Item Response Theory and Computerized Adaptive Testing

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Outline

- Item Response Theory
  - versus Classical Test Theory
- Uses of IRT
  - Item Banking
  - Short Forms
  - Computerized Adaptive Tests
Requirements for Measurement

- Measurement requires the concept of an underlying trait that can be expressed in terms of more or less
- Test items are the operational definition of the underlying trait
- Test items can be ordered from easy to hard
- Test takers can be ordered from less able to more able
IRT Modeling is Latent Trait Modeling

- A latent trait is an \textit{unobservable} latent dimension that is thought to give rise to a set of observed item responses.

I am too tired to do errands

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<th>False</th>
<th>True</th>
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<tr>
<th>Energetic</th>
<th>Severe</th>
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Fatigue
Latent Traits (cont.)

- These latent traits (constructs, variables, $\theta$) are measured on a *continuum* of severity.

I am too tired to do errands?

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<th>Energetic</th>
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<th>True</th>
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Fatigue
Test-takers and Items are Represented on the Same Scale
Are you able to get in and out of bed?
Are you able to walk a block on flat ground?
Are you able to run five miles?
More Basic Terms

- **Discrimination** = the degree to which an item discriminates person ability

- **Item Information** = the area where an item discriminates

- **Test Information** = the area where the test discriminates
Item “Parameters”

- IRT statistics about an item
- Primary: Item Difficulty
- Often: Item Discrimination
- Sometimes: Guessing
- Lots of other “ugly looking numbers”
Differential Item Functioning (DIF)

- Does an item have different item parameters for different subgroups?
- Gender
- Race
- Age
- Disease
The Three Main IRT Models

- Rasch model one parameter logistic model (1PL)
- Two parameter logistic model (2PL)
- Three parameter logistic model (3PL)
How to choose an appropriate IRT Model
OR
My religion is better than your religion!
WARNING!
You are about to see mathematical formulas!
One Parameter Logistic Model

\[ P_{1,0} = \frac{e^{(ability - difficulty)}}{1 + e^{(ability - difficulty)}} \]

When the difficulty of a given item exactly matches the Examinee’s ability level, then the person has 50% chance of answering that item correctly:

\[ P_{1,0} = \frac{e^{(0)}}{1 + e^{(0)}} = \frac{1}{2} = .50 \]
One Parameter Logistic Model

- Only option for small sample sizes
- Often the real model underlying a test labeled as three parameter
- Less costly
- “The simple solution is always the best”
Two Parameter Logistic Model

\[ P_{1,0} = \frac{e^{a(\text{ability} - b)}}{1 + e^{a(\text{ability} - b)}} \]

Two parameters
- a = Discrimination
- b = Item Difficulty
Two Parameter Examples

![Item Response Function](image1)

- $a=.5, b=.5$

![Item Response Function](image2)

- $a=1.5, b=.5$

![Item Response Function](image3)

- $a=2.5, b=.5$
Three Parameter Logistic Model

\[ P_{1,0} = c + (1-c) \frac{e^{a(\text{ability} - b)}}{1 + e^{a(\text{ability} - b)}} \]

Three parameters

- \( a \)= Discrimination
- \( b \)= Item Difficulty
- \( c \)= Guessing
Three Parameter Logistic Model (3PL)

- Requires a large sample size
- Significant research demonstrating that theoretically 3PL is better, but practically has little advantage over 1PL
- “Most accepted theoretical model”
Three Parameter Examples

\[ a=1.5, b=.5, c=.1 \quad \text{and} \quad a=2.5, b=.5, c=.25 \]
Polytomous Models

One Parameter
- Rating Scale Model
- Partial Credit Model

Two Parameter
- Graded Response Model
- Generalized Partial Credit Model
How does IRT differ from conventional test theory?
Classical Test Theory

- An individual takes an assessment
- Their total score on that assessment is used for comparison purposes
- High Score – The person is higher on the trait
- Low Score – The person is lower on the trait
Item Response Theory

- Each individual item can be used for comparison purposes
- Person endorses better rating on “hard items” - The person is higher on the trait
- Person endorses worse rating on “easy items” - The person is lower on the trait
- Items that measure the same construct can be aggregated into longer assessments
Reliability

**CTT**
- Reliability is based upon the total test.
- Regardless of patient “ability”, reliability is the same.

**IRT**
- Reliability is calculated for each patient “ability” and varies across the continuum.
- Typically, there is better reliability in the middle of the distribution.
# Validity

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| - Validity is based upon the total test.  
- Typically, validity would need to be re-assessed if the instrument is modified in any way. | - Validity is assessed for the entire item bank.  
- Subsets of items (full length tests, short forms and CAT) all inherit the validity assessed for the original item bank. |
Raw Scores vs. IRT Measures
IRT has Equal Interval Measurement

4 Item Test

Raw:

---
1 | 2 | 3 | 4
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Logit Measures:

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1.00 | 1.25 | 1.50 | 2.50
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I Have a Lack of Energy

Traditional Test Theory

4 = Not at All  3 = A Little Bit  2 = Somewhat  1 = Quite a Bit  0 = Very Much
I Have a Lack of Energy

Traditional Test Theory

4 = Not at All    3 = A Little Bit    2 = Somewhat    1 = Quite a Bit    0 = Very Much

Item Response Theory

Trait Measure
The IRT “Reality” of a 10 Point Rating-Scale Item

No Pain

Worst Pain
This is an Item Characteristic Curve (ICC) for a rating scale item (each option has its own curve)

4 = Not at All 3 = A Little Bit 2 = Somewhat 1 = Quite a Bit 0 = Very Much
I have a lack of energy

Trait Measure

Probability Curve

4 = Not at All  3 = A Little Bit  2 = Somewhat  1 = Quite a Bit  0 = Very Much
I have a lack of energy

4 = Not at All 3 = A Little Bit 2 = Somewhat 1 = Quite a Bit 0 = Very Much
I have a lack of energy

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I have a lack of energy

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IRT Polytomous Responses

I have been too tired to feel happy.
IRT Polytomous Responses

I have felt energetic

- None of the time
- A little of the time
- Some of the time
- Most of the time
- All of the time

Probability of Response
IRT Polytomous Responses

I have been too tired to read

None of the time
A little of the time
Some of the time
Most of the time
All of the time
Item Banking
Calibrated Item Banks can be used to Create Numerous Instrument Types

**Short Forms**
- 5-7 Items in each HRQL Area
- Constructed to cover full range of trait
- OR
- Multiple forms constructed to only cover a narrow range of trait (e.g., high, medium, or low)

**Emotional Distress**
- Pain

**Physical Function Item Bank**
- Item40
- Item38
- Item36
- Item34
- Item32
- Item30
- Item28
- Item26
- Item24
- Item22
- Item20
- Item18
- Item16
- Item14
- Item12
- Item10
- Item8
- Item6
- Item4
- Item2

**Computerized Adaptive Testing (CAT)**
- Custom individualized assessment
- Suitable for clinical use
- Accuracy level chosen by researcher

**Custom Item Selection**

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<th>Breast Cancer</th>
<th>Brain Tumor</th>
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- 3 Diseases
- 3 Trials
- 3 Unique Instruments
- Each based on content interest of individual researchers

Short Forms

5-7 Items in each HRQL Area

- Constructed to cover full range of trait
- OR
- Multiple forms constructed to only cover a narrow range of trait (e.g., high, medium, or low)

Emotional Distress

Pain

Physical Function

Item Bank

Physical Functioning Item Bank

Physical Function Form A

Physical Function Form B

Physical Function Form C

Item 1
Item 2
Item 3
Item 4
Item 5
Item 6
Item 7
Item 8
Item 9
Item 10
Item 11
Item 12
Item 13
Item 14
Item 15
Item 16
Computerized Adaptive Testing (CAT)

- Custom individualized assessment
- Suitable for clinical use
- Accuracy level chosen by researcher

Custom Item Selection

- Emotional Distress
- Pain
- Physical Function

Item Bank:
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- Item 12
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- Item 6
- Item 4
- Item 2

Prostate Cancer:
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Brain Tumor:
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- 3 Diseases
- 3 Trials
- 3 Unique Instruments
- Each based on content interest of individual researchers

In Summary, Calibrated Item Banks can be used to:

- Create a standard static instrument
- Construct short forms
- Enable CAT
- Select items based on unique content interests and formulate custom short-form or full-length instruments
In every case, using a validated, pre-calibrated item bank allows any of these instruments to be pre-validated and produce standardized scores on the same scale.
What is Computerized Adaptive Testing?

- Shorter
- Targeting
- Computerized Algorithm
CAT in the Military

- Armed Services Vocational Aptitude Battery (ASVAB)
CAT for Certification

AANA
American Association of Nurse Anesthetists

ASCP
American Society of Clinical Pathology

CompTIA

Microsoft
CAT for Licensure

AMERICAN DIETETIC ASSOCIATION

NASD

National Council of State Boards of Nursing, Inc.
CAT for College Entrance

ACCUPLACER OnLine
Low Able  Pass Point  High Able

PASS!
Example – Binary Search

- Binary search
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Simulate Measure = 48

GP1 – I have a lack of energy

0 = Very Much  1 = Quite a Bit  2 = Somewhat  3 = A Little Bit  4 = Not at All
Simulate Measure = 48

GP1 – I have a lack of energy

0 = Very Much; 1 = Quite a Bit; 2 = Somewhat; 3 = A Little Bit; 4 = Not at All
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Simulate Measure = 48
### Simulate Measure = 15

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This is called a “ceiling” effect. The test doesn’t have good items to assess people at the “ceiling” of the trait range.

If the test didn’t have items to assess people at the bottom of the trait range this would be called a “floor” effect.
Item Response Theory and Computerized Adaptive Testing

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Feinberg School of Medicine
Northwestern University
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November 15, 2011