	≤3.5	>3.5 and ≤7.0	> 7.0
Sedentary	Inactive	Moderately inactive	Moderately active	Active
Standing	Moderately inactive	Moderately active	Active	Active
Manual	Moderately active	Active	Active	Active
Heavy manual	Active	Active	Active	Active

(InterAct Consortium, Eur J Epid, 2012)

How do we map this exposure to PAEE?

Work activity	Leisure time physical activity (Duration of sport and cycling in hrs/wk)			
	No	≤3.5	>3.5 and ≤7.0	> 7.0
Sedentary	Inactive	Moderately inactive	Moderately active	Active
Standing	Moderately inactive	Moderately active	Active	Active
Manual	Moderately active	Active	Active	Active
Heavy manual	Active	Active	Active	Active

?

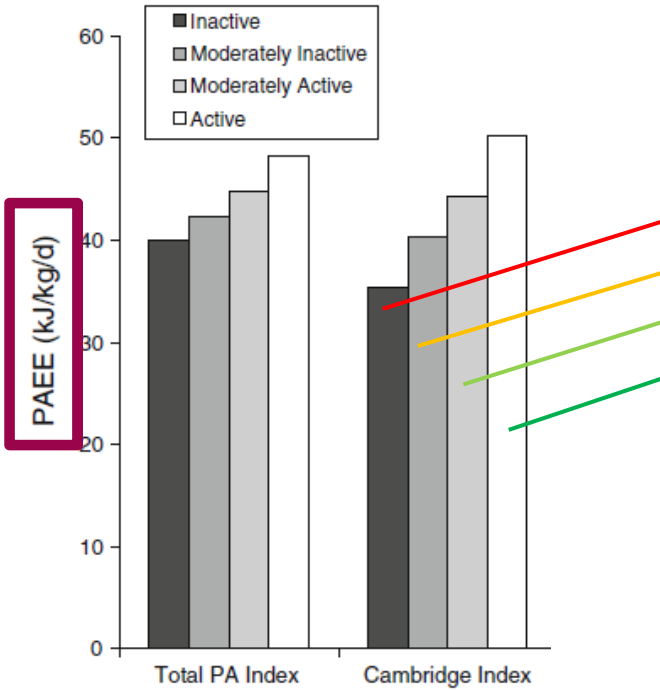


PAEE

- 2-level index
- 4-level index
- 16-level index

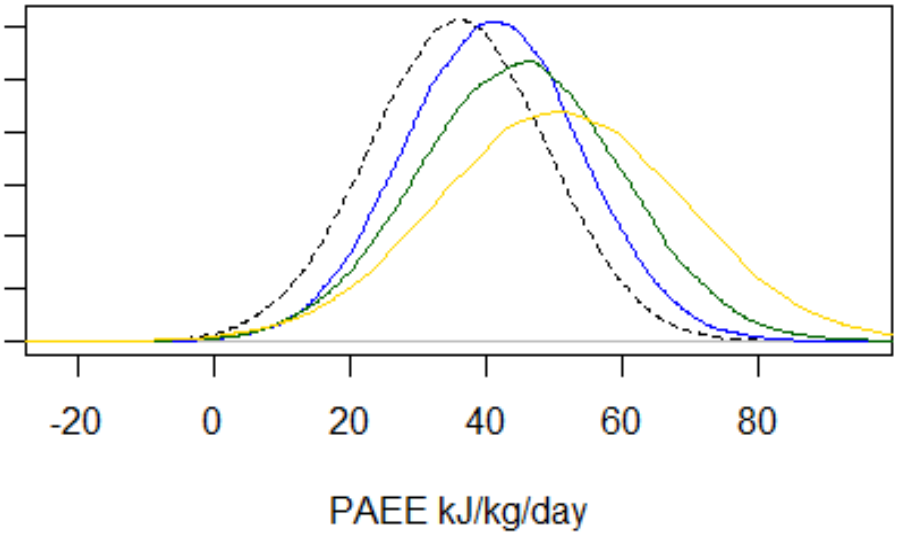
Validation study: Obj assessment of PA

- Combined PA Index (Occupational & Leisure-time PA)



OPA	LTPA (Duration of cycling and sport hrs/wk) None	≤ 3.5	>3.5 and ≤ 7.0	> 7.0
Sedentary	Inactive	Moderately inactive	Moderately active	Active
Standing	Moderately inactive	Moderately active	Active	Active
Physical	Moderately active	Active	Active	Active
Heavy Manual	Active	Active	Active	Active

- Validation study
  - n=1941 sampled from EPIC-Europe population
  - EPIC PAQ
  - Individually calibrated ACC + HR
  - (Interact Consortium, 2012)



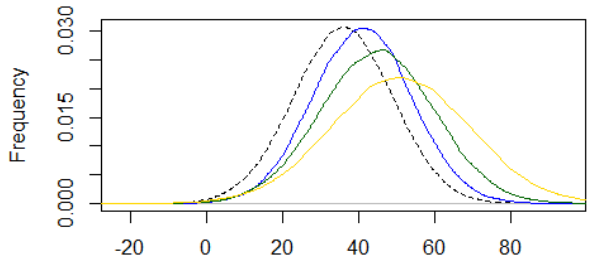
Validation results

	Men (*n*=591)			Women (*n*=1350)		
	n	Mean	SD	*n*	Mean	SD
Inactive	*114*	35.6	13.7	*178*	36.5	12.8
Mod. inactive	*152*	43.7	15.2	*492*	39.8	12.7
Mod. active	*164*	49.0	17.9	*374*	43.6	13.9
Active	*161*	56.2	18.4	*306*	48.2	16.6

Analysis example:

PAEE association with diabetes

- Simulate **3 different self-report methods**:
  - **A**. **Binary** inactive/active → → → **PAEE** from validation
  - **B**. **4-level** PA index → → → **PAEE** from validation
  - **C**. **16-level** PA index → → → **PAEE** from validation
- Cox regression to model harmonised PAEE-T2DM association for each method in each InterAct cohort
- Meta-analysis across cohorts



Exposure mapping

Work activity	Leisure time physical activity (Duration of sport and cycling in hrs/wk)			
	No	≤3.5	>3.5 and ≤7.0	> 7.0
Sedentary	Inactive	Moderately inactive	Moderately active	Active
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Manual	Moderately active	Active	Active	Active
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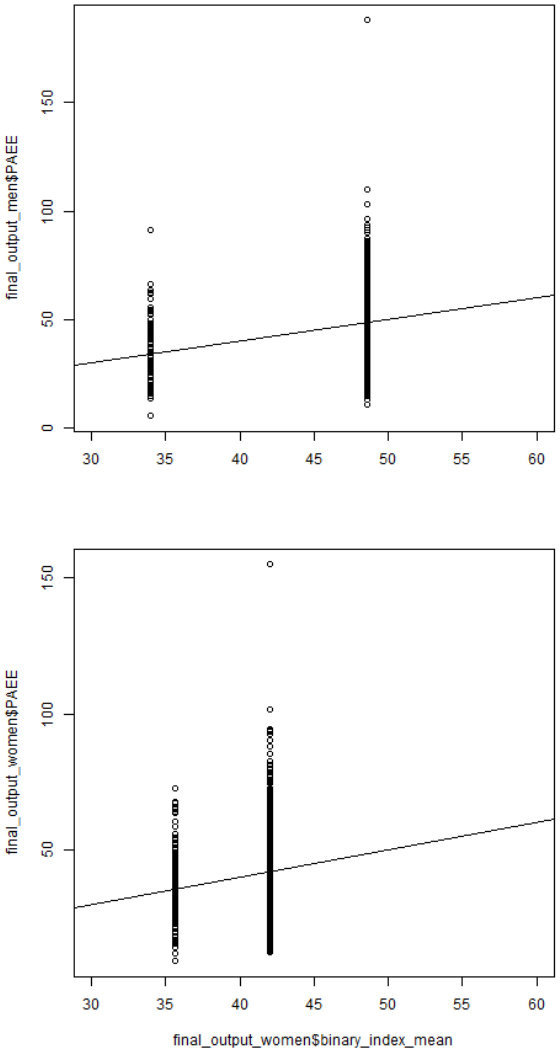
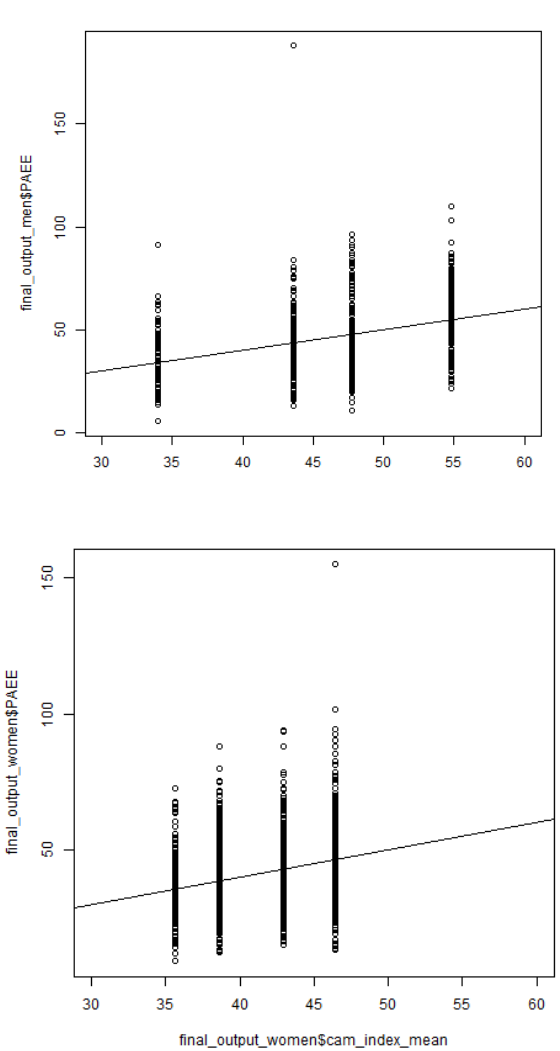
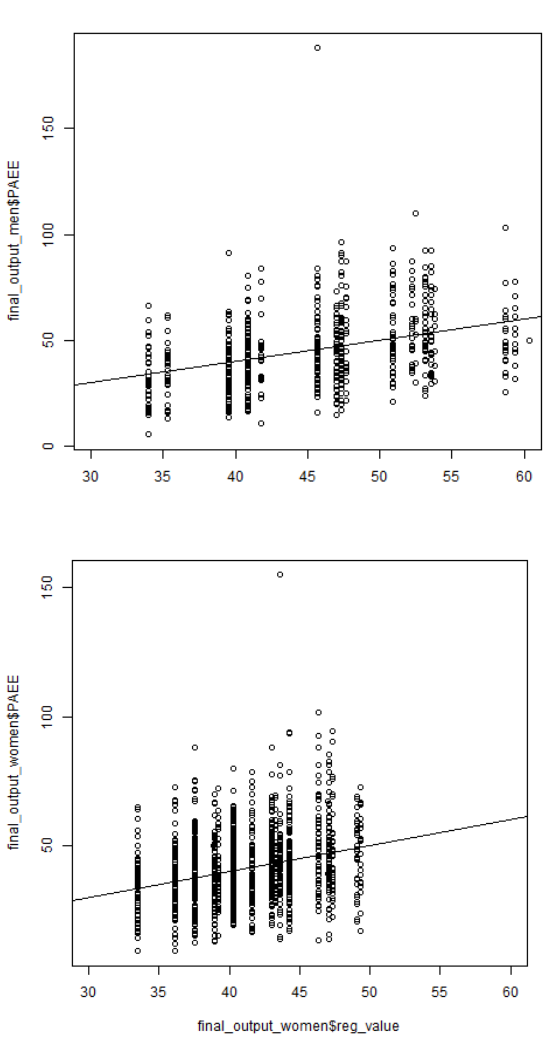
A. Binary



B. 4-level index

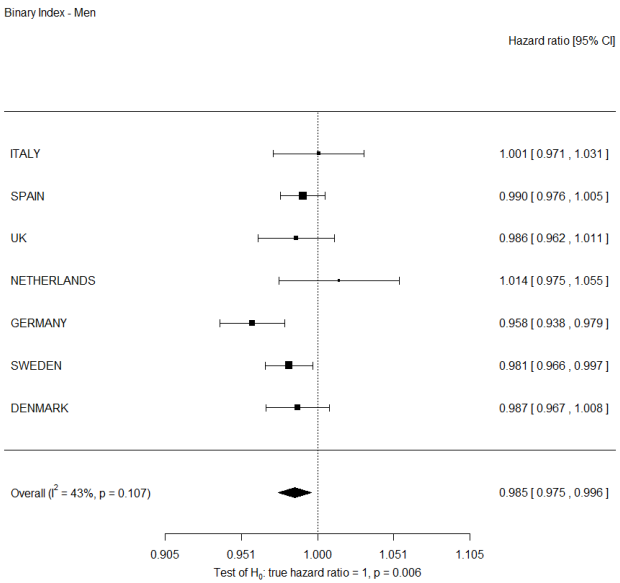


C. 16-level index

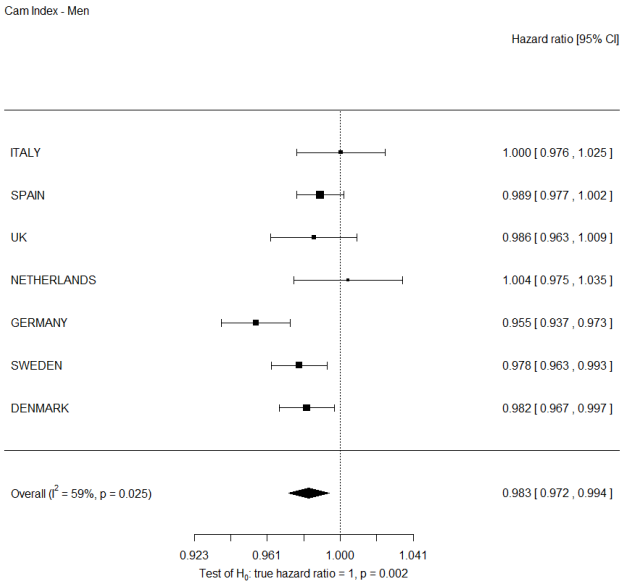


Association between PAEE and T2DM (men)

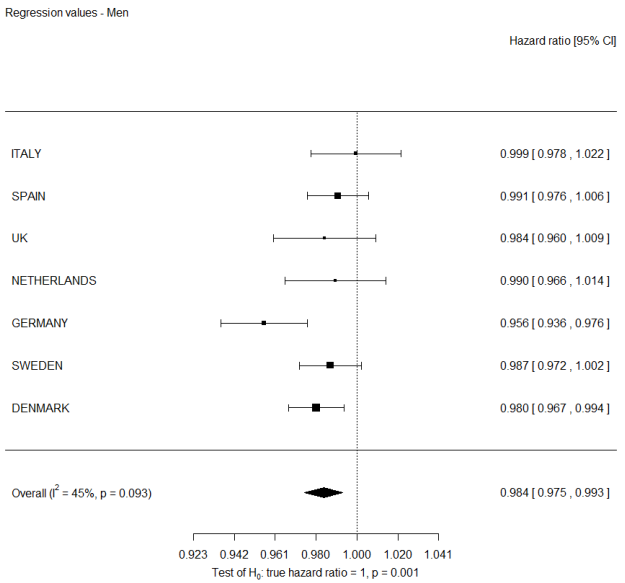
A. Binary



B. 4-level index



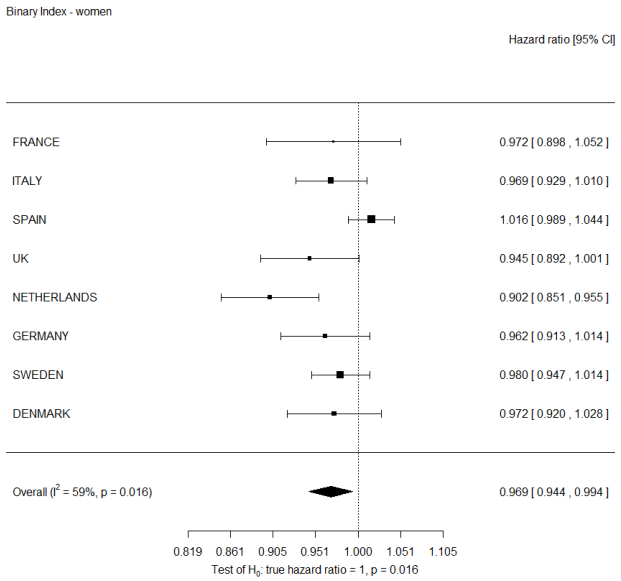
C. 16-level index



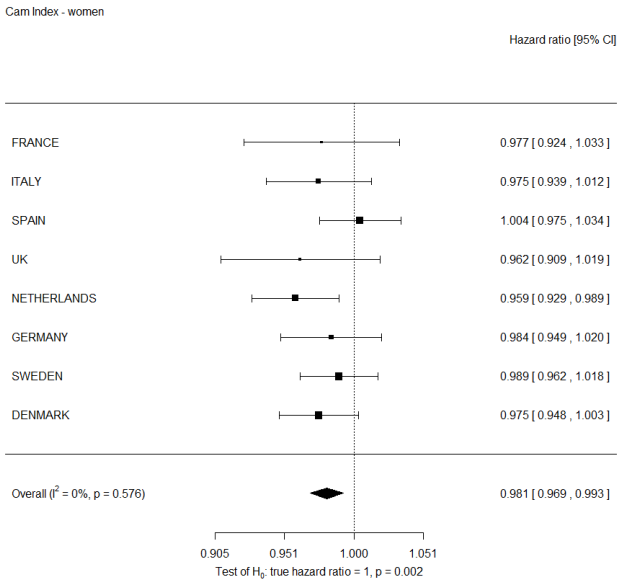
Method	A	B	C
HR per 1kj	0.985	0.983	0.984
HR per 10kj	**0.860**	**0.842**	**0.851**
P-value	*0.006*	*0.002*	*0.001*

Association between PAEE and T2DM (women)

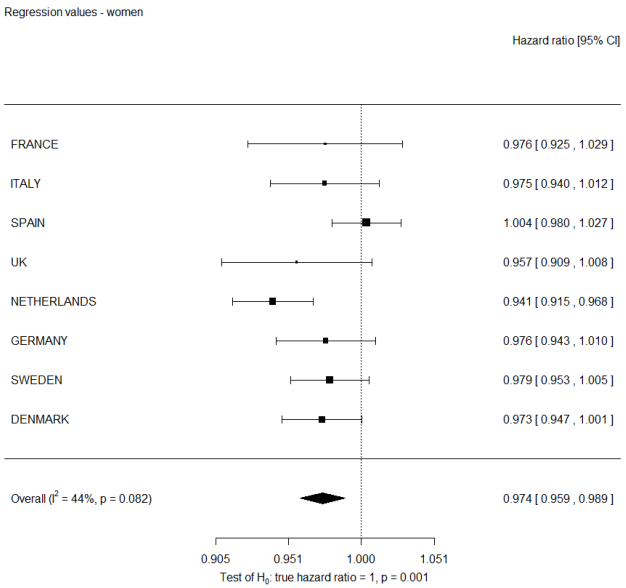
A. Binary



B. 4-level index

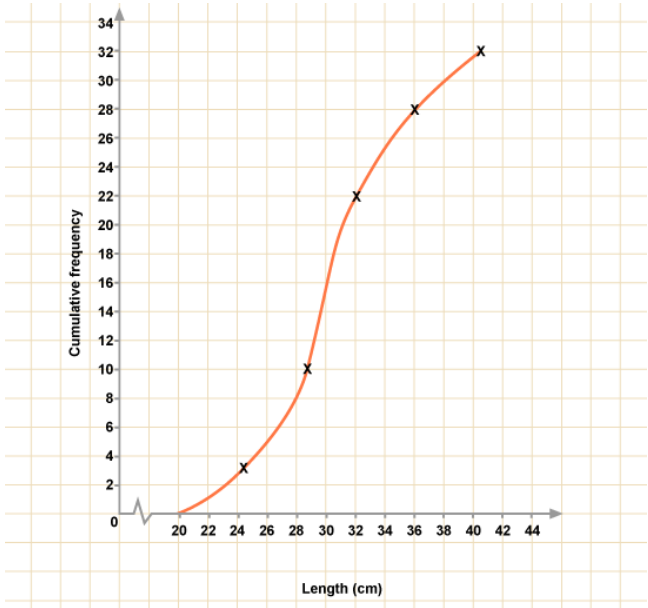


C. 16-level index



Method	**A**	**B**	**C**
HR per 1kj	0.969	0.981	0.974
HR per 10kj	**0.730**	**0.825**	**0.768**
P-value	*0.016*	*0.002*	*0.001*

Marginalisation, validation, interpolation



Dose-response Meta-analysis - Motivating Example

Exposure Harmonisation: Meta-data

	A	B	C	D	E	F	G	H	I	J	K
1	STUDY	YEAR	location	PA DOMAIN	PA MEASUREMENT TOOL	PA Units	EFFECT TYPE	PA CATs	EFFECT SIZE	LCI	UCI
3	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	<45 METs/wk	1		
4	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	45–69 METs/wk	0.97	0.91	1.04
5	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	69–96 METs/wk	0.94	0.89	1.02
6	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	96–134 METs/wk	0.9	0.83	0.97
7	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	134 METs/wk	0.87	0.8	0.95
9	Danish Nurse Cohort Study	2015	Denmark	LTPA	questionnaire (Saltin and Grimby)	category	HR	Sedentary	1.62	1.15	2.27
10	Danish Nurse Cohort Study	2015	Denmark	LTPA	questionnaire (Saltin and Grimby)	category	HR	Moderate	1.1	0.91	1.33
11	Danish N							Vigorous	1		
13	Blac							Low	1		
14	Bla								1.01	0.64	1.58
15	Bla								0.95	0.4	2.27
17	Bla								1		
18	Bla								0.91	0.55	1.52
19	Bla								0.58	0.22	1.57
21	Bla								1		
22	Bla								0.98	0.87	1.09
23	Bla								0.85	0.74	0.97
25									1		
26									1	0.942	1.062
27									0.998	0.939	1.061
28									0.993	0.934	1.056
29									0.987	0.926	1.051
31									1		
32									0.983	0.938	1.029
33									0.944	0.899	0.99
34						MET quintiles	HR	96–134 METs/wk	0.932	0.886	0.98
35	EPIC-Europe	2016	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	134 METs/wk	0.911	0.863	0.961
37	Sax Institute's 45 and Up study	2016	Australia	MV-LTPA	questionnaire (http://www.45andUp.org.au)	mins/wk MVPA	HR	0 - 10 min/wk of MVPA	1		
38	Sax Institute's 45 and Up study	2016	Australia	MV-LTPA	questionnaire (http://www.45andUp.org.au)	mins/wk MVPA	HR	10 - 149 min/wk of MVPA	0.66	0.61	0.71
39	Sax Institute's 45 and Up study	2016	Australia	MV-LTPA	questionnaire (http://www.45andUp.org.au)	mins/wk MVPA	HR	150 - 299 min/wk of MVPA	0.53	0.48	0.57
40	Sax Institute's 45 and Up study	2016	Australia	MV-LTPA	questionnaire (http://www.45andUp.org.au)	mins/wk MVPA	HR	≥ 300 min/wk of MVPA	0.46	0.43	0.49
42	Sax Institute's 45 and Up study	2016	Australia	MV-LTPA	questionnaire (http://www.45andUp.org.au)	category	HR	0% of MVPA from VPA	1		
43	Sax Institute's 45 and Up study	2016	Australia	MV-LTPA	questionnaire (http://www.45andUp.org.au)	category	HR	>0% to <30% of MVPA from VPA	0.89	0.81	0.98
44	Sax Institute's 45 and Up study	2016	Australia	MV-LTPA	questionnaire (http://www.45andUp.org.au)	category	HR	≥30% of MVPA from VPA	0.86	0.79	0.94
46	EPIC - Italy	2016	Italy	LTPA	EPIC lifestyle questionnaire	MET-hr/wk	HR	<73.9	1		

Exposure Calibration - using Objective Validation Study

Eur J Epidemiol (2012) 27:15–25
DOI 10.1007/s10654-011-9625-y

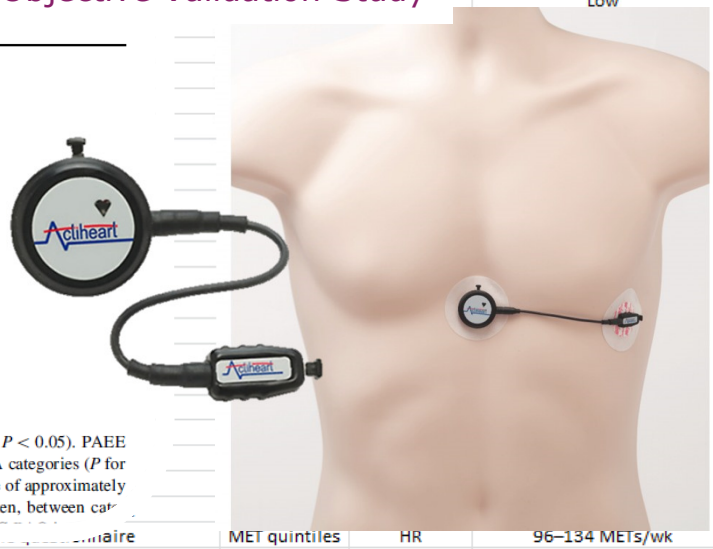
METHODS

Validity of a short questionnaire to assess physical activity in 10 European countries

The InterAct Consortium

Received: 16 August 2011 / Accepted: 7 October 2011 / Published online: 17 November 2011

Abstract To accurately examine associations of physical activity (PA) with disease outcomes, a valid method of assessing free-living activity is required. We examined the validity of a brief PA questionnaire (PAQ) used in ... indices ($I^2 > 48\%$, $P < 0.05$, $I^2 > 47\%$, $P < 0.05$). PAEE increased linearly across self-reported PA categories (P for trend <0.001), with an average difference of approximately 460 kJ/d for men and 365 kJ/d for women, between ca...



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Dose-response Meta-analysis - Motivating Example

Exposure Calibration: using Objective Validation Study

	A	B	C	D	E	F	G	H	I	J	K
1	STUDY	YEAR	location	PA DOMAIN	PA MEASUREMENT TOOL	PA Units	EFFECT TYPE	PA CATs	EFFECT SIZE	LCI	UCI
2											
3	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	<45 METs/wk	1		
4	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	45–69 METs/wk	0.97	0.91	1.04
5	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	69–96 METs/wk	0.94	0.89	1.02
6	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	96–134 METs/wk	0.9	0.83	0.97
7	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	134 METs/wk	0.87	0.8	0.95

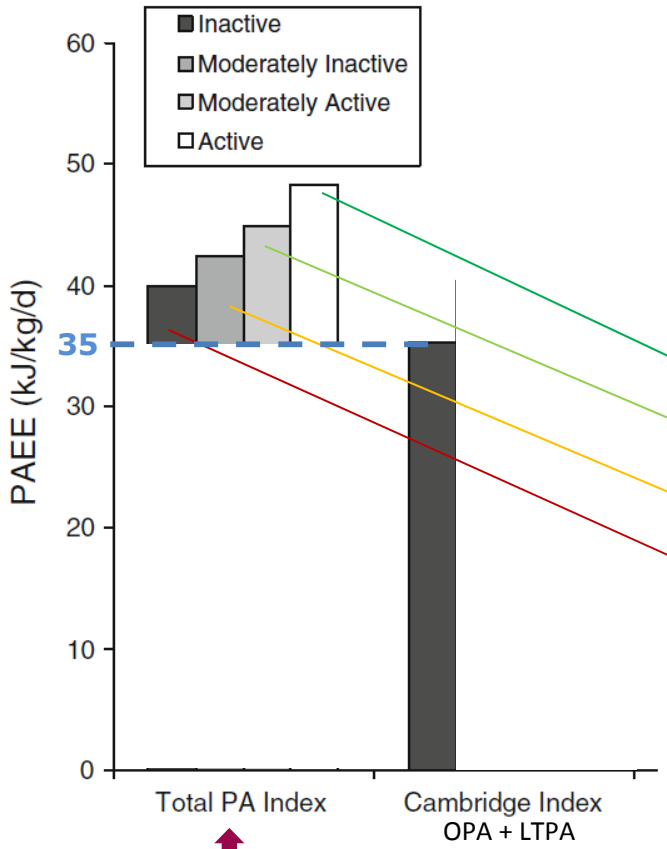

Fig. 3 Mean PAEE (kJ/kg/day) from the combi ment sensor stratified by each physical activi

Target variable : Marginal METs for LTPA

- PAEE above resting EE
- Cambridge index = OPA + LTPA
- LTPA MMETs = Total PA index – Cam. index (level 1)

1) Active = 48 – 35 = 13
2) Mod Active = 45 – 35 = 10
3) Mod Inactive = 42.5 – 35 = 7.5
4) Inactive = 40 – 35 = 5 *kJ/kg/day*

1 kJ/kg/day to *1 MMET.hrs/wk*

PAEE (MMET.hrs/week) = PAEE (kJ/d/kg) x 7 days/wk ÷ (3.5 mlO_2/kg/min/MET x 0.02035 kJ/mlO_2 x 60 min/hr)

Dose-response Meta-analysis - Motivating Example

Exposure Calibration: using Objective Validation Study

	A	B	C	D	E	F	G	H	I	J	K
1	STUDY	YEAR	location	PA DOMAIN	PA MEASUREMENT TOOL	PA Units	EFFECT TYPE	PA CATs	EFFECT SIZE	LCI	UCI
2											
3	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	<45 METs/wk	1		
4	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	45–69 METs/wk	0.97	0.91	1.04
5	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	69–96 METs/wk	0.94	0.89	1.02
6	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	96–134 METs/wk	0.9	0.83	0.97
7	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	134 METs/wk	0.87	0.8	0.95

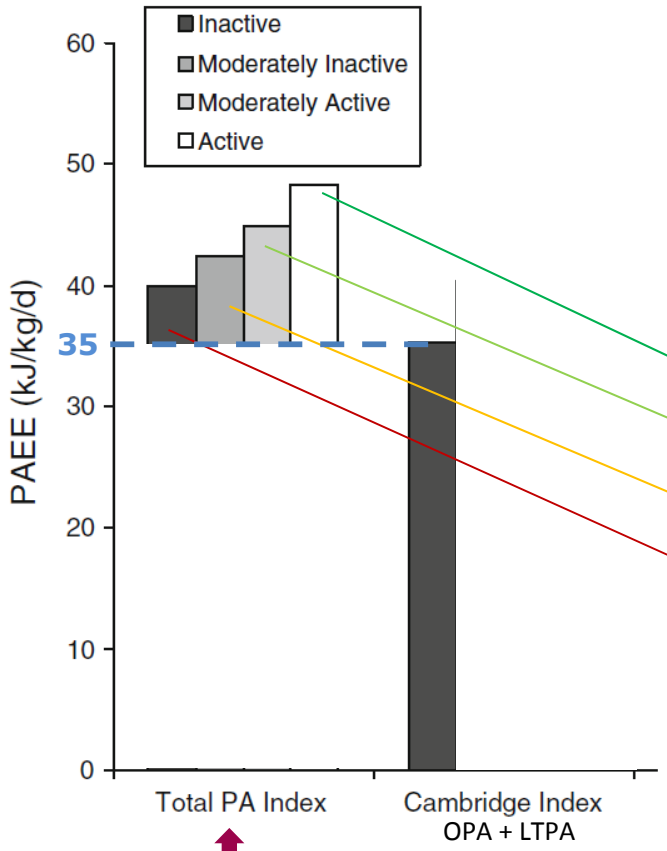

Fig. 3 Mean PAEE (kJ/kg/day) from the combi ment sensor stratified by each physical activi

Target variable : Marginal METs for LTPA

- PAEE above resting EE
- Cambridge index = OPA + LTPA
- LTPA MMETs = Total PA index – Cam. index (level 1)

1)	Active	= 48	– 35 = 13	= 21.3	
2)	Mod Active	= 45	– 35 = 10	= 16.4	
3)	Mod Inactive	= 42.5	– 35 = 7.5	= 12.3	
4)	Inactive	= 40	– 35 = 5	= 8.2	MMET.hr/wk

1 kJ/kg/day to *1 **M**-MET.hrs/wk*

PAEE (MMET.hrs/week) = PAEE (kJ/d/kg) x 7 days/wk ÷ (3.5 mlO_2/kg/min/MET x 0.02035 kJ/mlO_2 x 60 min/hr)

Dose-response Meta-analysis - **Motivating Example**

Exposure Calibration: Interpolation

	A	B	C	D	E	F	G	H	I	J	K
1	STUDY	YEAR	location	PA DOMAIN	PA MEASUREMENT TOOL	PA Units	EFFECT TYPE	PA CATs	EFFECT SIZE	LCI	UCI
2											
3	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	<45 METs/wk	1		
4	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	45–69 METs/wk	0.97	0.91	1.04
5	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	69–96 METs/wk	0.94	0.89	1.02
6	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	96–134 METs/wk	0.9	0.83	0.97
7	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	134 METs/wk	0.87	0.8	0.95

Data Editor (Browse) - [Untitled]

File Edit View Data Tools

quartile[1] 25

	quartile	quantile_mid	PAEE
1	25	12.5	8.19
2	50	37.5	12.29
3	75	62.5	16.38
4	100	87.5	21.29

1) Active = 48 – 35 = 13 = 21.3
2) Mod Active = 45 – 35 = 10 = 16.4
3) Mod Inactive = 42.5 – 35 = 7.5 = 12.3
4) Inactive = 40 – 35 = 5 = 8.2 MMET.hr/wk

Dose-response Meta-analysis - Motivating Example

Exposure Calibration: Interpolation

	A	B	C	D	E	F	G	H	I	J	K
1	STUDY	YEAR	location	PA DOMAIN	PA MEASUREMENT TOOL	PA Units	EFFECT TYPE	PA CATs	EFFECT SIZE	LCI	UCI
2											
3	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	<45 METs/wk	1		
4	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	45–69 METs/wk	0.97	0.91	1.04
5	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	69–96 METs/wk	0.94	0.89	1.02
6	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	96–134 METs/wk	0.9	0.83	0.97
7	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	134 METs/wk	0.87	0.8	0.95

7.6
11.1
14.5
18.0
21.5

Data Editor (Browse) - [Untitled]

File Edit View Data Tools

quartile[1] 25

	quartile	quantile_mid	PAEE
1	25	12.5	8.19
2	50	37.5	12.29
3	75	62.5	16.38
4	100	87.5	21.29

Do-file Editor - do file example pa dose harmonisation.do

File Edit View Project Tools

do file example pa dose harmonis...

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4
5   reg PAEE quantile_mid
6
7   /*quantile mid 10% */ di 10* .17356 + 5.8595 //= 7.6
8   /*quantile mid 30% */ di 30* .17356 + 5.8595 //= 11.1
9   /*quantile mid 50% */ di 50* .17356 + 5.8595 //= 14.5
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11  /*quantile mid 90% */ di 90* .17356 + 5.8595 //= 21.5
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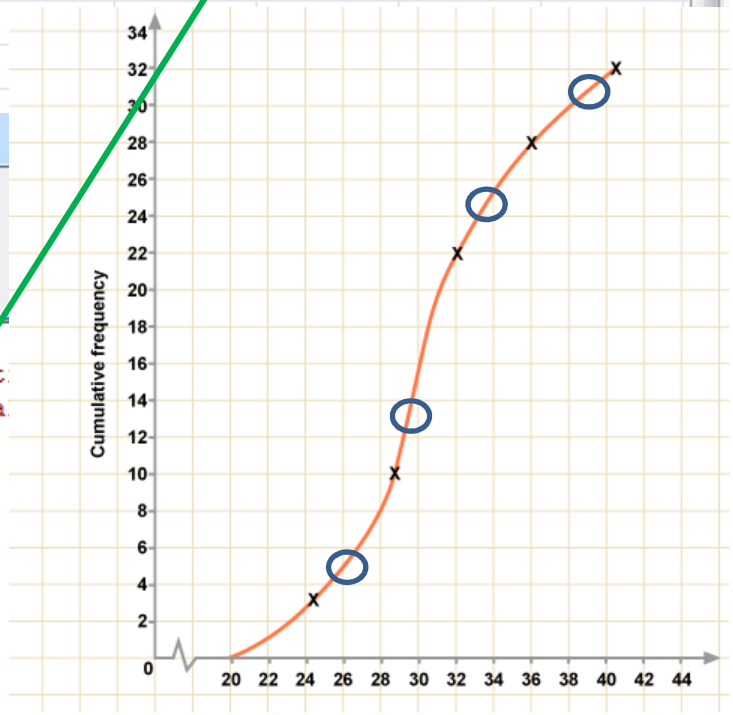

Dose-response Meta-analysis - Motivating Example

Exposure Harmonisation: Meta-data

	A	B	C	D	E	F	G	H	I	J	K
1	STUDY	YEAR	location	PA DOMAIN	PA MEASUREMENT TOOL	PA Units	EFFECT TYPE	PA CATs	EFFECT SIZE	LCI	UCI
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4	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	45–69 METs/wk	0.97	0.91	1.04
5	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	69–96 METs/wk	0.94	0.89	1.02
6	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	96–134 METs/wk	0.9	0.83	0.97
7	EPIC-Europe	2015	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	134 METs/wk	0.87	0.8	0.95
8											
9	Danish Nurse Cohort Study	2015	Denmark	LTPA	questionnaire (Saltin and Grimby)	category	HR	Sedentary	1.62	1.15	2.27
10	Danish Nurse Cohort Study	2015	Denmark	LTPA	questionnaire (Saltin and Grimby)	category	HR	Moderate	1.1	0.91	1.33
11	Danish Nurse Cohort Study	2015	Denmark	LTPA	questionnaire (Saltin and Grimby)	category	HR	Vigorous	1		
12											
13	Black Women's Health Study	2016	USA	LTPA	questionnaire	category	HR	Low	1		
14	Black Women's Health Study	2016	USA	LTPA	questionnaire	category	HR	Moderate	1.01	0.64	1.58
15	Black Women's Health Study	2016	USA	LTPA	questionnaire	category	HR	High	0.95	0.4	2.27
16											
17	Black Women's Health Study	2016	USA	LTPA	questionnaire	category	HR	Low	1		
18	Black Women's Health Study	2016	USA	LTPA	questionnaire	category	HR	Moderate	0.91	0.55	1.52
19	Black Women's Health Study	2016	USA	LTPA	questionnaire	category	HR	High	0.58	0.22	1.57
20											
21	Black Women's Health Study	2016	USA	LTPA	questionnaire	category	HR	Low	1		
22	Black Women's Health Study	2016	USA	LTPA	questionnaire	category	HR	Moderate	0.98	0.87	1.09
23	Black Women's Health Study	2016	USA	LTPA	questionnaire	category	HR	High	0.85	0.74	0.97
24											
25	EPIC-Europe	2016	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	<45 METs/wk	1		
26	EPIC-Europe	2016	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	45–69 METs/wk	1	0.942	1.062
27	EPIC-Europe	2016	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	69–96 METs/wk	0.998	0.939	1.061
28	EPIC-Europe	2016	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	96–134 METs/wk	0.993	0.934	1.056
29	EPIC-Europe	2016	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	134 METs/wk	0.987	0.926	1.051
30											
31	EPIC-Europe	2016	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	<45 METs/wk	1		
32	EPIC-Europe	2016	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	45–69 METs/wk	0.983	0.938	1.029
33	EPIC-Europe	2016	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	69–96 METs/wk	0.944	0.899	0.99
34	EPIC-Europe	2016	Europe	LTPA (plus household)	EPIC lifestyle questionnaire	MET quintiles	HR	96–134 METs/wk	0.932	0.886	0.98
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37	Sax Institute's 45 and Up study	2016	Australia	MV-LTPA	questionnaire (http://www.45andUp.org.au)	mins/wk MVPA	HR	0 - 10 min/wk of MVPA	1		
38	Sax Institute's 45 and Up study	2016	Australia	MV-LTPA	questionnaire (http://www.45andUp.org.au)	mins/wk MVPA	HR	10 - 149 min/wk of MVPA	0.66	0.61	0.71
39	Sax Institute's 45 and Up study	2016	Australia	MV-LTPA	questionnaire (http://www.45andUp.org.au)	mins/wk MVPA	HR	150 - 299 min/wk of MVPA	0.53	0.48	0.57
40	Sax Institute's 45 and Up study	2016	Australia	MV-LTPA	questionnaire (http://www.45andUp.org.au)	mins/wk MVPA	HR	≥ 300 min/wk of MVPA	0.46	0.43	0.49
41											
42	Sax Institute's 45 and Up study	2016	Australia	MV-LTPA	questionnaire (http://www.45andUp.org.au)	category	HR	0% of MVPA from VPA	1		
43	Sax Institute's 45 and Up study	2016	Australia	MV-LTPA	questionnaire (http://www.45andUp.org.au)	category	HR	>0% to <30% of MVPA from VPA	0.89	0.81	0.98
44	Sax Institute's 45 and Up study	2016	Australia	MV-LTPA	questionnaire (http://www.45andUp.org.au)	category	HR	≥30% of MVPA from VPA	0.86	0.79	0.94
45											
46	EPIC - Italy	2016	Italy	LTPA	EPIC lifestyle questionnaire	MET-hr/wk	HR	<73.9	1		

7.6
11.1
14.5
18.0
21.5

form | dictionary | Legend

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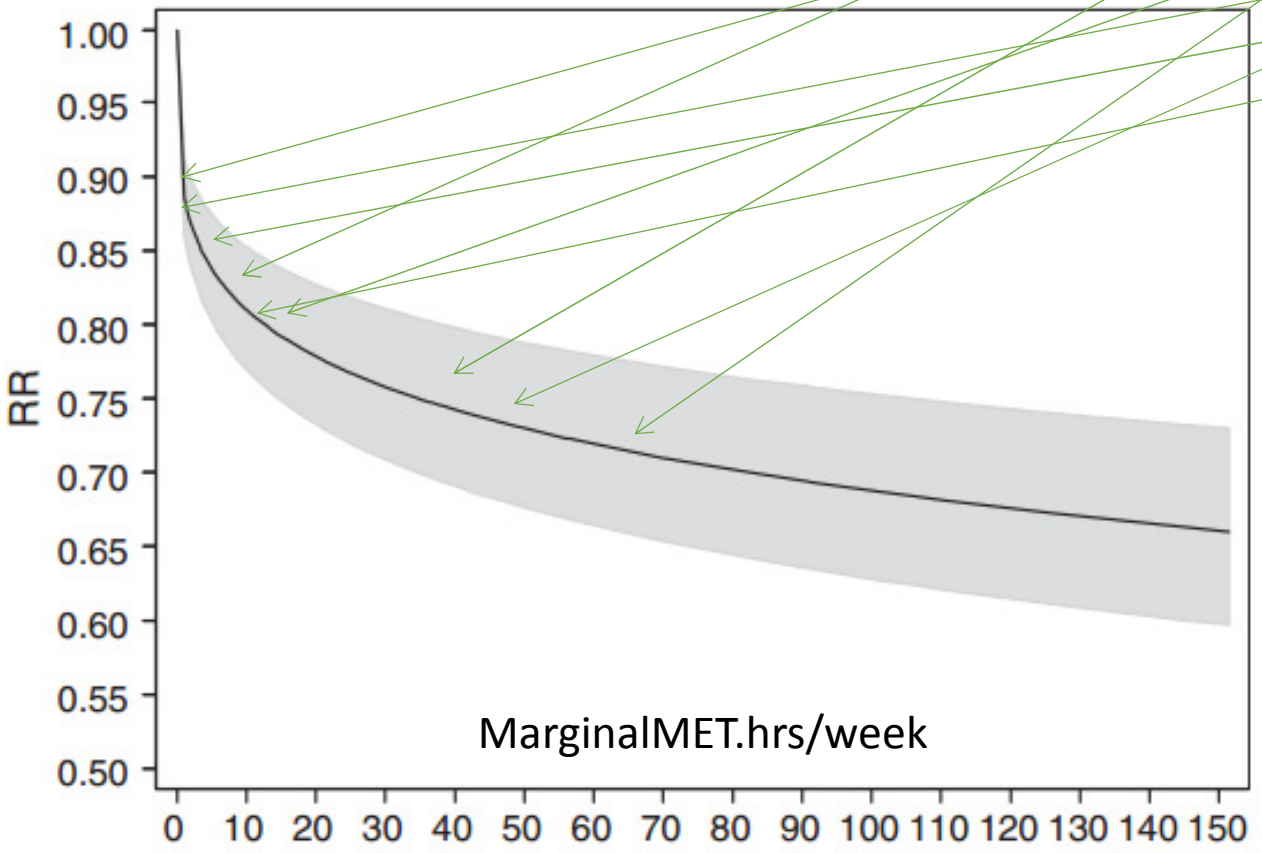
First author	Year	Sex	Exposure type (units)	Exposure categories	Harmonised exposure (MMET.h/week)
Wu	1987		Duration	<1 hour/day	12.25
			(hours/day)	1 - 2 hour/day	36.75
				>2 hour/day	61.25
Arraiz	1992		Volume	sedentary (<1749)	5.45
			(MET.min/2 weeks)	moderate (1750 - 2999)	15.07
				active (3000 - 5499)	27.58
				very active (>5500)	45.10
Bostick	1994		Categorical	low	1.31
				moderate	5.25
				vigorous	10.50
				0 hour/week	0.00
				<1 hour/week	1.75
				1 - 2 hours/week	5.25
				>2 hours/week	8.75
				sedentary	0.00
				R2 = walking, bicycling or physical activities ≥4 hours/week	21.00
				R3 = exercise to keep fit, participating in recreational athletics, etc. ≥4 hours/week; or R4 = regular hard training or participation in competitive sports several times/week	42.00
				low (<1 time/week)	1.31
				medium (VPA once/week or MPA 1 - 4 times/week)	5.25



Indirect validation

Harmonisation in absence of direct validation

ACC = β_1 * MVPA+ α_1
(Bridge Equation 1)

Trunk ACC
Acceleration (m/s^2)

PAEE = β_2 * ACC + α_2
(Bridge Equation 2)

PAEE = β_2 * (β_1 * MVPA + α_1) + α_2

Indirect Validation Model

Self-report, eg MVPA

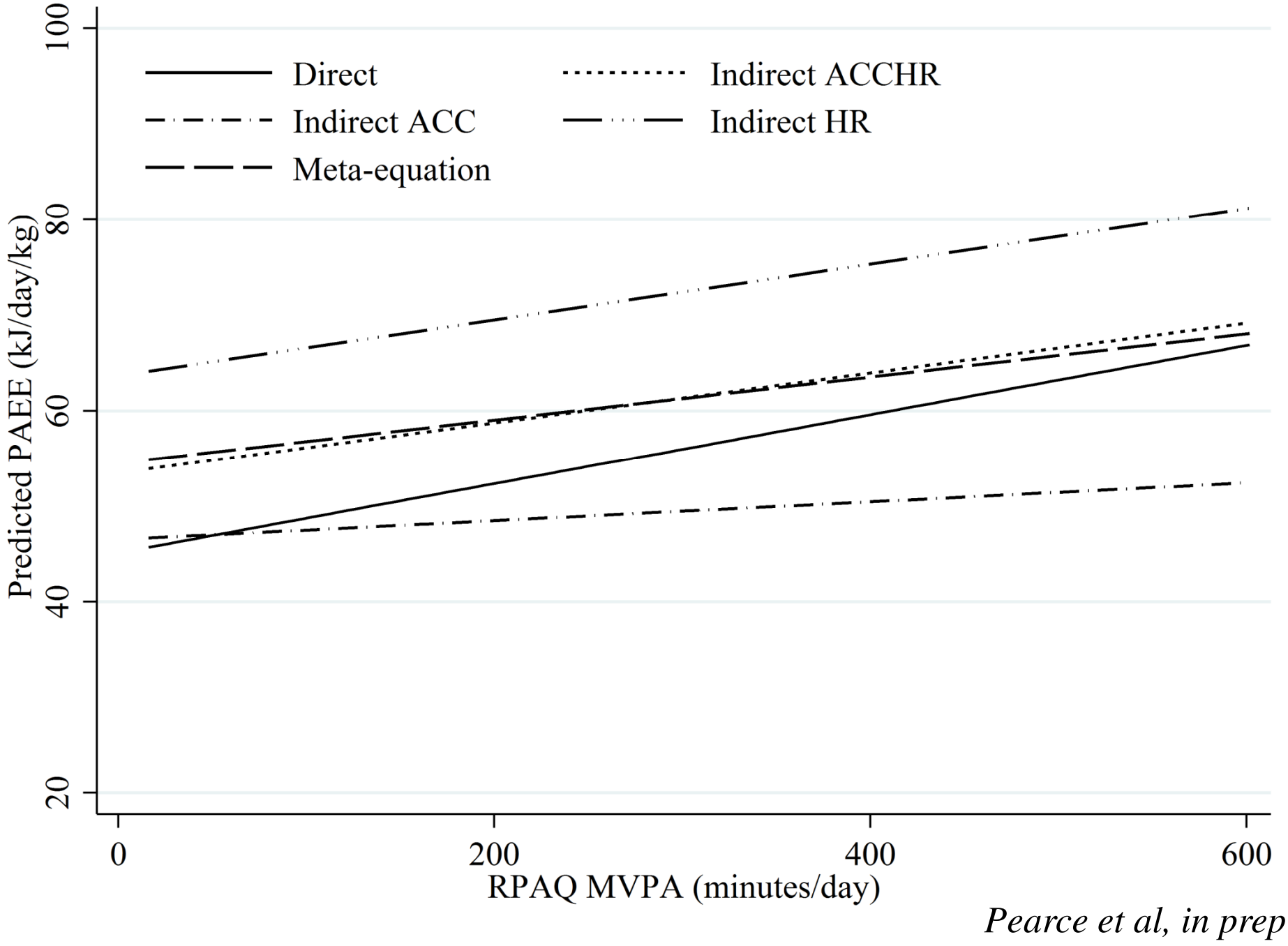
Direct Validation Model

DLW method
PAEE (kJ/kg/day)

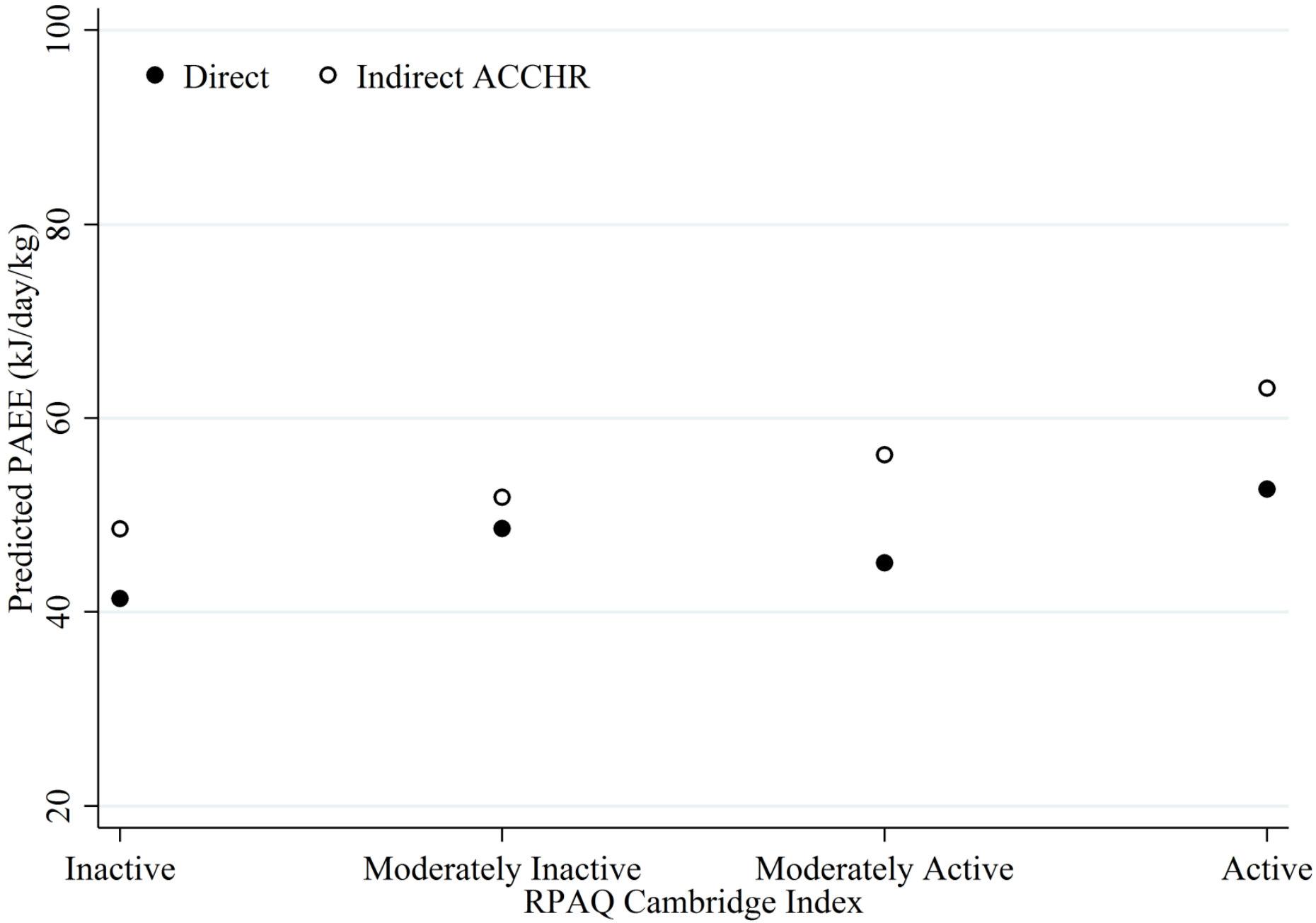
Bridge equations

Bridge	Starting Variable	Intermediate Variable	Target Variable	N	β (SE)	α (SE)	r^2
Indirect harmonisation of RPAQ MVPA via $\mathbf{ACC_{TRUNK}}$							
AC	RPAQ MVPA (minutes•day^{-1})	ACC_{TRUNK} (m•s^{-2})	-	2121	$5.84 \cdot 10^{-5}$ ($7.9 \cdot 10^{-6}$)	.1199 (.0015)	.02
CB	-	ACC_{TRUNK} (m•s^{-2})	DLW PAEE (kJ•day^{-1}•kg^{-1})	46	165 (32)	26.7 (8.2)	.37
Indirect harmonisation of RPAQ MVPA via PAEE from HR							
AC	RPAQ MVPA (minutes•day^{-1})	HR PAEE (kJ•day^{-1}•kg^{-1})	-	2121	.0840 (.0061)	60.9 (1.2)	.08
CB	-	HR PAEE (kJ•day^{-1}•kg^{-1})	DLW PAEE (kJ•day^{-1}•kg^{-1})	46	.34 (.07)	42.7 (5.8)	.34
Indirect harmonisation of RPAQ MVPA via PAEE from ACCHR							
AC	RPAQ MVPA (minutes•day^{-1})	ACCHR PAEE (kJ•day^{-1}•kg^{-1})	-	2120	.0390 (.0030)	50.69 (.57)	.07
CB	-	ACCHR PAEE (kJ•day^{-1}•kg^{-1})	DLW PAEE (kJ•day^{-1}•kg^{-1})	46	.66 (.11)	20.0 (8.1)	.45
Indirect harmonisation of RPAQ PAEE via PAEE from ACCHR							
AC	RPAQ PAEE (kJ•day^{-1}•kg^{-1})	ACCHR PAEE (kJ•day^{-1}•kg^{-1})	-	2120	.239 (.014)	45.63 (.69)	.12
CB		ACCHR PAEE (kJ•day^{-1}•kg^{-1})	DLW PAEE (kJ•day^{-1}•kg^{-1})	46	.66 (.11)	20.0 (8.1)	.45
Indirect harmonisation of Cambridge Index via PAEE from ACCHR							
AC	RPAQ Cambridge Index	ACCHR PAEE (kJ•day^{-1}•kg^{-1})	-	2120	*Inactive =0; Moderately inactive = 4.5 (2.6); Moderately active = 11.1 (2.6); Active = 21.5 (2.6)	42.9 (2.5)	.11
CB		ACCHR PAEE (kJ•day^{-1}•kg^{-1})	DLW PAEE (kJ•day^{-1}•kg^{-1})	46	.66 (.11)	20.0 (8.1)	.45
Indirect harmonisation of $\mathbf{ACC_{WRIST}}$ ***via*** $\mathbf{ACC_{TRUNK}}$							
AC	ACC_{WRIST} (milli-g)	ACC_{TRUNK} (m•s^{-2})	-	1050	$.4.78 \cdot 10^{-3}$ ($9.0 \cdot 10^{-5}$)	-.097 (.0036)	.53
CB		ACC_{TRUNK} (m•s^{-2})	DLW PAEE (kJ•day^{-1}•kg^{-1})	46	165 (32)	26.7 (8.2)	.37
Indirect harmonisation of $\mathbf{ACC_{WRIST}}$ ***via PAEE from ACCHR***							
AC	ACC_{WRIST} (milli-g)	ACCHR PAEE (kJ•day^{-1}•kg^{-1})	-	1050	1.232 (.012		
CB		ACCHR PAEE (kJ•day^{-1}•kg^{-1})	DLW PAEE (kJ•day^{-1}•kg^{-1})	46	.66 (.11)		

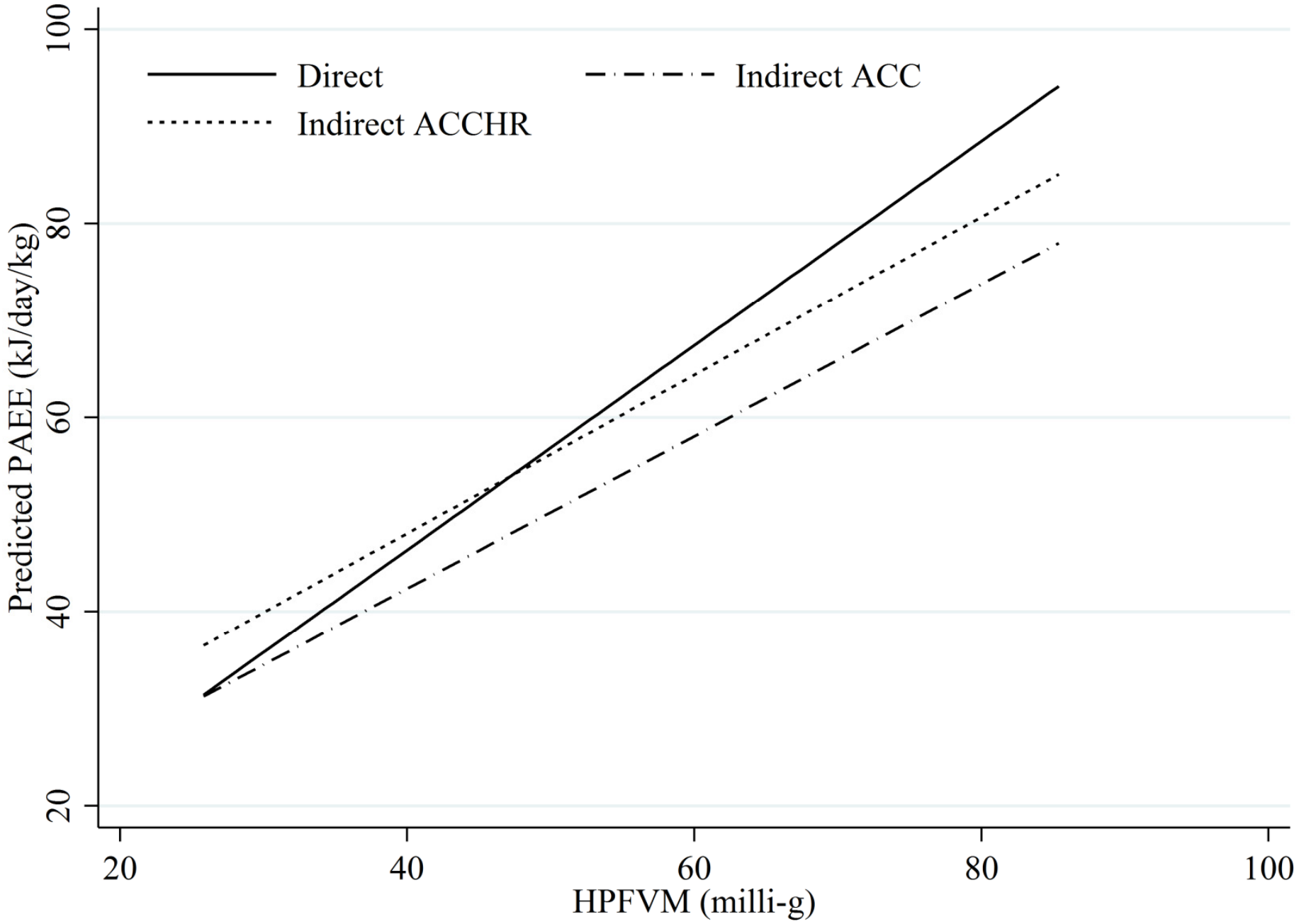
Pearce et al, in prep



Pearce et al, in prep

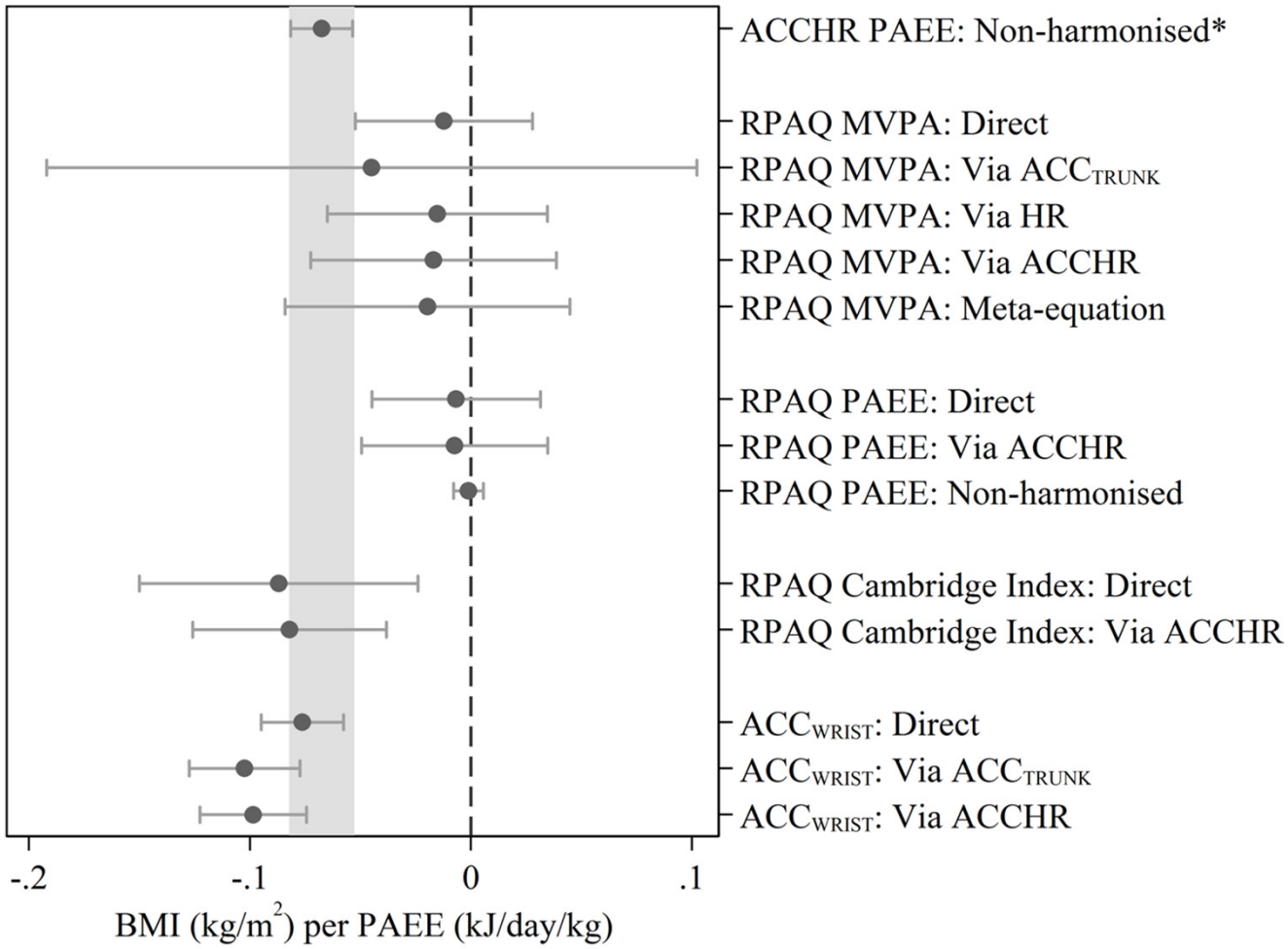


Pearce et al, in prep



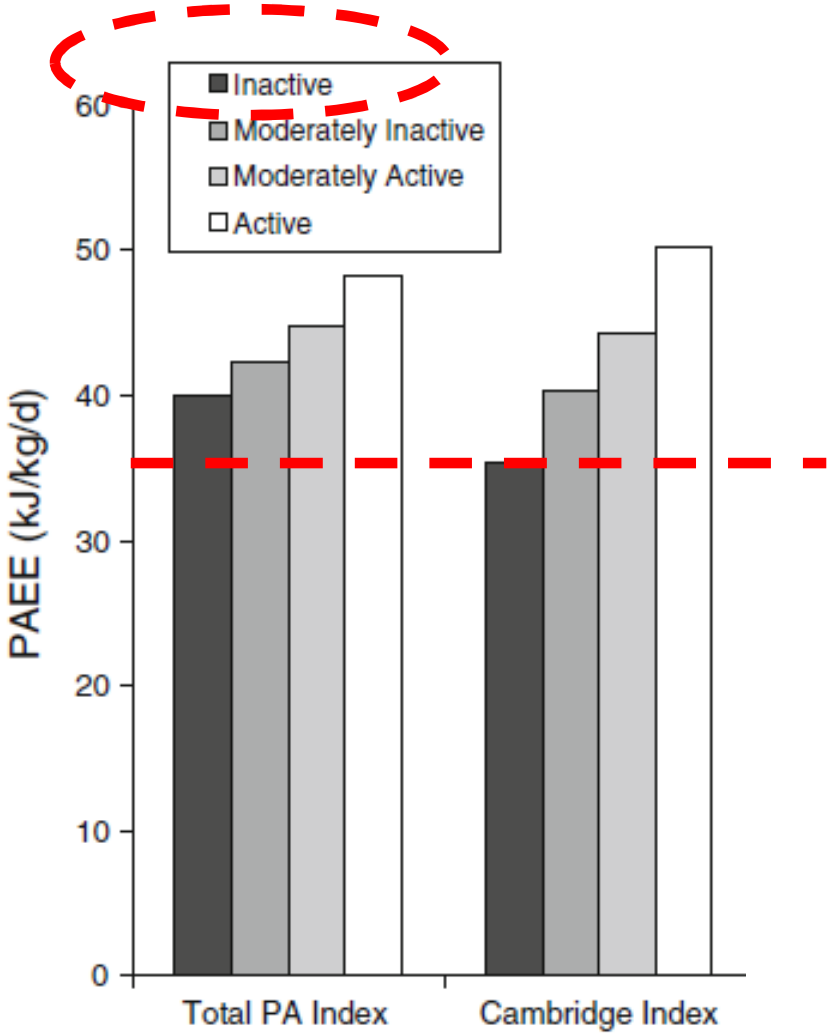
Pearce et al, in prep

Inferentially equivalent?
Association with BMI

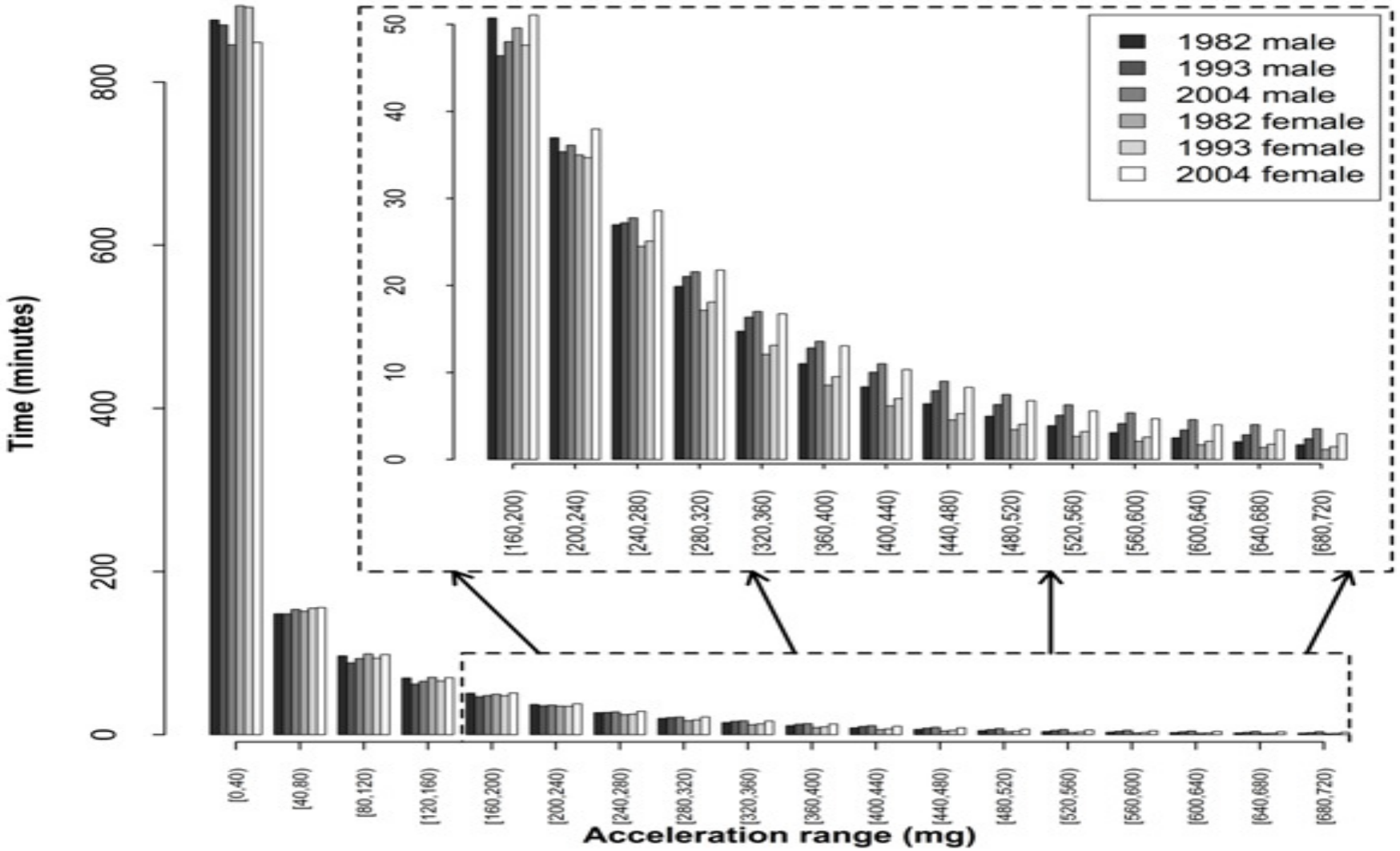


Pearce et al, in prep

Absolute versus marginalised mapping…



Other target variables:
Movement intensity distributions



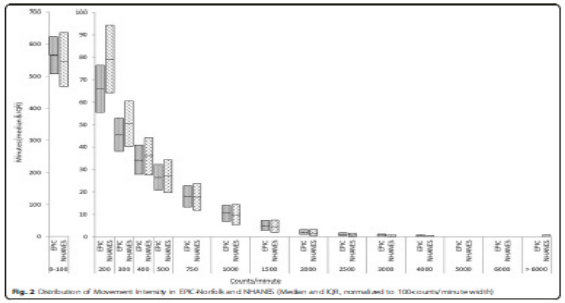
Cohorts were **7, 18, and 30 yrs** old at time of assessment

da Silva et al, IJE 2014

Large cohorts and surveillance

e.g. UKBB, WHO STEPS?

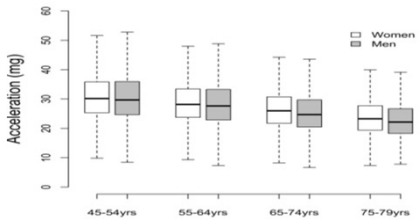
EPIC



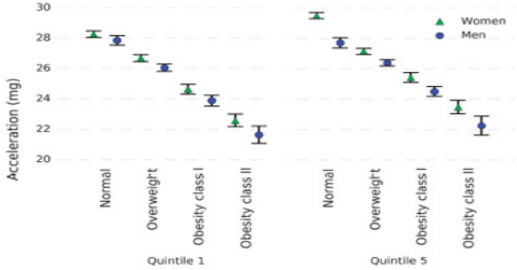
(Berkemeyer et al, 2016; Yerrakalva et al, 2017; Hajna et al, 2018)

biobank

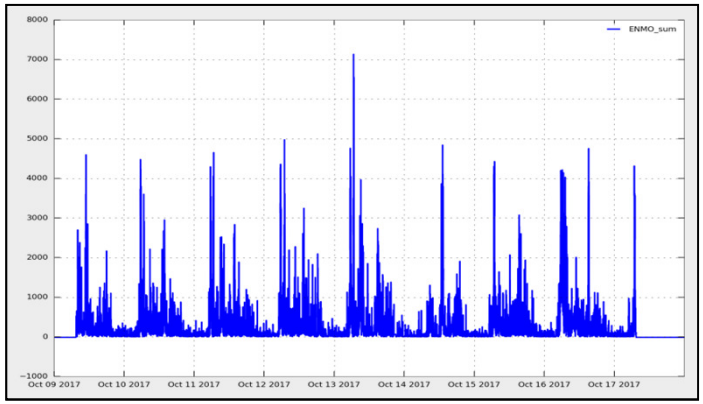
n~100k



(Doherty et al, 2017)



(Kim et al, 2017)



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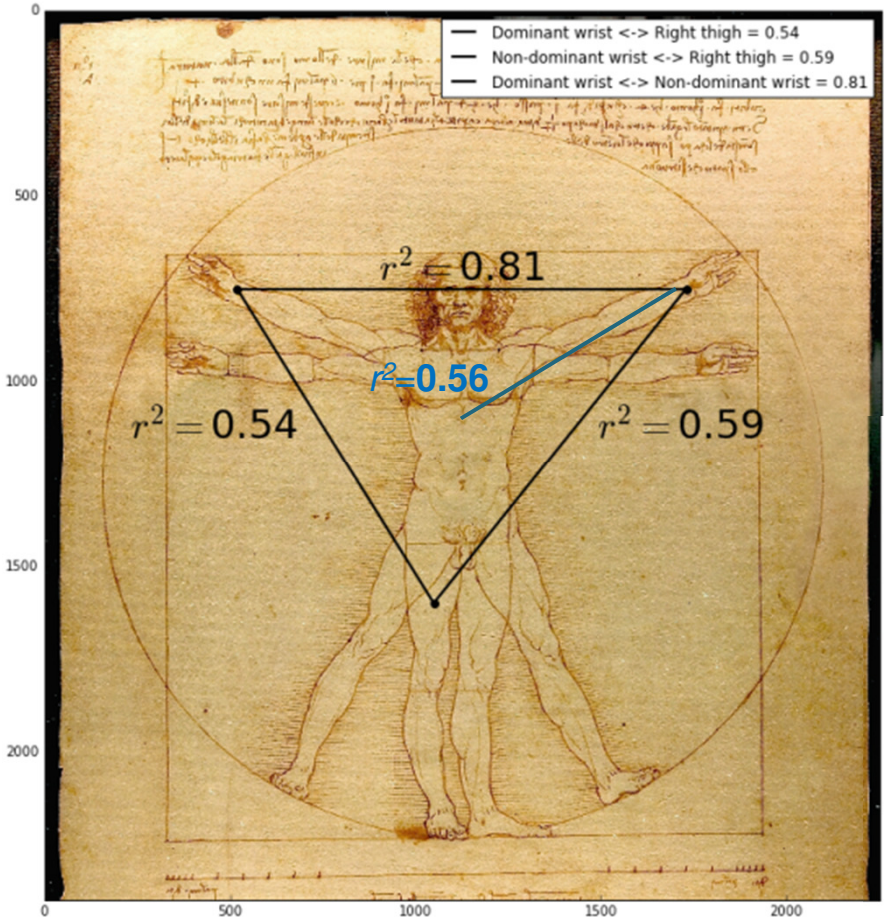
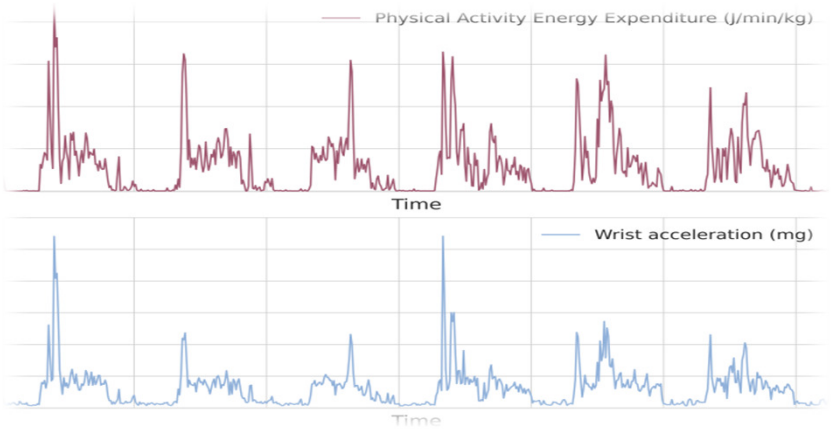
What should be the criterion measure for movement?

Segment vs whole-body movement?



Segment vs whole-body PAEE?

Within-id vs between-id?



White et al, 2016+2018

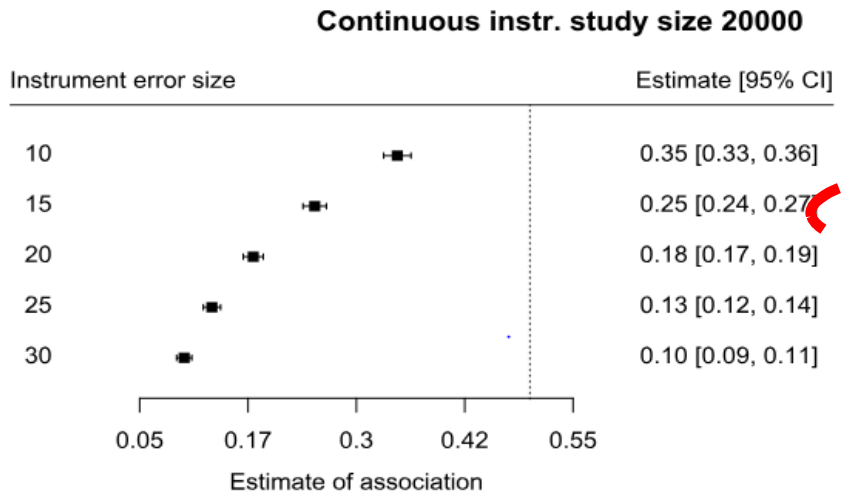
Discoverability of method relationships

- Published peer-reviewed papers
- Published papers, eg BioRxiv
- Share **bridge equations** and meta-data
- Share raw data

- What format?
- Who will host (fund)?
- Who will contribute?
- How to make that attractive?

Relation to measurement error correction

Imagine a study with true association = 0.5



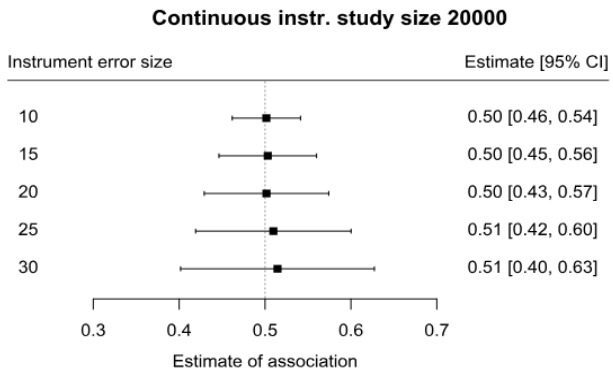
Naïve model: $Y = \alpha + \hat{\beta} \cdot \hat{X}$

Error model: $X = \lambda \cdot \hat{X} + \varepsilon$

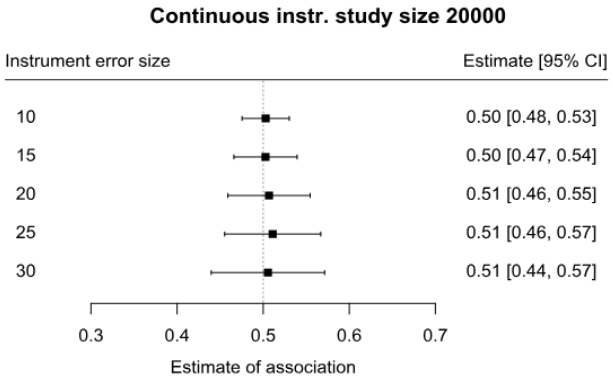
Error-corrected model:

$Y = \alpha + \hat{\beta}/\lambda \cdot X$

Using validation study with… ***n=400***



and… ***n=1600***



Bishop et al, in prep

Conclusion

- Multiple ways of **connecting** data help harmonisation
- **Marginalisation** is a (blunt!) tool
- Some **assumptions** needed, most are testable
- Mapping to latent variable by use of **validation** data is a viable alternative to classic harmonisation
  - **Inclusive**: Allows ALL data sources to be integrated
  - Implicitly quantifies **uncertainty** of the process
- Achieves **inferential equivalence** in downstream analyses?
- Harmonisation using **indirect validation is** a viable alternative to direct validation
  - **Narrows** the **range** of harmonised values compared with DLW
- **Population specificity** an issue
- *Further work*:
  - Full integration with **measurement error correction** techniques

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