Establishing Physical Activity Guidelines

An Application of Shape Constrained Regression

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Introduction

- This talk is based in part on Development and Testing of an Integrated Score for Physical Behaviors by Keadle et al.
- Scan QR code to take you to the paper

SCAN ME

Motivation

- Common in epidemiology to take complicated multidimensional behavior and reduce it to a single interpretable number between 0 and 100
  - often called a composite score or an index
  - Ex: Healthy Eating Index
- Use this number to predict risk of disease
- Currently, no scoring system exist for physical activity.

Healthy Eating Index (HEI)

Component	Maximum points	Standard for maximum score	Standard for minimum score of zero
Total Fruit (includes 100% juice)	5	≥0.8 cup equiv. per 1,000 kcal	No Fruit
Whole Fruit (not juice)	5	≥0.4 cup equiv. per 1,000 kcal	No Whole Fruit
Total Vegetables	5	≥1.1 cup equiv. per 1,000 kcal	No Vegetables
Dark Green and Orange Vegetables and Legumes[2]	5	≥0.4 cup equiv. per 1,000 kcal	No Dark Green or Orange Vegetables or Legumes
Total Grains	5	≥3.0 oz equiv. per 1,000 kcal	No Grains
Whole Grains	5	≥1.5 oz equiv. per 1,000 kcal	No Whole Grains
Milk[3]	10	≥1.3 cup equiv. per 1,000 kcal	No Milk
Meat and Beans	10	≥2.5 oz equiv. per 1,000 kcal	No Meat or Beans
Oils[4]	10	≥12 grams per 1,000 kcal	No Oil
Saturated Fat	10	≤7% of energy[5]	≥15% of energy
Sodium	10	≤0.7 gram per 1,000 kcal[5]	≥2.0 grams per 1,000 kcal
Calories from Solid Fats, Alcoholic beverages, and Added Sugars (SoFAAS)	20	≤20% of energy	≥50% of energy

[1]Intakes between the minimum and maximum levels are scored proportionately, except for Saturated Fat and Sodium (see note 5).
[2]Legumes counted as vegetables only after Meat and Beans standard is met.
[3]Includes all milk products, such as fluid milk, yogurt, and cheese, and soy beverages.
[4]Includes nonhydrogenated vegetable oils and oils in fish, nuts, and seeds.
[5]Saturated Fat and Sodium get a score of 8 for the intake levels that reflect the 2005 Dietary Guidelines, <10% of calories from saturated fat and 1.1 grams of sodium/1,000 kcal, respectively.

Physical Activtiy Data

- We work with the NIH-AARP Study of Diet and Health
  - Adults between 50-71 year old
  - The self-report questionnaire asked how much time per week was spent in 16 different physical behaviors during the past 12 months.
  - The physical behaviors were categorized into 5 exercise or sport activities, two sitting behaviors and sleep.

Physical Activity Components

- Activity is broken down as:
  1. Light household activity: cooking, cleaning, laundry, dusting
  2. Moderate-vigorous household activity:vacuuming, sweeping weeding, raking, home repairs painting
  3. Moderate activity: walking for exercise, walking for other daily activities, playing golf
  4. Vigorous Exercise: playing tennis, swimming laps, bicycling, jogging
  5. Weight training
  6. Sitting watching television
  7. Other sitting: reading, knitting, using a computer
  8. Sleeping: at night or napping during the day

Inital Model

- How do the 8 physical activity components and additional covariates relate to overall health?
- Use a Generalized Additive Model (GAM) with **survival** as the outcomes of interest:

$$Pr(Y = 1|X, Z) = H\{\sum_{j=1}^{d} f_j(X_{ij}) + Z^T\theta\},$$

where $H(\cdot)$ is the logistic distribution function, X_{ij} are physical activity measurements, $f_j(\cdot)$ are unspecified smooth functions, and Z_i are covariates,

- Pros: Flexible model, doesn't require any parametric assumptions, no one has done this in the physical activity literature.

“Prior” Information

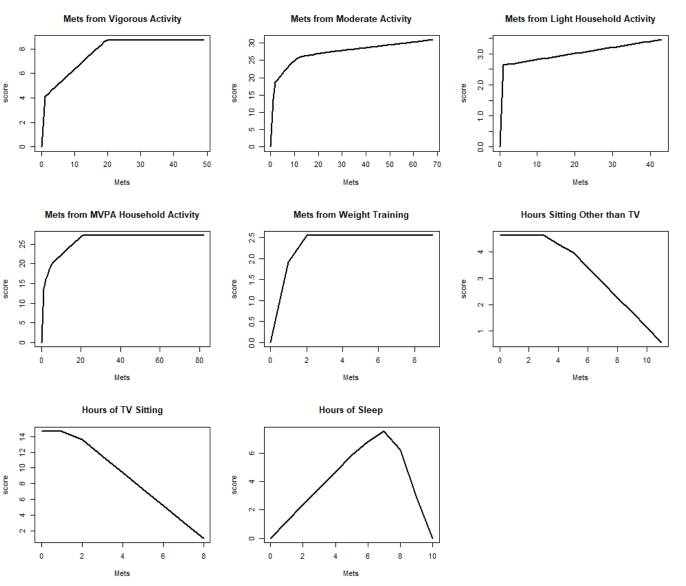
- Our collaborator gave us some additional information, some of which is common sense and some is unexpected:
  - Activity is always good for you but the effect levels off
  - No sleep is bad for you, sleep is good for your health until some change point which indicates poor health
  - Sitting is bad for your health but fine in moderation
- We can use this information to apply shape constraints to the individual functions, f_j, in the GAM.
- Two methods for doing this: SCAR (Yining Chen and Richard Samworth) and SCAM (Natalya Pya and Simon Wood)

Shape Constraints

Activity	Constraint
Vigorous Activity	Concave Increasing
Moderate Activity	Concave Increasing
Light Household Activity	Concave Increasing
MVPA Household Activity	Concave Increasing
Weight Training	Concave Increasing
Hours Sitting Other than TV	Concave Decreasing
Hours of TV Sitting	Concave Decreasing
Hours of Sleep	Concave

Each constraint is justified in the physical activity literature and make sense to our collaborators

Shape Constraints



Shape Constraints

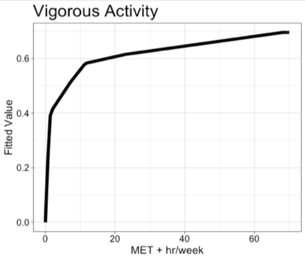


Figure 1: Aerobic Activity Concave, increasing

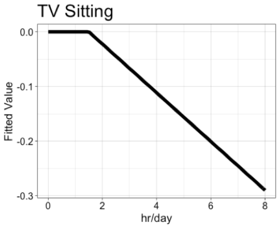


Figure 2: Sedentary Behavior:Concave, decreasing

Making a composite score

- Want our results to be on same scale as other composite scores
- We proportionally rescale the physical activity fitted values, $\sum_j f_j(x_{ij})$ to take values between 0 and 100.

Composite Score

Component	Contribution to Total	Criteria for Maximum
Vigorous Activity	10	$>$20 MET-hrs/wk
Moderate Activity	32	$>$50 MET-hrs/wk
Light Household Activity	3	$>$3 MET-hrs/wk
MVPA Household Activity	25	$>$20 MET-hrs/wk
Weight Training	3	$>$2 MET-hrs/wk
Sitting Other than TV	5	0 hours
Hours of TV Sitting	14	0 hours
Hours of Sleep	8	7.5 hours
Total	100	

Validation Concerns

- We've built a 0-to-100-score. Now we ask is our score meaningful?
  - Is a higher score (more physical activity) predictive of longer survival time?
- Ideal Scenario: Build a score for one population → validate on a different population
- Validation with a second dataset is not possible.

Validation Concerns

- Denote the new physical activity scores as $\mathcal{S}$, the covariates as Z, and time of death as t:

$$h(t) = h_0(t)exp(\beta\mathcal{S} + Z^T\theta)$$

- Is β estimated correctly? Is the variability of $\hat{\beta}$ estimated correctly?
- The hypothesis test $H_0 : \beta = 0$ is very important, indicates if $\mathcal{S}$ is useful.
  - Do not want to incorrectly reject $H_0 \rightarrow$ conclude $\mathcal{S}$ is predictive of mortality when it really is not.

Sample Splitting

- Possible Solution: Split the data in half into a "training" set and "test" set.
  - Can be highly variable, a single "lucky" split can cause us to underestimate standard error and improperly estimate coefficient (simulation error)
- Idea: Repeatedly split the data in half into training and test. Aggregate all the estimates
  - Explored by Meinshausen et. all (2008).
  - Variants of this technique are used in high dimensional variable selection literature, Wasserman and Roeder (2008), Lei et. all (2016)

This should reduce simulation error.

Sample Splitting Procedure

1. Split data in half, $b = 1, \ldots, B$ times to create B partitions of the data. Denote these partitions as $D_{in}^{(b)}$ and $D_{out}^{(b)}$
2. Fit shape constrained GAM on $D_{in}^{(b)}$.
3. Use the fitted value of the GAM to assign a score, $\mathcal{S}$ to every person in $D_{out}^{(b)}$. Run a cox regression using $D_{out}^{(b)}$ to get $\widehat{\beta}^{(b)}$ and p-value, $P^{(b)}$

New Estimates

- New estimate of β: $\widehat{\beta} = B^{-1} \sum_{b=1}^{B} \widehat{\beta}^{(b)}$
- Standard error: sample standard deviation of $\{\widehat{\beta}^{(b)} | b = 1, \ldots, B\}$
- New p-value is more complicated:
  - Define $Q(\gamma) = q_\gamma(\{P^{(b)}/\gamma; b = 1, \ldots, B\})$, where $q_\gamma(\cdot)$ is the γ^{th} quantile function
  - Search for the best quantile: $P = min\{1, (1 - log\gamma_{min}) \inf_{\gamma \in (\gamma_{min}, 1)} Q(\gamma)\}$

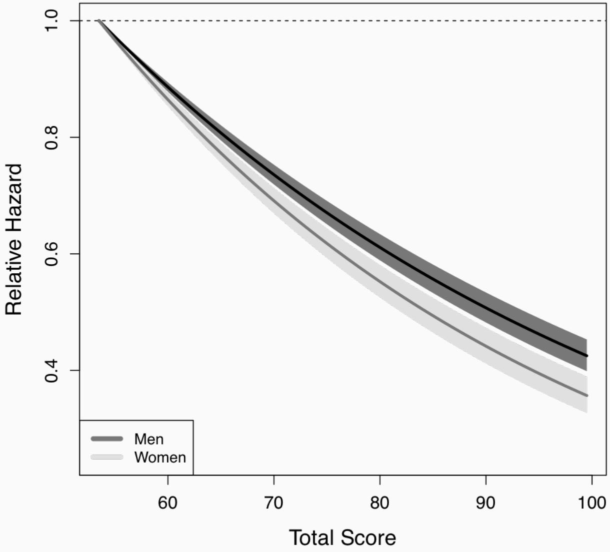
New Estimates

- Our estimate, $\widehat{\beta}$ is consistent and the Type-I error is controled.
- Justification is messy and technical. Involves a lot of frequentist asymptotics.
- Excluded it from this talk, talk to me after if you want more information.

Results

	coef	exp(coef)	se(coef)	Conf Int.	p-value
PA Score Quintile 1	·	·	·	·	
PA Score Quintile 2	-0.27	0.76	0.021	(0.73, 0.80)	0
PA Score Quintile 3	-0.39	0.68	0.023	(0.65, 0.71)	0
PA Score Quintile 4	-0.51	0.60	0.024	(0.57, 0.63)	0
PA Score Quintile 5	-0.61	0.54	0.027	(0.52, 0.57)	0

Results


Relative Hazard
1.0
0.8
0.6
0.4
Men
Women
60
70
80
90
100
Total Score