SUPPLEMENTARY MATERIAL

An interactive tool to personalise 24-hour activity, sitting and sleep prescription for optimal health outcomes. Maddison L Mellow[1], Tyman E Stanford[1], Timothy Olds[1], Aaron Miatke[1], & Ashleigh E Smith[1†], Dorothea Dumuid[1†*].

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Supplementary File 1

Summary of inclusion and exclusion criteria

UK Biobank code and URL link	Description of variable	Rules for inclusion
f.864.0.0 (864)		Response was not -2 ("unable to walk")
f.864.1.0 (864)	Number of days/week walked 10+ minutes	
f.864.2.0 (864)		
f.864.3.0 (864)		
f.90015.0.0 (90015)	Valid wear time (indicator of accelerometry data quality)	valid_wear=1 (yes)
f.90002.0.0 (90002)	Data problem indicator	Data_prob_ind=NA (no problems indicated)
f.20242.0.0 (20242)	Fluid intelligence completion status	≥4 cognitive tests completed
f.20244.0.0 (20244)	Pairs matching completion status	
f.20245.0.0 (20245)	Symbol digit substitution completion status	*note: based on completion status variables=1 (yes), and date/time numeric memory test completed ≠ NA.
f.20246.0.0 (20246)	Trail making completion status	
f.20138.0.0 (20138)	When numeric memory test completed	
f.53.0.0 (53)		At least one date ≠ NA (i.e., participant has attended at least one assessment centre visit)
f.53.1.0 (53)	Date of attending assessment centre	
f.53.2.0 (53)		
f.53.3.0 (53)		
f.90010.0.0 (90010)	Start time of accelerometer wear	
(130836)	Date F00 (dementia in Alzheimer's disease) first reported	Date of diagnosis occurred later than: 1. Date of attending assessment centre (53) 2. Start of accelerometer wear time (90010) 3. When numeric memory test completed (20138)
(130838)	Date F01 (vascular dementia) first reported	
(130840)	Date F02 (dementia in other diseases classified elsewhere) first reported	

UK Biobank code and URL link	Description of variable	Rules for inclusion
(130842)	Date F03 (unspecified dementia) first reported	4. When pairs matching test completed (20134)
(130844)	Date F04 (organic amnesic syndrome, not induced by alcohol and other psychoactive substances) first reported	5. When fluid intelligence test completed (20135) 6. When trail making test completed (20136)
(130846)	Date F05 (delirium, not induced by alcohol and other psychoactive substances) first reported	7. When symbol digit substitution test completed (20137)
(131012)	Date G10 (Huntington's disease) first reported	
(131014)	Date G11 (hereditary ataxia) first reported	
(131016)	Date G12 (spinal muscular atrophy and related syndromes) first reported	
(131018)	Date G13 (systemic atrophies primarily affecting central nervous system in diseases classified elsewhere) first reported	
(131022)	Date G20 (Parkinson's disease) first reported	
(131024)	Date G21 (secondary parkinsonism) first reported	
(131026)	Date G22 (parkinsonism in diseases classified elsewhere) first reported	
(131036)	Date G30 (Alzheimer's disease) first reported	
(131038)	Date G31 (other degenerating diseases of the nervous system, not classified elsewhere) first reported	
(131042)	Date G35 (multiple sclerosis) first reported	
(131044)	Date G36 (other acute disseminated demyelination) first reported	
(131046)	Date G37 (other demyelinating diseases of the central nervous system) first reported	
(131212)	Date H54 (blindness and low vision) first reported	

Supplementary File 2

Summary of original and re-classified variables included in final analyses

UK Biobank code and URL link	Variable/risk factor	Description of measure	Original levels and/or format	Restructured variable*	Notes
f.eid	ID	ID code	*Numeric*	*Numeric*	
f.31.0.0 ([31])	Sex	Sex	Male	Male	
			Female	Female	
f.34.0.0 ([34])	Age	Year of birth	YYYY	Approximate age at cognitive testing	All birthdates assumed to be on the 15th day of the month. Age was defined as the years between the approximated birth date, and the date of cognitive testing.
f.52.0.0 ([52])		Month of birth	MM		
f.53.0.0 ([53]) f.53.1.0 ([53]) f.53.2.0 ([53]) f.53.3.0 ([53])	Date of attending assessment centre	Date of attending assessment centre	YYYY-MM-DD	YYYY-MM-DD	
f.1558.0.0 ([1558]) f.1558.1.0 ([1558]) f.1558.2.0 ([1558]) f.1558.3.0 ([1558])	Alcohol consumption	"About how often do you drink alcohol?"	Daily or almost daily	"Often/very often"	
			Three to four times a week		
			Once or twice a week	"Sometimes/never"	
			One to three times a month		
			Special occasions only		
			Never		

UK Biobank code and URL link	Variable/risk factor	Description of measure	Original levels and/or format	Restructured variable*	Notes
			Prefer not to answer	"Unknown"	
f.21001.0.0 (21001) f.21001.1.0 (21001) f.21001.2.0 (21001) f.21001.3.0 (21001)	Obesity	BMI value derived from height and weight measured during initial assessment centre visit	Numeric	Overweight	BMI>25
				Not overweight	BMI≤25
f.2020.0.0 (2020) f.2020.1.0 (2020) f.2020.2.0 (2020) f.2020.3.0 (2020)	Social isolation	"Do you often feel lonely?"	Yes	Yes	
			No	No	
			Do not know	"Unknown"	
			Prefer not to answer		
f.2247.0.0 (2247) f.2247.1.0 (2247) f.2247.2.0 (2247) f.2247.3.0 (2247)	Hearing loss	"Do you have any difficulty with your hearing?"	I am completely deaf	"Yes"	
			Yes		
			No	No	
			Do not know	"Unknown"	
			Prefer not to answer		
f.6150.0.0 (6150) f.6150.0.1 (6150) f.6150.0.2 (6150) f.6150.0.3 (6150)	Hypertension	"Has a doctor ever told you that you have had any of the following conditions?"	Yes	Yes	Hypertension was one of six possible conditions that could be indicated as 'yes', 'no', or 'unknown'.
			No	No	
			Unknown	Unknown	
f.4596.0.0 (4598)	Depression	"Looking back over your life, have you ever had a time when you were feeling depressed or down for at least a whole week?"	Yes	Yes	
			No	No	
			Do not know	"Unknown"	
			Prefer not to answer		
f.2443.0.0 (2443)	Diabetes	"Has a doctor ever told you that you have diabetes?"	Yes	Yes	
			No	No	
			Do not know	"Unknown"	
			Prefer not to answer		

UK Biobank code and URL link	Variable/risk factor	Description of measure	Original levels and/or format	Restructured variable*	Notes
f.6138.0.0 ([6138](#)) f.6138.0.1 ([6138](#)) f.6138.0.2 ([6138](#)) f.6138.0.3 ([6138](#)) f.6138.0.4 ([6138](#)) f.6138.0.5 ([6138](#)) f.6138.1.0 ([6138](#)) f.6138.1.1 ([6138](#)) f.6138.1.2 ([6138](#)) f.6138.1.3 ([6138](#)) f.6138.1.4 ([6138](#)) f.6138.1.5 ([6138](#)) f.6138.2.0 ([6138](#)) f.6138.2.1 ([6138](#)) f.6138.2.2 ([6138](#)) f.6138.2.3 ([6138](#)) f.6138.2.4 ([6138](#)) f.6138.2.5 ([6138](#)) f.6138.3.0 ([6138](#)) f.6138.3.1 ([6138](#)) f.6138.3.2 ([6138](#)) f.6138.3.3 ([6138](#)) f.6138.3.4 ([6138](#)) f.6138.3.5 ([6138](#))	Education/qualifications	"Which of the following qualifications do you have? (You can select more than one)"	A levels/ AS levels or equivalent O levels/ GCSEs or equivalent CSEs or equivalent	"High school"	Restructured variable "*highest qualification*" ranked the reported qualifications (across all available assessment centre datapoints) from highest to lowest, resulting in only one category per ID number. Original education levels were mapped to Australian equivalents, as the final Shiny application was used by Australian participants.
			NVQ or HND or HNC or equivalent	"Certificate III/Diploma"	
			Other professional qualifications e.g., nursing, teaching	"Other professional qualification"	
			College or university degree	"College/University"	
			None of the above		
			Prefer not to answer	"Unknown"	
f.20116.0.0 ([20116](#)) f.20116.1.0 ([20116](#)) f.20116.2.0 ([20116](#)) f.20116.3.0 ([20116](#))	Smoking status	Combination of two questions: "Do you smoke tobacco now?" and "In the past, how often have you smoked tobacco?"	Current Previous Never Prefer not to answer	Current Previous Never "Unknown"	
f.21000.0.0 ([21000](#))	Ethnic background	"What is your ethnic group?"	White Mixed	White Non-White	The top-level response for this

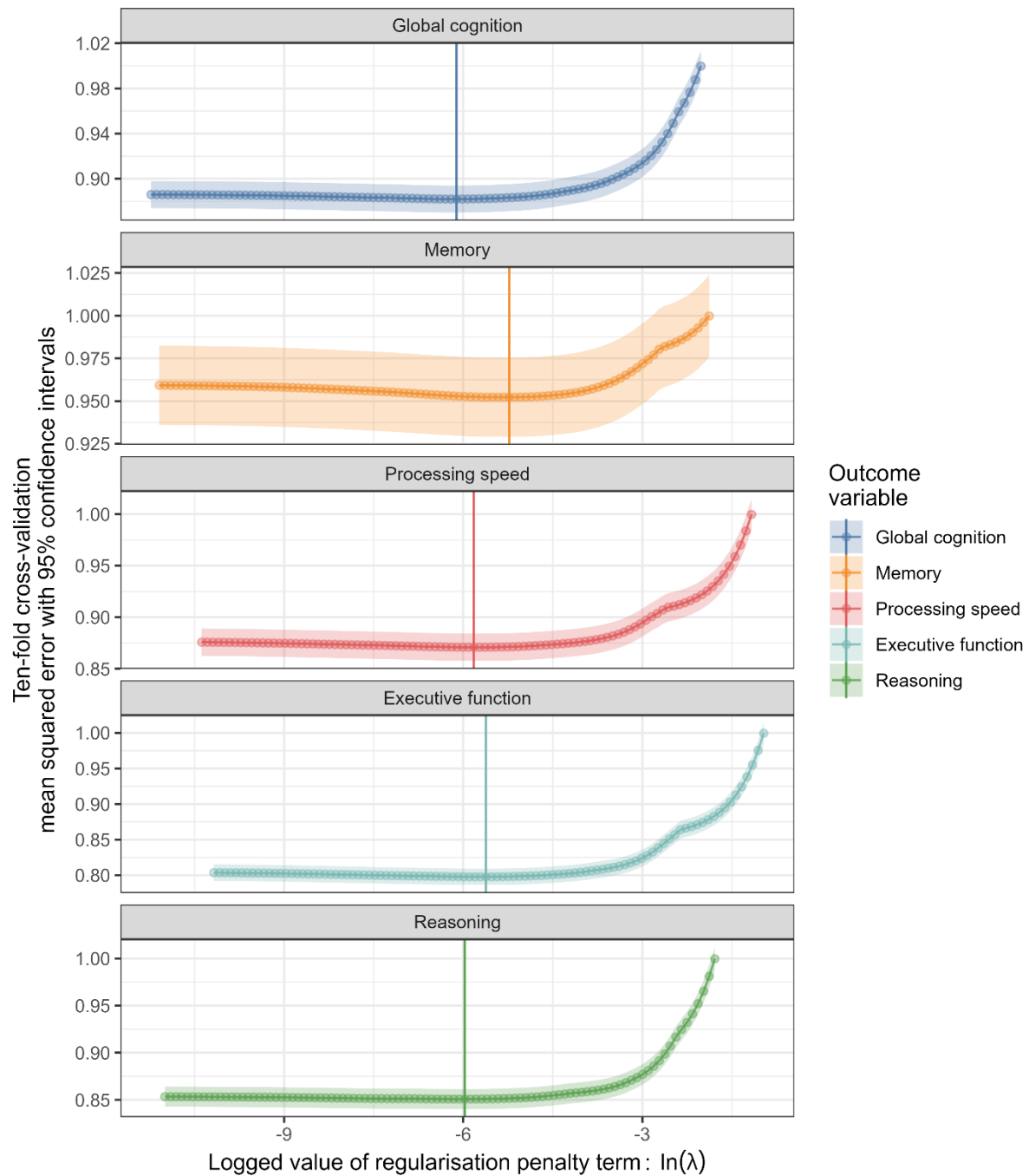| UK Biobank code and URL link	Variable/risk factor	Description of measure	Original levels and/or format	Restructured variable*	Notes
			Asian or Asian British		variable was used to classify ethnic background.
			Black or Black British		
			Chinese		
			Other ethnic group		Due to extreme skewness in ethnicity variable, the default level 'White' was used in all modelling. The question was not asked in the final app due to misalignment with Australian contexts.
			Do not know		
			Prefer not to answer		
f.20132.0.0 ([20132](#))	Memory	Pairs Matching: number of incorrect matches in round	*Numeric*	*Numeric* (age- and sex-standardised z-score)	
f.20240.0.0 ([20240](#))		Numeric Memory: maximum digits remembered correctly	*Numeric*		
f.20156.0.0 ([20156](#)) f.20159.0.0 ([20159](#))	Processing Speed	Trail Making: duration to complete Trails A (numeric path)	*Numeric*	*Numeric* (age- and sex-standardised z-score)	
		Symbol Digit Substitution: number of symbol digit matches made correctly	Numeric		
f.20157.0.0 ([20157](#))	Executive Function	Trail Making: duration to complete Trails B (alphanumeric path)	*Numeric*	*Numeric*	

UK Biobank code and URL link	Variable/risk factor	Description of measure	Original levels and/or format	Restructured variable*	Notes
f.20191.0.0 (20191)	Reasoning	Fluid Intelligence: fluid intelligence score global	*Numeric*	*Numeric*	
-	Global cognitive function	*mean of Memory, Processing Speed, Executive Function and Reasoning z-scores/scores	*Numeric*	*Numeric*	
f.90010.0.0 (90010)	Start time of accelerometer wear	Start time of accelerometer wear			

Note. The original UK biobank variables, their levels and format, compared to the restructured variable. Where necessary, variables were re-structured to align with Australian classifications. BMI=body mass index.

Supplementary File 3

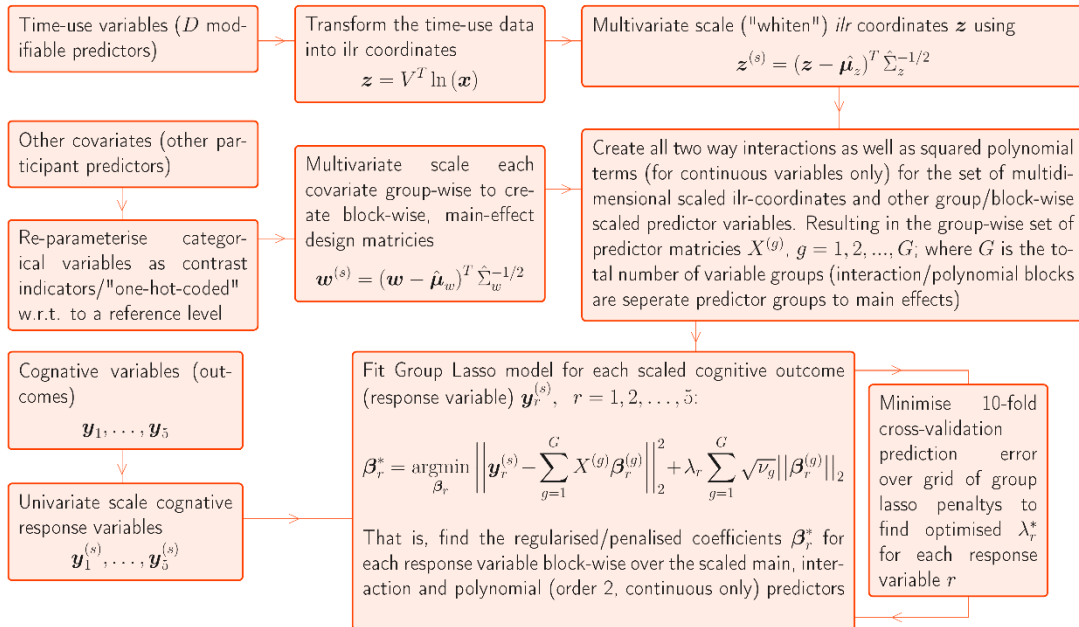Lambda value derived from 10-fold cross-validation

Note. Empirically derived penalty values applied to the group LASSO shrinkage procedure for each cognitive outcome (listed in header). The logged value of the regularisation penalty term (ln(λ)) is displayed (x-axis, with lambda value indicated by vertical coloured line) against the mean squared error (MSE, y-axis).
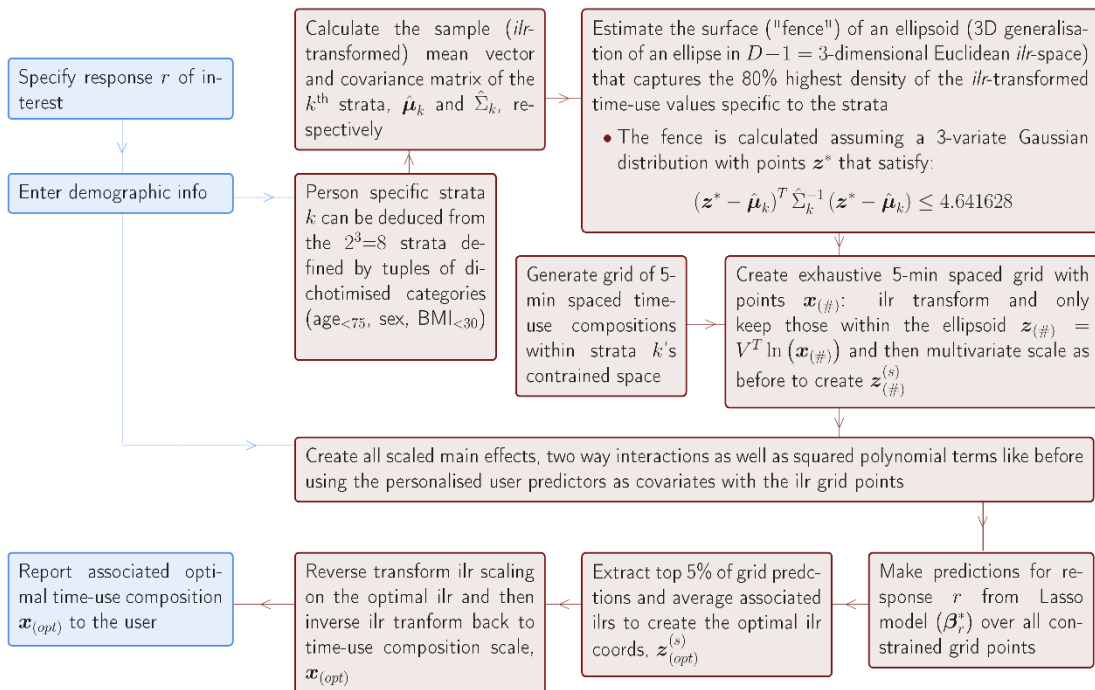
Supplementary File 4

Workflow underpinning the R Shiny 'ideal day' app.

Model building

Time-use variables (D modifiable predictors)

Transform the time-use data into ilr coordinates
$$\boldsymbol{z} = V^T \ln\left(\boldsymbol{x}\right)$$

Multivariate scale ("whiten") *ilr* coordinates $\boldsymbol{z}$ using
$$\boldsymbol{z}^{(s)} = (\boldsymbol{z} - \hat{\boldsymbol{\mu}}_z)^T \hat{\Sigma}_z^{-1/2}$$

Other covariates (other participant predictors)

Re-parameterise categorical variables as contrast indicators/"one-hot-coded" w.r.t. to a reference level

Multivariate scale each covariate group-wise to create block-wise, main-effect design matricies
$$\boldsymbol{w}^{(s)} = (\boldsymbol{w} - \hat{\boldsymbol{\mu}}_w)^T \hat{\Sigma}_w^{-1/2}$$

Create all two way interactions as well as squared polynomial terms (for continuous variables only) for the set of multidimensional scaled ilr-coordinates and other group/block-wise scaled predictor variables. Resulting in the group-wise set of predictor matrices $X^{(g)}$, $g = 1, 2, ..., G$; where G is the total number of variable groups (interaction/polynomial blocks are seperate predictor groups to main effects)

Cognative variables (outcomes)
$$\boldsymbol{y}_1, \ldots, \boldsymbol{y}_5$$

Univariate scale cognative response variables
$$\boldsymbol{y}_1^{(s)}, \ldots, \boldsymbol{y}_5^{(s)}$$

Fit Group Lasso model for each scaled cognitive outcome (response variable) $\boldsymbol{y}_r^{(s)}$, $r = 1, 2, \ldots, 5$:
$$\boldsymbol{\beta}_r^* = \underset{\boldsymbol{\beta}_r}{\operatorname{argmin}} \left\| \boldsymbol{y}_r^{(s)} - \sum_{g=1}^{G} X^{(g)} \boldsymbol{\beta}_r^{(g)} \right\|_2^2 + \lambda_r \sum_{g=1}^{G} \sqrt{\nu_g} || \boldsymbol{\beta}_r^{(g)} ||_2$$
That is, find the regularised/penalised coefficients $\boldsymbol{\beta}_r^*$ for each response variable block-wise over the scaled main, interaction and polynomial (order 2, continuous only) predictors

Minimise 10-fold cross-validation prediction error over grid of group lasso penaltys to find optimised λ_r^* for each response variable r

User side

Personalised optimisation

Specify response r of interest

Enter demographic info

Calculate the sample (*ilr*-transformed) mean vector and covariance matrix of the kth strata, $\hat{\boldsymbol{\mu}}_k$ and $\hat{\Sigma}_k$, respectively

Estimate the surface ("fence") of an ellipsoid (3D generalisation of an ellipse in $D-1 = 3$-dimensional Euclidean *ilr*-space) that captures the 80% highest density of the *ilr*-transformed time-use values specific to the strata

- The fence is calculated assuming a 3-variate Gaussian distribution with points $\boldsymbol{z}^*$ that satisfy:
$$(\boldsymbol{z}^* - \hat{\boldsymbol{\mu}}_k)^T \hat{\Sigma}_k^{-1} (\boldsymbol{z}^* - \hat{\boldsymbol{\mu}}_k) \leq 4.641628$$

Person specific strata k can be deduced from the $2^3 = 8$ strata defined by tuples of dichotimised categories (age$_{<75}$, sex, BMI$_{<30}$)

Generate grid of 5-min spaced time-use compositions within strata k's contrained space

Create exhaustive 5-min spaced grid with points $\boldsymbol{x}_{(\#)}$: ilr transform and only keep those within the ellipsoid $\boldsymbol{z}_{(\#)} = V^T \ln\left(\boldsymbol{x}_{(\#)}\right)$ and then multivariate scale as before to create $\boldsymbol{z}_{(\#)}^{(s)}$

Create all scaled main effects, two way interactions as well as squared polynomial terms like before using the personalised user predictors as covariates with the ilr grid points

Report associated optimal time-use composition $\boldsymbol{x}_{(opt)}$ to the user

Reverse transform ilr scaling on the optimal ilr and then inverse ilr tranform back to time-use composition scale, $\boldsymbol{x}_{(opt)}$

Extract top 5% of grid predctions and average associated ilrs to create the optimal ilr coords, $\boldsymbol{z}_{(opt)}^{(s)}$

Make predictions for response r from Lasso model ($\boldsymbol{\beta}_r^*$) over all constrained grid points

Supplementary File 5

Demographic characteristics across strata

Characteristic	Level	Overall sample	Strata classification							
			Females, <65, wo/ obesity	Females, <65, w/obesity	Females, ≥65, wo/ obesity	Females, ≥65, w/obesity	Males, <65, wo/ obesity	Males, <65, w/obesity	Males, ≥65, wo/ obesity	Males, ≥65, w/obesity
N		53,057	15,303	3,259	9,465	2,064	9,610	2,451	8,809	2,096
Age (years)		62 (8)	57 (5)	57 (5)	69 (3)	69 (3)	57 (5)	57 (5)	70 (3)	70 (3)
Sex (%)	Female	30,091 (57%)	15,303 (100%)	3,259 (100%)	9,465 (100%)	2,064 (100%)	-	-	-	-
	Male	22,966 (43%)	-	-	-	-	9,610 (100%)	2,451 (100%)	8,809 (100%)	2,096 (100%)
24-hr time-use composition	Sleep	542.7	542.3	542.2	543.8	542.3	533.4	528.7	546.6	551.2
	SB	576.9	549.4	595.7	549.4	603.1	595.5	632.2	588.0	630.8
	LPA	291.2	318.1	287.0	322.6	283.0	267.3	251.8	267.9	237.8
	MVPA	29.2	30.1	15.0	24.3	11.6	43.7	27.3	37.4	20.2
BMI		26.6 (4.5)	24.2 (2.8)	34.5 (4.1)	24.7 (2.7)	33.8 (3.7)	25.5 (2.5)	33.4 (3.4)	25.8 (2.4)	33.0 (3.0)
Highest qualification	High school	10,637 (20%)	3,234 (21%)	799 (25%)	2,332 (25%)	532 (26%)	1,552 (16%)	472 (19%)	1,336 (15%)	380 (18%)

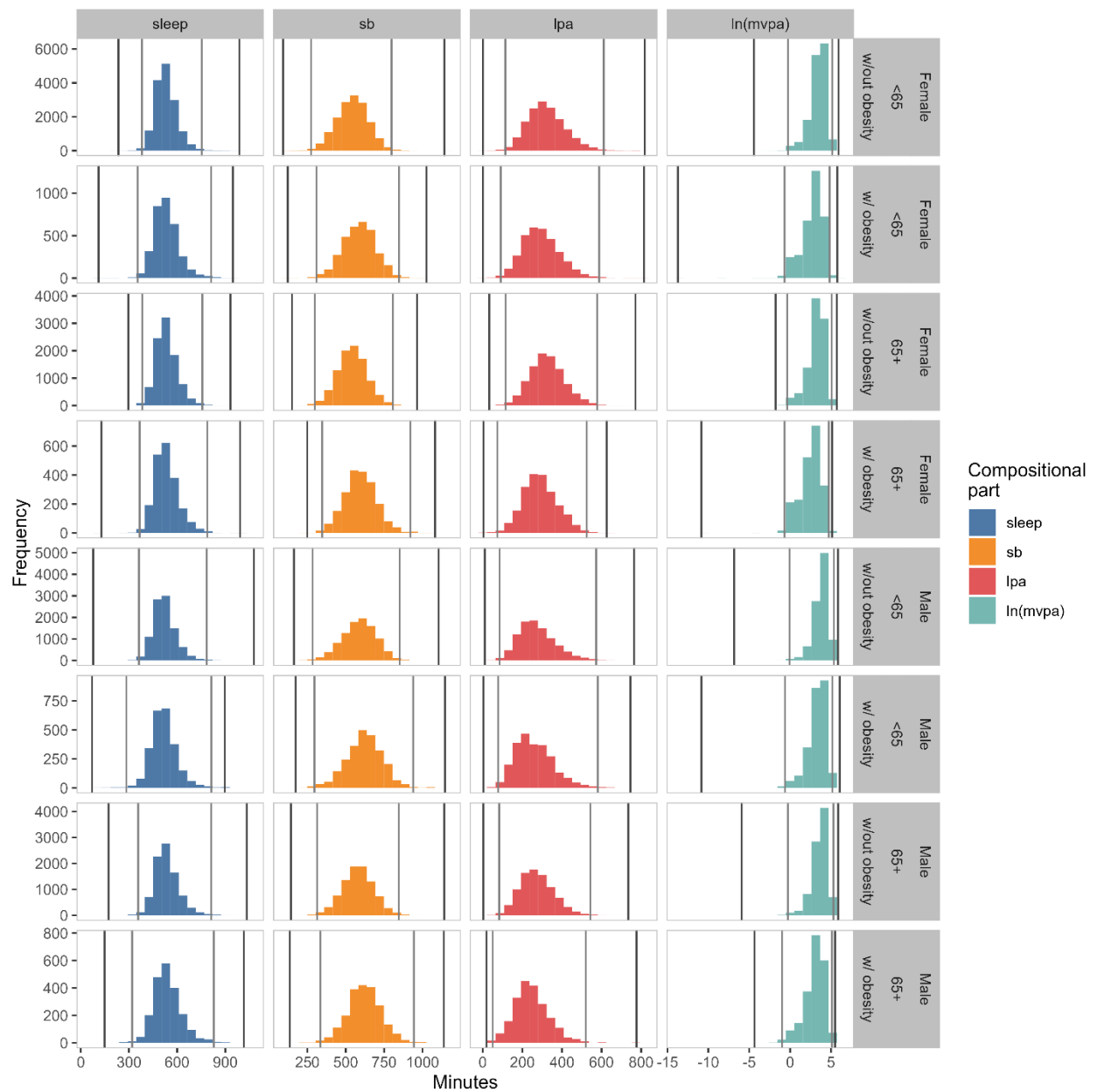| Characteristic	Level	Overall sample	Strata classification							
			Females, <65, wo/ obesity	Females, <65, w/obesity	Females, ≥65, wo/ obesity	Females, ≥65, w/obesity	Males, <65, wo/ obesity	Males, <65, w/obesity	Males, ≥65, wo/ obesity	Males, ≥65, w/obesity
	Certificate III or Diploma	5,805 (11%)	1,499 (9.8%)	424 (13%)	549 (5.8%)	176 (8.5%)	1,298 (14%)	404 (16%)	1,138 (13%)	317 (15%)
	College/University	24,742 (47%)	7,918 (52%)	1,336 (41%)	3,820 (40%)	638 (31%)	5,232 (54%)	1,012 (41%)	4,081 (46%)	705 (34%)
	Other professional qualification	8,092 (15%)	2,148 (14%)	520 (16%)	1,712 (18%)	401 (19%)	1,208 (13%)	420 (17%)	1,317 (15%)	366 (17%)
	Unknown	3,781 (7.1%)	504 (3.3%)	180 (5.5%)	1,052 (11%)	317 (15%)	320 (3.3%)	143 (5.8%)	937 (11%)	328 (16%)
	Yes	10,734 (20%)	3,470 (23%)	840 (26%)	1,977 (21%)	465 (23%)	1,658 (17%)	511 (21%)	1,422 (16%)	391 (19%)
Depression	No	9,141 (17%)	2,302 (15%)	400 (12%)	1,544 (16%)	338 (16%)	1,863 (19%)	443 (18%)	1,798 (20%)	453 (22%)
	Unknown	33,182 (63%)	9,531 (62%)	2,019 (62%)	5,944 (63%)	1,261 (61%)	6,089 (63%)	1,497 (61%)	5,589 (63%)	1,252 (60%)
	Yes	1,665 (3.2%)	157 (1.0%)	181 (5.6%)	160 (1.7%)	143 (6.9%)	166 (1.7%)	207 (8.4%)	357 (4.1%)	294 (14%)
Diabetes	No	51,295 (97%)	15,120 (99%)	3,071 (94%)	9,290 (98%)	1,915 (93%)	9,429 (98%)	2,233 (91%)	8,438 (96%)	1,799 (86%)
	Unknown	97 (0.2%)	26 (0.2%)	7 (0.2%)	15 (0.2%)	6 (0.3%)	15 (0.2%)	11 (0.4%)	14 (0.2%)	3 (0.1%)

Strata classification

Characteristic	Level	Overall sample	Females, <65, wo/obesity	Females, <65, w/obesity	Females, ≥65, wo/obesity	Females, ≥65, w/obesity	Males, <65, wo/obesity	Males, <65, w/obesity	Males, ≥65, wo/obesity	Males, ≥65, w/obesity
Hearing difficulty	Yes	12,713 (24%)	2,492 (16%)	667 (20%)	2,287 (24%)	557 (27%)	2,157 (22%)	641 (26%)	3,143 (36%)	769 (37%)
	No	38,221 (72%)	12,138 (79%)	2,401 (74%)	6,744 (71%)	1,412 (68%)	7,152 (74%)	1,731 (71%)	5,379 (61%)	1,264 (60%)
	Unknown	2,123 (4.0%)	673 (4.4%)	191 (5.9%)	434 (4.6%)	95 (4.6%)	301 (3.1%)	79 (3.2%)	287 (3.3%)	63 (3.0%)
Hypertension	Yes	12,595 (24%)	1,723 (11%)	949 (29%)	2,319 (25%)	924 (45%)	1,558 (16%)	948 (39%)	2,963 (34%)	1,211 (58%)
	No	40,390 (76%)	13,561 (89%)	2,304 (71%)	7,130 (75%)	1,135 (55%)	8,040 (84%)	1,501 (61%)	5,836 (66%)	883 (42%)
	Unknown	72 (0.1%)	19 (0.1%)	6 (0.2%)	16 (0.2%)	5 (0.2%)	12 (0.1%)	2 (<0.1%)	10 (0.1%)	2 (<0.1%)
Social isolation	Yes	7,851 (15%)	2,592 (17%)	777 (24%)	1,373 (15%)	376 (18%)	1,283 (13%)	447 (18%)	750 (8.5%)	253 (12%)
	No	44,584 (84%)	12,506 (82%)	2,443 (75%)	7,981 (84%)	1,661 (80%)	8,201 (85%)	1,983 (81%)	7,979 (91%)	1,830 (87%)
	Unknown	622 (1.2%)	205 (1.3%)	39 (1.2%)	111 (1.2%)	27 (1.3%)	126 (1.3%)	21 (0.9%)	80 (0.9%)	13 (0.6%)
Smoking status	Current	3,447 (6.5%)	1,000 (6.5%)	220 (6.8%)	366 (3.9%)	88 (4.3%)	851 (8.9%)	222 (9.1%)	562 (6.4%)	138 (6.6%)

Characteristic	Level	Overall sample	Females, <65, wo/ obesity	Females, <65, w/obesity	Females, ≥65, wo/ obesity	Females, ≥65, w/obesity	Males, <65, wo/ obesity	Males, <65, w/obesity	Males, ≥65, wo/ obesity	Males, ≥65, w/obesity
						Strata classification				
	Previous	18,960 (36%)	4,529 (30%)	1,090 (33%)	3,483 (37%)	845 (41%)	2,906 (30%)	968 (39%)	3,915 (44%)	1,224 (58%)
	Never	30,532 (58%)	9,743 (64%)	1,944 (60%)	5,589 (59%)	1,127 (55%)	5,837 (61%)	1,256 (51%)	4,312 (49%)	724 (35%)
	Unknown	118 (0.2%)	31 (0.2%)	5 (0.2%)	27 (0.3%)	4 (0.2%)	16 (0.2%)	5 (0.2%)	20 (0.2%)	10 (0.5%)
	Often/very often	12,415 (23%)	2,750 (18%)	337 (10%)	2,402 (25%)	314 (15%)	2,395 (25%)	519 (21%)	3,042 (35%)	656 (31%)
Alcohol consumption (frequency)	Sometimes/never	26,641 (50%)	8,474 (55%)	2,298 (71%)	4,818 (51%)	1,393 (67%)	4,282 (45%)	1,281 (52%)	3,231 (37%)	864 (41%)
	Unknown	14,001 (26%)	4,079 (27%)	624 (19%)	2,245 (24%)	357 (17%)	2,933 (31%)	651 (27%)	2,536 (29%)	576 (27%)
History of traumatic brain injury		106 (0.2%)	24 (0.2%)	3 (<0.1%)	16 (0.2%)	3 (0.1%)	29 (0.3%)	5 (0.2%)	20 (0.2%)	6 (0.3%)
	White	51,577 (97%)	14,765 (96%)	3,123 (96%)	9,320 (98%)	2,024 (98%)	9,276 (97%)	2,357 (96%)	8,658 (98%)	2,054 (98%)
Ethnicity	Non-white	1,480 (2.8%)	538 (3.5%)	136 (4.2%)	145 (1.5%)	40 (1.9%)	334 (3.5%)	94 (3.8%)	151 (1.7%)	42 (2.0%)
Days between accelerometry and cognitive testing		52 (232)	55 (234)	53 (233)	52 (232)	49 (226)	54 (232)	47 (228)	50 (231)	49 (235)

Supplementary File 6

Feasible limits of time-use behaviours within strata

Note. Histograms representing distribution of time-use behaviours (header) within each strata (listed on far right). Darker vertical lines within each facet represent the minimum and maximum values of the distribution. Grey vertical lines represent the truncating 0.5% percentile values at the distribution extremes (regarding ellipsoid fencing).