National Cancer Institute

measurement ERROR webinar series

Combining self-report dietary assessment instruments to reduce the effects of measurement error

Douglas Midthune
National Cancer Institute

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
National Institutes of Health

measurement ERROR webinar series

This series is dedicated to the memory of

Dr. Arthur Schatzkin

In recognition of his internationally renowned contributions to the field of nutrition epidemiology and his commitment to understanding measurement error associated with dietary assessment.

Presenters and Collaborators

Sharon Kirkpatrick
Series Organizer

Regan Bailey	Laurence Freedman	Douglas Midthune
Dennis Buckman	Patricia Guenther	Amy Subar
Raymond Carroll	Victor Kipnis	Fran Thompson
Kevin Dodd	Susan Krebs-Smith	Janet Tooze

Wake Forest School of Medicine · The Gertner Institute · STATISTICS Texas A&M University

Learning objectives

- Understanding how measurement error leads to loss of precision in estimating diet-health associations
- Learning how to combine self-report dietary instruments to regain precision and improve power to detect associations
- Understanding the limitations of such an approach

Why combine self-report instruments? → Regression calibration → Comparing study designs → Limitations and other considerations → Summary

WHY COMBINE SELF-REPORT INSTRUMENTS?

Impact of measurement error

- Measurement error (ME) in self-report dietary assessment instruments leads to:
  - Bias (attenuation) in estimated diet-health associations
  - Loss of precision in estimated associations

    $E(\alpha_Q) / s.e.(\alpha_Q) < E(\alpha_T) / s.e.(\alpha_T)$
  - Loss of power to detect associations

Why combine self-report instruments?

Impact of measurement error

- Statistical methods such as regression calibration can correct for bias due to measurement error
- These methods do not typically recover lost precision or power

Why combine self-report instruments?

Impact of measurement error

- Ways to improve precision and power
  - Increase the sample size
  - Decrease the measurement error
    - Improve existing dietary instruments
    - Develop new instruments
    - **Combine different self-report dietary instruments**

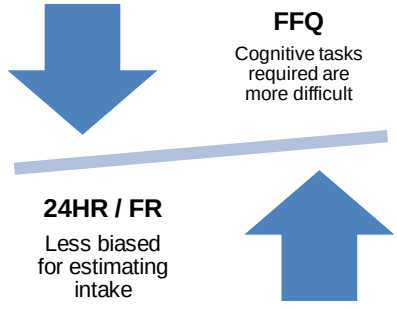
Why combine self-report instruments?

Combining instruments

- Examples of self-report instruments that could be combined:
  - Food frequency questionnaire (FFQ)
  - 24-hour dietary recall (24HR)
  - Multiple-day food record (FR)
- Each instrument has its own strengths and weakness

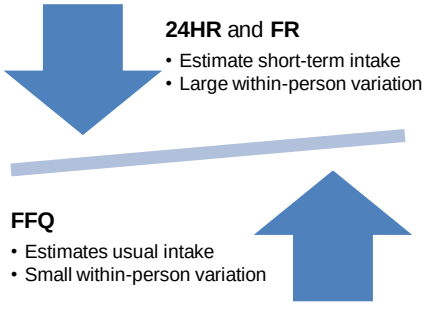
Why combine self-report instruments?

Self-report dietary instruments



Why combine self-report instruments?

Self-report dietary instruments



Why combine self-report instruments?

Self-report dietary instruments

- Potential for significant gain in precision by combining instruments with different types of information
  - FFQ measures long-term diet
  - 24HR/FR less bias, measure short-term diet
- Problem:
  - Traditional 24HR and FR are expensive to administer and/or process
  - Not practical for use in large cohort studies

Self-report dietary instruments

- Recent developments in dietary assessment
  - Self-administered automated 24HR, such as the ASA24 (NCI)
  - Automated FR, some using mobile phone technology
  - Much less expensive than traditional 24HR/FR
  - Practical for use in large cohort studies

USING REGRESSION CALIBRATION TO COMBINE SELF-REPORT INSTRUMENTS

Regression calibration

- **Regression calibration** corrects estimated diet-health associations for bias due to ME in reported intake
  - (Relatively) simple and intuitive
  - Applicable in many situations (e.g., linear and logistic regression, survival analysis)
  - Often nearly as efficient as maximum likelihood estimation
  - Extends naturally to combine multiple instruments

Review of regression calibration

- Diet-health model:

$$\text{Log}\{\text{Odds}(Y=1)\} = \alpha_0 + \alpha_T T$$

  - Y = health outcome variable (0 or 1)
  - Odds(Y=1) = Prob(Y=1) / Prob(Y=0)
  - T = **true** usual dietary intake (**unobserved**)
  - α_T = log odds ratio (quantifies diet-health association)
  - R = **self-reported** dietary intake (**observed**)

Review of regression calibration

- Diet-health model:

$$\text{Log}\{\text{Odds}(Y=1)\} = \alpha_0 + \alpha_T \cancel{T}$$ E(T|R)

Prediction equation: $E(T \mid R) = \lambda_0 + \lambda_1 R$

- Regression calibration: **replace T** with its **predicted value E(T | R)** in diet-health model and perform standard analysis
- E(T | R) is the **conditional expectation** (mean) of true intake T given reported intake R
- E(T | R) is the **best** predictor of T given R

Review of regression calibration

- Diet-health model:

$$\text{Log}\{\text{Odds}(Y=1)\} = \alpha_0 + \alpha_T \cancel{T}$$ E(T|R)

- **Assumption**:
  - R has "**nondifferential error**" with respect to disease Y
  - R provides no information about disease Y beyond that provided by T
- Under this assumption, regression calibration estimates are (approximately) **unbiased**

Using RC to combine instruments

Review of regression calibration

- Diet-health model:

$\text{Log\{Odds}(Y=1)\} = \alpha_0 + \alpha_T E(T|R)$

Prediction equation: $E(T \mid R) = \lambda_0 + \lambda_1 R$

- Predicted value $E(T \mid R)$ provides no more **information** about true intake than R
- As a result, regression calibration does **not** recover **power** lost due to measurement error

Using RC to combine instruments

Can RC be made more powerful?

- If we can **improve prediction** of true intake, we can increase precision and power

Improve **Prediction** of True Intake → Reduce ME → Improve **Power** to Detect Diet-Health Associations

Using RC to combine instruments

Can RC be made more powerful?

- **Conditional expectation** is the best predictor of true intake T
  - **Q**: How can we improve prediction if the RC predictor is already the "best"?
  - **A**: Conditional expectation is the best predictor of true intake given reported intake (given the information provided)
- Can improve prediction by adding information

Using RC to combine instruments

Enhanced regression calibration

- Enhanced RC: predict T using E(T| R,C), where C is an additional variable that:
  1. Helps to **predict** true intake, but
  2. Not related to health outcome given **true** intake
     - Not a confounder
     - Has nondifferential error
- Requirement 2) crucial: if C is related to intake, estimated diet-health association will be **biased**
- Additional **self-report** instruments seem to be perfect candidates for enhanced regression calibration

Using RC to combine instruments

Example: Enhanced RC

- Enhanced RC with two 24HR (R) and FFQ (Q)
  - Assumption: 24HR **unbiased** for true intake
  - Prediction equation:

$$E(T \mid R_1, R_2, Q) = w \times \bar{R} + (1-w) \times E(T \mid Q)$$

  - $\bar{R}$ = mean of two 24HR
  - w = var(u) / {var(u) + var(e) / 2}
  - var(u) = between-person variance in 24HR
  - var(e) = within-person variance in 24HR
- Parameters estimated in **linear mixed effects model**

Why combine self-report instruments? → Regression calibration → Comparing study designs → Limitations and other considerations → Summary

COMPARING DIFFERENT COMBINATIONS OF SELF-REPORT INSTRUMENTS

Comparing study designs

- In remainder of talk, we compare 3 possible **study designs** (or dietary assessment **strategies**) for estimating dietary intake:
  - **FFQ** alone: one FFQ per subject
  - **24HR** alone: one or more 24HR per subject
  - **24HR** and **FFQ**: one FFQ and one or more 24HR per subject
- **Carroll et al.** Taking advantage of the strengths of two different dietary assessment instruments to improve intake estimates for nutritional epidemiology. *Am J Epidemiol*. (in press)

Comparing study designs

- Study designs evaluated by ability to predict true intake (detect diet-health associations)
- **R-squared** value of the predictor
  - The R-squared value of a predictor is defined as the **squared correlation coefficient** between true and predicted intake
  - Equivalently, it can be thought of as the **proportion of variation** in true intake that is explained by the predictor

Why is the R-squared value important?

- R-squared value is a direct measure of the ability to predict true intake
- R-squared value determines:
  - **Variance** (precision) of estimated diet-health association
  - **Power** to detect the association
  - **Sample size** needed to obtain desired power

EATS study

- Comparisons based on data from the Eating at America's Table Study (EATS)
  - Conducted 1997-1998
  - Representative sampling of U.S. population
  - 965 men and women, aged 20-70

EATS study

- Dietary instruments:
  - Four 24HR
    - Administered 3 months apart
    - By telephone
    - Multiple-pass methodology (USDA)
  - One FFQ
    - Diet History Questionnaire (NCI)

EATS study

- Dietary variables:
  - Total fat
  - Whole grains
  - Dark-green vegetables
- Dietary variables are energy-adjusted (residual method)
- Carroll et al. looked at 10 dietary components, both unadjusted for energy and energy-adjusted

Comparing different combinations

Assumptions

Assumptions:

- **24HR** provides an **unbiased** estimate of true usual intake for each individual
- **24HR** and **FFQ** have **non-differential** error with respect to health outcome

Comparing different combinations

Comparing study designs

- Comparison does not explicitly consider **cost** of study designs (will be discussed later)
- To simplify comparison, will ignore uncertainty due to estimating parameters in the prediction equation

Comparing different combinations

Comparing study designs

- Study designs (dietary assessment strategies):
  1. Single **FFQ**
  2. From one to twelve **24HR**
  3. Single **FFQ plus** from one to twelve **24HR**
- Since subjects in EATS completed only four 24HR, must simulate 5 or more
- **FFQ plus twelve 24HR** is the "best" study design
  - Adding information always improves prediction
  - More than twelve 24HR may impose unreasonable burden

Comparing different combinations

Research questions

- Research questions:
  1. Does a single **FFQ** work better or worse than (one or more) **24HR**?
  2. How many **24HR** per subject?
  3. How much does adding the **FFQ** improve the performance of the **24HR** (and vice versa)?
  4. Is it better to add another **24HR** or add the **FFQ**?

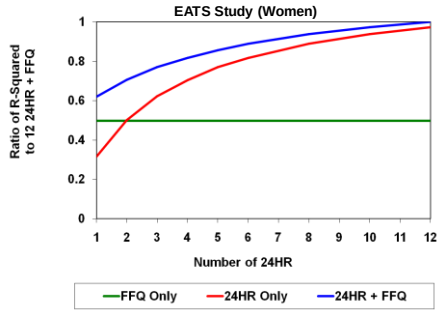
Comparing different combinations

Graphical comparisons

- Three ways of looking at the data:
  - R-squared value
  - Power to detect diet-health associations
  - Sample size needed to achieve 90% power
- Comparisons relative to the "best" predictor = **FFQ plus twelve 24HR**
- Results presented for women (results for men are similar)

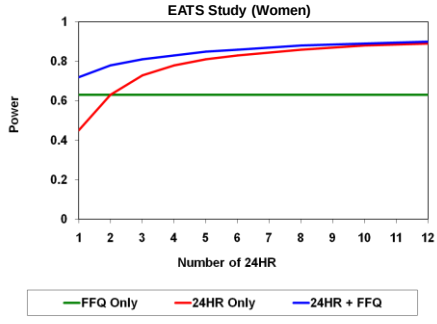
Comparing different combinations

Ratio of R-squared values: total fat



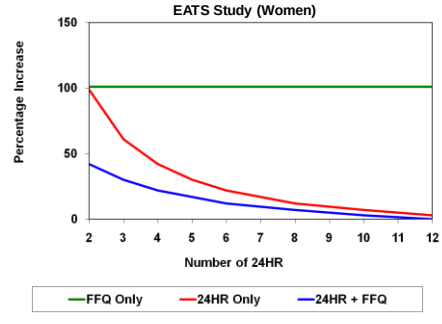
Comparing different combinations

Power to detect association: total fat



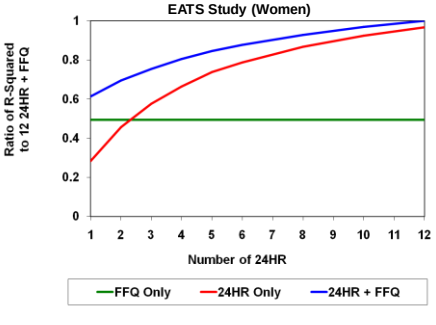
Comparing different combinations

Percentage increase in sample size: total fat



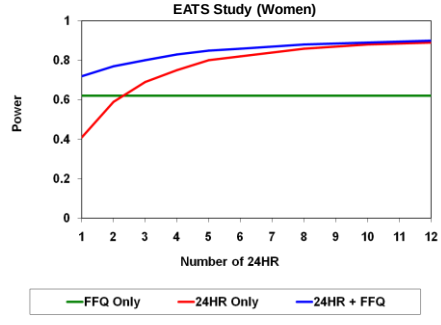
Comparing different combinations

Ratio of R-squared values: whole grains



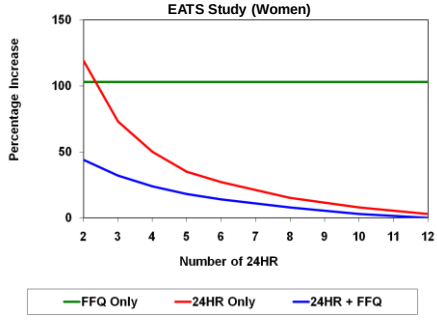
Comparing different combinations

Power to detect association: whole grains



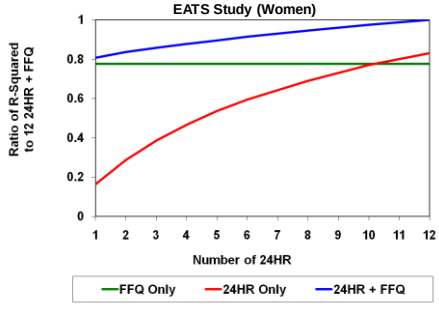
Comparing different combinations

Percentage increase in sample size: whole grains



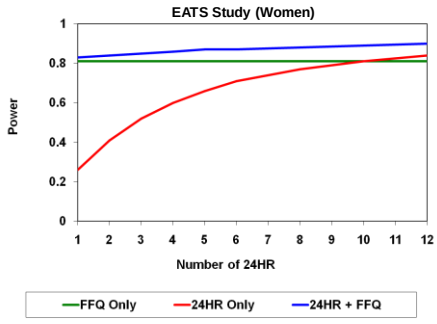
Comparing different combinations

Ratio of R-squared values: dark-green vegetables



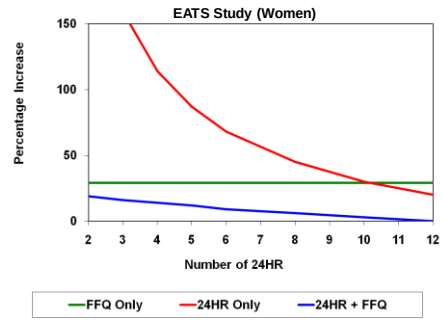
Comparing different combinations

Power to detect association: dark-green vegetables



Comparing different combinations

Percentage increase in sample size: dark-green vegetables



Comparing different combinations

Summary of comparisons

- In general, calibrated FFQ performs about as well as two 24HR
- For some dietary variables (e.g. dark-green veg.) FFQ performs better than 6 or more 24HR
- Using 4-6 24HR seems to capture most of the information available in 24HR

Comparing different combinations

Summary of comparisons

- Combining FFQ and 24HR can lead to substantial gains over either alone
- Adding an FFQ to a 24HR is usually better than adding a second 24HR
- For **episodically-consumed** dietary components, it may be especially important to include an FFQ

Why combine self-report instruments? → Regression calibration → Comparing study designs → Limitations and other considerations → Summary

LIMITATIONS AND OTHER CONSIDERATIONS

Limitations and other considerations

Limitations of comparisons

- Had to simulate 5 or more 24HR (assumes quality will not drop off)
- Study designs with FFQ alone or just a single 24HR require a **calibration sub-study** of participants who complete two 24HR
- Did not take into account the **uncertainty** due to estimating parameters in prediction equation
- Assumed that the 24HR provided an **unbiased** estimate of true intake for each individual

Limitations and other considerations

Limitations of comparisons

- Studies with **reference biomarkers** of intake (doubly-labeled water for total energy, urinary nitrogen for protein) have shown that 24HR are biased for these nutrients
- In general, incorrectly assuming that the 24HR is unbiased leads to:
  - **Biased** estimates of diet-health associations
  - **Invalid comparisons** of precision and power, unless bias is the same for all instruments

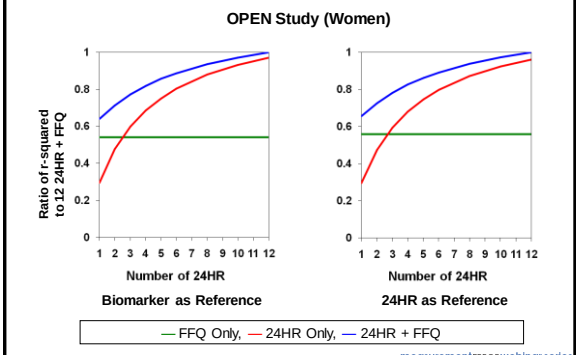
Limitations and other considerations

OPEN study

- Use OPEN to examine effect of **biased** 24HR
- OPEN study (1999-2000)
- 484 men and women, aged 40-69
- Dietary Assessment:
  - **FFQ** (2 per subject)
  - **24HR** (2 per subject)
  - **Reference biomarkers** for energy, protein and potassium

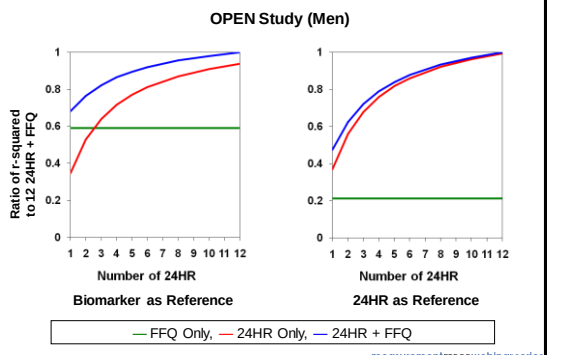
Limitations and other considerations

Ratio of R-squared values: protein



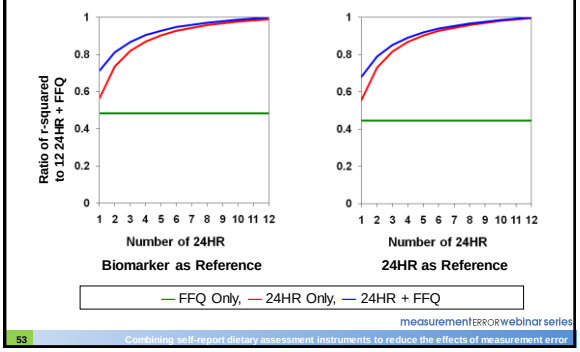
Limitations and other considerations

Ratio of R-squared values: protein



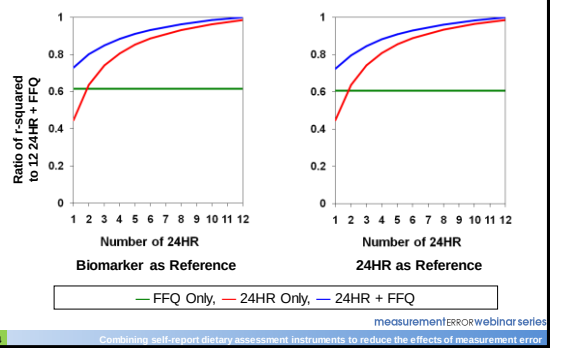
Limitations and other considerations

Ratio of R-squared values: potassium



Limitations and other considerations

Ratio of R-squared values: potassium



Limitations and other considerations

Summary of OPEN study

- In 3 out of 4 cases, assuming 24HR is unbiased produces very similar comparisons as **reference biomarkers** known to be unbiased
- When comparing study designs assuming 24HR is unbiased
  - Conclusions about any **particular** dietary component may or may not be valid
  - Conclusions about **general patterns** that are consistent over many dietary components are probably valid

Limitations and other considerations

Is it worth the cost?

- Gain in precision vs. cost
- 24HR and FR impose substantial burden on participants
- New automated 24HR/FR reduce cost but not burden

Limitations and other considerations

Other questions

- How many 24HR can we reasonably expect participants to complete?
  - Response rates?
  - Declining quality?
- Will automated 24HR perform as well as the traditional 24HR?
- Will FR perform similarly to 24HR?
  - Does a 4-day FR = four 24HR?

Limitations and other considerations

Looking for answers

- Biomarker studies designed to answer these questions (and more)
  - Six ASA24
  - Two FR
  - Two FFQ
  - Biomarkers of energy, protein and potassium
  - Also: ACT24 (physical activity), accelerometers, blood

Limitations and other considerations

Repeat FFQ?

- What about using more than one FFQ?
  - Less within-person variation, so less potential for gain in precision
  - Challenges in interpretation:

    Do differences in two FFQ taken 1 year apart reflect random within-person error or a real change in diet?

    How to define true usual intake if diet is changing over time?

SUMMARY

Summary

Summary

- Combining self-report dietary instruments can lead to significant improvement in estimating diet-health associations
- Regression calibration is an effective way to combine instruments

Summary

Summary

- 4-6 24HR capture most of the information available in 24HR
- Adding FFQ to 1 or more 24HR generally improves prediction more than adding another 24HR

Summary

Summary

- When designing diet-health studies, one should consider using FFQ plus 4-6 24HR to measure diet
- Other factors such as **cost** and participant **burden** must also be considered and balanced with need for **precision** and **power**

Summary

Summary

- These conclusions:
  - Apply to estimating diet-health relationships (predicting individual intake)
  - Do not apply to estimating population distributions of dietary intake
- Tooze et al. (*J Am Diet Assoc*, 2006) found that adding FFQ to two 24HR did not improve estimated population distributions

QUESTIONS & ANSWERS

Moderator: Amy Subar

Please submit questions using the *Chat* function

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Next Session

Tuesday, November 29, 2011
10:00-11:30 EST

Combining self-report dietary intake data and biomarker data to reduce the effects of measurement error

Laurence Freedman
Gertner Institute