Lesson 5: Differential Item Functioning

Patrícia Martinková

Department of Statistical Modelling
Institute of Computer Science, Czech Academy of Sciences

NMST 570, December 12, 2017

Contents

Motivation: Development and Validation of HCI

Complex validation of Homeostasis Concept Inventory (HCI)

McFarland et al. Development and Validation of the Homeostasis Concept Inventory. *CBE Life Sciences Education*, vol. 16 no. 2 ar35, 2017. doi 10.1187/cbe.16-10-0305

Motivation: Development and Validation of HCI

Complex validation of Homeostasis Concept Inventory (HCI)

- Males / English as a first language / White and Asian students performed better

McFarland et al. Development and Validation of the Homeostasis Concept Inventory. *CBE Life Sciences Education*, vol. 16 no. 2 ar35, 2017. doi 10.1187/cbe.16-10-0305

Motivation: Development and Validation of HCI

Complex validation of Homeostasis Concept Inventory (HCI)

- Males / English as a first language / White and Asian students performed better

Is the test fair?

McFarland et al. Development and Validation of the Homeostasis Concept Inventory. *CBE Life Sciences Education*, vol. 16 no. 2 ar35, 2017. doi 10.1187/cbe.16-10-0305

Motivation: Development and Validation of HCI

Differential Item Functioning (DIF) Analysis

- Analytical method to address item fairness
- Ubiquitous in large-scale assessments development
- Less used in conceptual assessment development

Martinková et al. Checking Equity: Why DIF Analysis should be a Routine Part of Developing Conceptual Assessments. *CBE Life Sciences Education*, 16(2), rm2. doi 10.1187/cbe.16-10-0307

Motivation: Development and Validation of HCI

Differential Item Functioning (DIF) Analysis

- Analytical method to address item fairness
- Ubiquitous in large-scale assessments development
- Less used in conceptual assessment development

- None of the HCI items exhibited DIF
  - with respect to gender, ethnicity or ELL status

Martinková et al. Checking Equity: Why DIF Analysis should be a Routine Part of Developing Conceptual Assessments. *CBE Life Sciences Education*, 16(2), rm2. doi 10.1187/cbe.16-10-0307

Motivation: Development and Validation of HCI

Differential Item Functioning (DIF) Analysis

- Analytical method to address item fairness
- Ubiquitous in large-scale assessments development
- Less used in conceptual assessment development

- None of the HCI items exhibited DIF
  - with respect to gender, ethnicity or ELL status

Methods paper: Importance of DIF Analysis

Martinková et al. Checking Equity: Why DIF Analysis should be a Routine Part of Developing Conceptual Assessments. *CBE Life Sciences Education*, 16(2), rm2. doi 10.1187/cbe.16-10-0307

Differential Item Functioning

Differential Item Functioning (DIF)

Two subjects with the same underlying ability but from different groups have different probability to answer question correctly

Differential Item Functioning

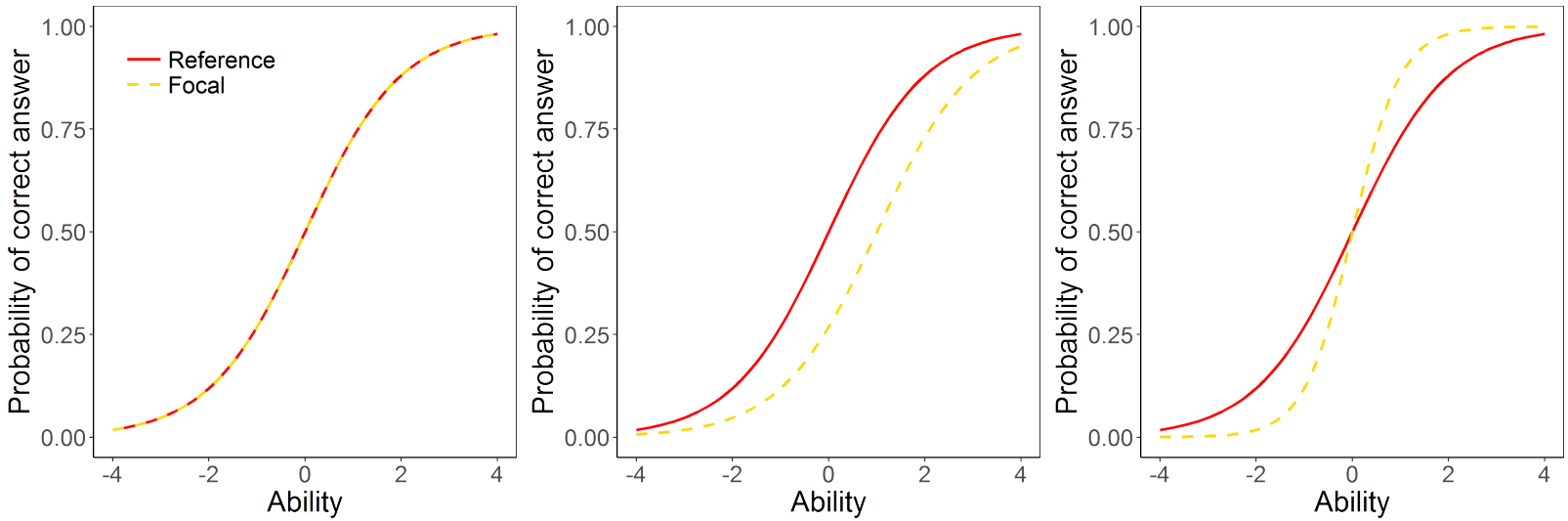
Differential Item Functioning (DIF)
Two subjects with the same underlying ability but from different groups have different probability to answer question correctly

- Two groups referred to as reference and focal (usually minority)

Differential Item Functioning

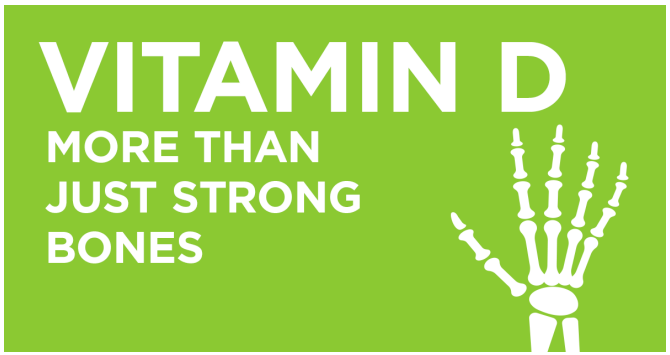
Differential Item Functioning (DIF)
Two subjects with the same underlying ability but from different groups have different probability to answer question correctly

- Two groups referred to as reference and focal (usually minority)
- Two types of DIF - uniform and non-uniform



Example of DIF item

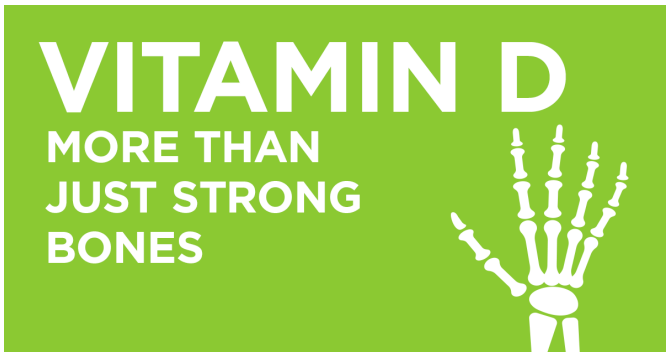
Childhood illnesses (Drabinová & Martinková, 2017)



Deficiency of vitamin D in childhood could cause

Example of DIF item

Childhood illnesses (Drabinová & Martinková, 2017)

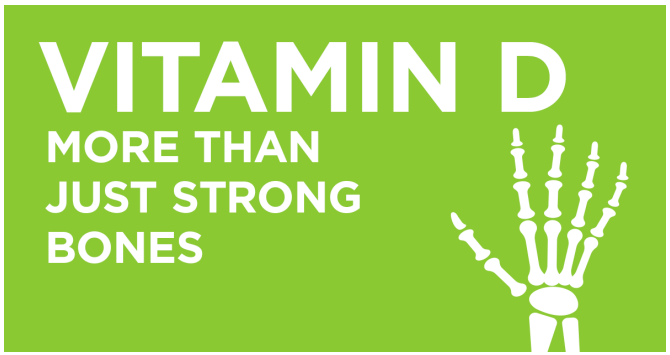


Deficiency of vitamin D in childhood could cause

a. rickets

Example of DIF item

Childhood illnesses (Drabinová & Martinková, 2017)



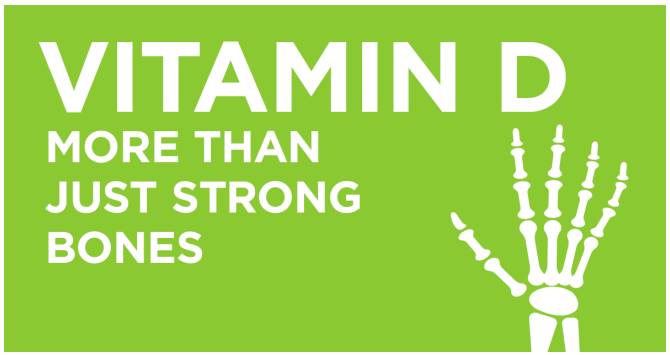
Deficiency of vitamin D in childhood could cause

a. rickets

b. scurvy

Example of DIF item

Childhood illnesses (Drabinová & Martinková, 2017)

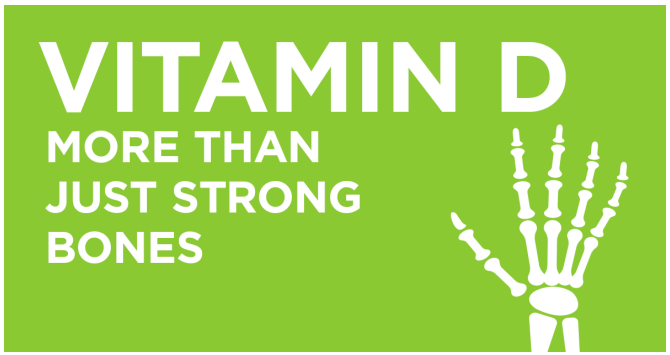


Deficiency of vitamin D in childhood could cause

a. rickets
b. scurvy
c. dwarfism

Example of DIF item

Childhood illnesses (Drabinová & Martinková, 2017)



Deficiency of vitamin D in childhood could cause

a. rickets
b. scurvy
c. dwarfism
d. mental retardation

Example of DIF item

Tipping example (Martiniello et al., 2012)

Of the following, which is the closest approximation of a 15 percent tip on a restaurant check of $24.99?

a. $2.50
b. $3.00
c. $3.75
d. $4.50

Example of DIF items

- Example: Spelling test (orally administered)
  - spell word girder

Example of DIF items

- Example: Spelling test (orally administered)
  - spell word girder

- Example (SAT): Runner is to marathon as
  a. envoy is to embassy
  b. martyr is to massacre
  c. oarsman is to regatta
  d. referee is to tournament
  e. horse is to stable

Example of DIF items

- Example: Spelling test (orally administered)
  - spell word girder

- Example (SAT): Runner is to marathon as
  a. envoy is to embassy
  b. martyr is to massacre
  c. oarsman is to regatta
  d. referee is to tournament
  e. horse is to stable

Example of DIF items

- Example: Spelling test (orally administered)
  - spell word girder

- Example (SAT): Runner is to marathon as
  a. envoy is to embassy
  b. martyr is to massacre
  c. oarsman is to regatta
  d. referee is to tournament
  e. horse is to stable

Who might have been dissadvantaged?

Terminology: Reference group (R), Focal group (F)

DIF as multidimensionality problem

DIF as multidimensionality problem:

- Existence of another dimension tested on the particular item besides the primary latent variable

DIF as multidimensionality problem

DIF as multidimensionality problem:

- Existence of another dimension tested on the particular item besides the primary latent variable

What is the primary and the secondary latent variable tested in mentioned examples?

DIF and item fairness

DIF items are **potentially** unfair

- Content experts must decide on item fairness

DIF and item fairness

DIF items are **potentially** unfair

- Content experts must decide on item fairness
- Secondary latent trait causing DIF

DIF and item fairness

DIF items are **potentially** unfair

- Content experts must decide on item fairness
- Secondary latent trait causing DIF
  - Unrelated to content being tested
    - DIF item is considered unfair
    - Item should be reworded or removed
    - Example: Tipping

DIF and item fairness

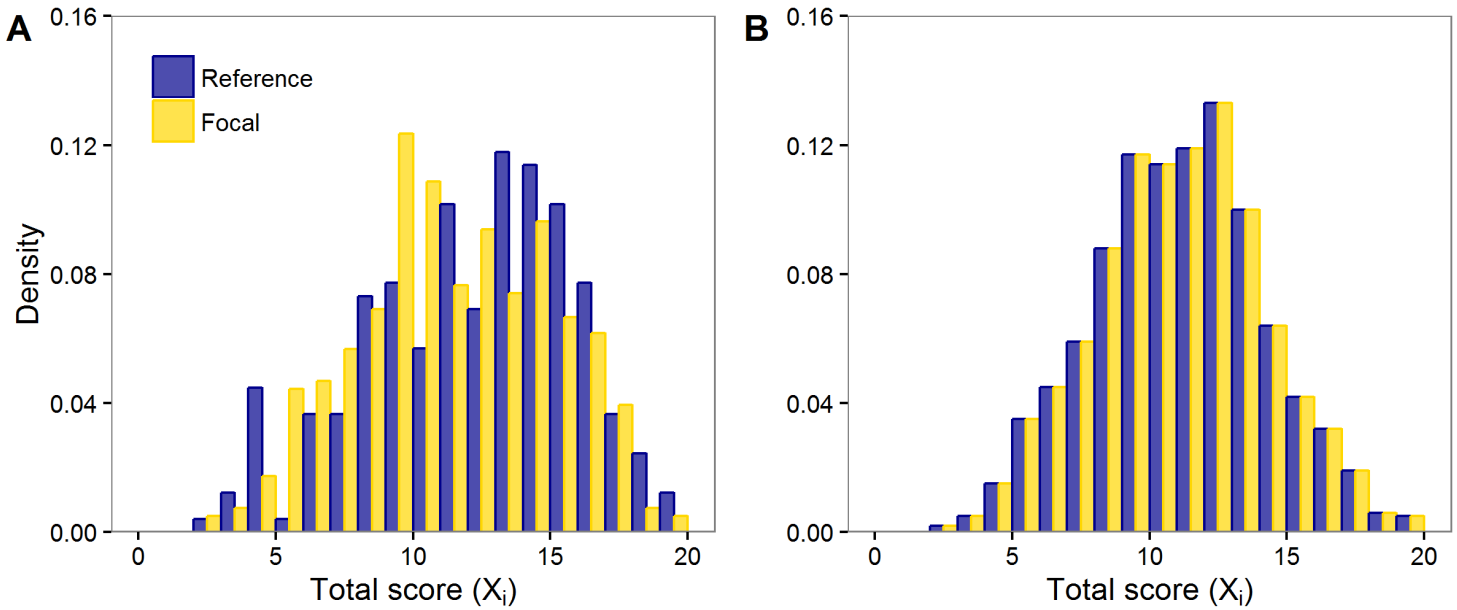
DIF items are **potentially** unfair

- Content experts must decide on item fairness
- Secondary latent trait causing DIF
  - Unrelated to content being tested
    - DIF item is considered unfair
    - Item should be reworded or removed
    - Example: Tipping
  - Related to content being tested
    - DIF item is not considered unfair
    - Item can inform teaching
    - Example: Item on childhood illnesses
      as part of Czech Medical School Admission Test in Biology

DIF vs. Difference in total scores

Comparing total scores only can lead to incorrect conclusions about item/test fairness:

- Case study 1: Homeostasis Concept Inventory
  - Significant difference between males and females in total score (Fig A)
- Case study 2: Simulated dataset based on GMAT
  - Identical distributions of total score (Fig B)



Martinková et al. (2017)

DIF vs. Difference in total scores (cont.)

Comparing total scores only can lead to incorrect conclusions about item/test fairness:

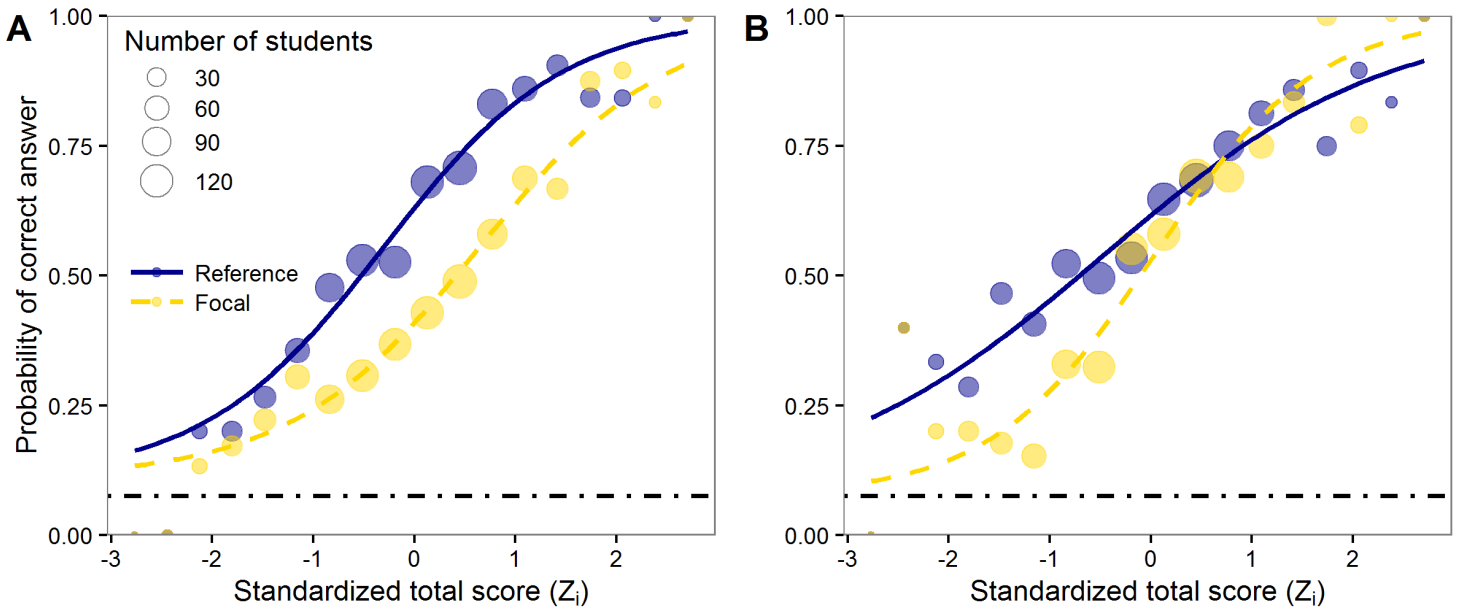
- Case study 1: No HCI item detected as DIF

Martinková et al. (2017)

DIF vs. Difference in total scores (cont.)

Comparing total scores only can lead to incorrect conclusions about item/test fairness:

- Case study 1: No HCI item detected as DIF
- Case study 2: DIF detected in two items of simulated dataset
  - Item 1 exhibits uniform DIF (Fig A)
  - Item 2 exhibits non-uniform DIF (Fig B)



Martinková et al. (2017)

DIF detection methods

DIF detection methods

- Based on **total score**

DIF detection methods

- Based on **total score**

- Based on **latent ability**

DIF detection methods

- Based on **total score**
  - Mantel-Haenszel test
  - \+ simple, easily implemented
  - − cannot detect non-uniform DIF
  - − doesn't account for possibility of guessing/inattention

- Based on **latent ability**

DIF detection methods

- Based on **total score**
  - Mantel-Haenszel test
  - \+ simple, easily implemented
  - − cannot detect non-uniform DIF
  - − doesn't account for possibility of guessing/inattention
  - Logistic regression
  - \+ simple, easily implemented, detects both forms of DIF
  - − doesn't account for possibility of guessing/inattention
- Based on **latent ability**

DIF detection methods

- Based on **total score**
  - Mantel-Haenszel test
  - \+ simple, easily implemented
  - − cannot detect non-uniform DIF
  - − doesn't account for possibility of guessing/inattention
  - Logistic regression
  - \+ simple, easily implemented, detects both forms of DIF
  - − doesn't account for possibility of guessing/inattention
- Based on **latent ability**
  - Item Response Theory models (non-linear mixed effect models)
  - \+ detects both forms of DIF, accounts for possibility of guessing/inattention
  - − more complex, computationally demanding

Mantel-Haenszel test

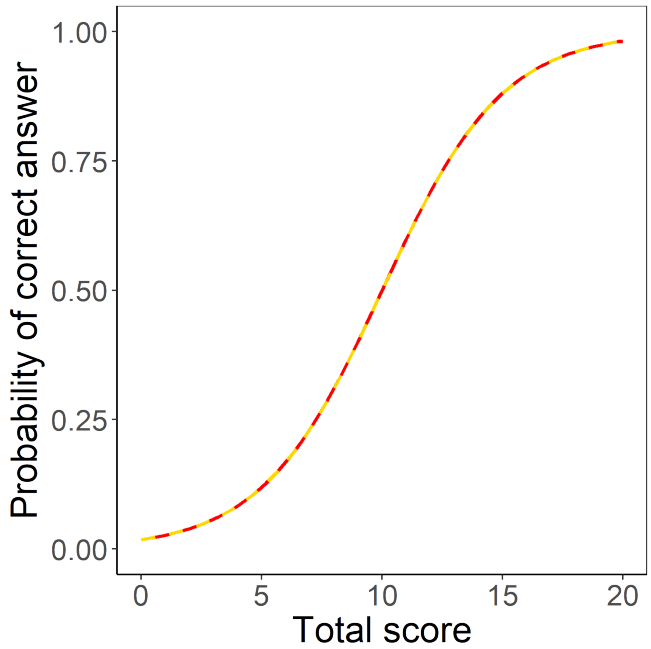
- Test of independence of two binary variables: item score and group membership.
- X^2 test, but incorporating also ability score
- Looking at contingency tabels for each level of total score, adding up

Logistic regression for DIF detection

$$\mathrm{P}(Y_{ij} = 1|X_i, G_i) = \frac{e^{\beta_{0j}+\beta_{1j}X_i}}{1 + e^{\beta_{0j}+\beta_{1j}X_i}}$$

$=$ probability of correct answer of student i to item j

X_i total score, G_i group

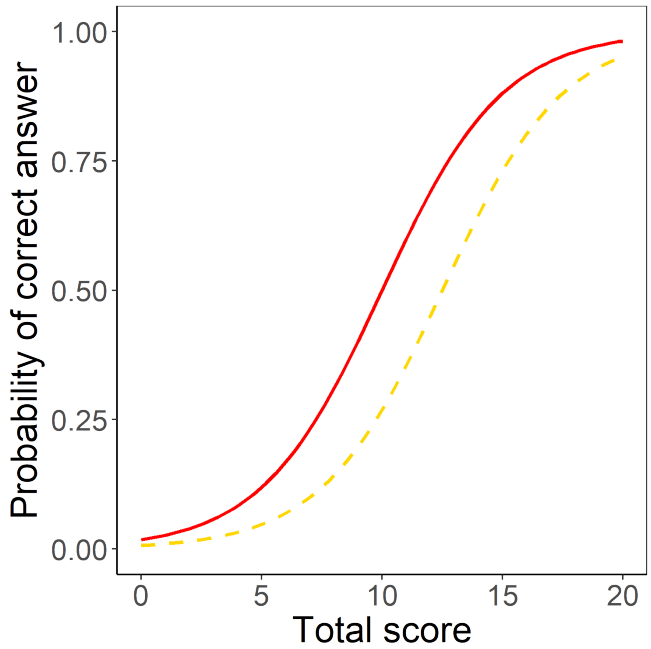


Logistic regression for DIF detection

$$\mathrm{P}(Y_{ij} = 1|X_i, G_i) = \frac{e^{\beta_{0j}+\beta_{1j}X_i+\beta_{2j}G_i}}{1 + e^{\beta_{0j}+\beta_{1j}X_i+\beta_{2j}G_i}}$$

$=$ probability of correct answer of student i to item j

X_i total score, G_i group

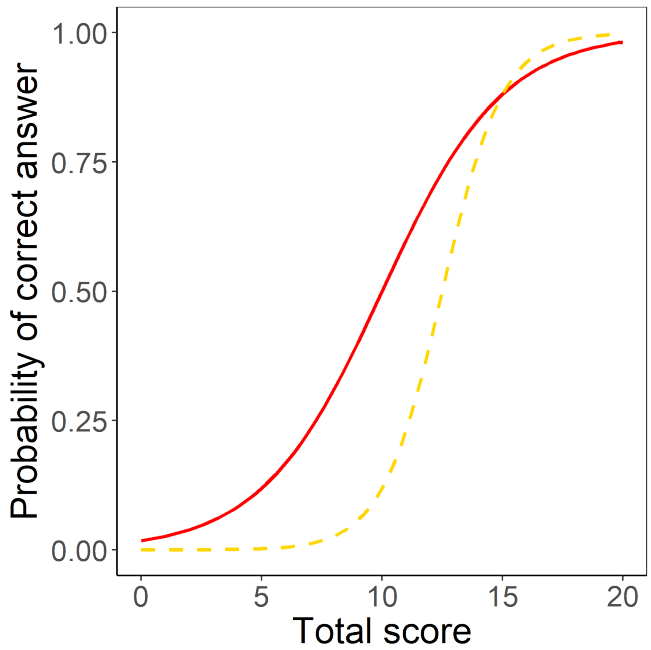


Logistic regression for DIF detection

$$\mathrm{P}(Y_{ij} = 1|X_i, G_i) = \frac{e^{\beta_{0j}+\beta_{1j}X_i+\beta_{2j}G_i+\beta_{3j}X_iG_i}}{1 + e^{\beta_{0j}+\beta_{1j}X_i+\beta_{2j}G_i+\beta_{3j}X_iG_i}}$$

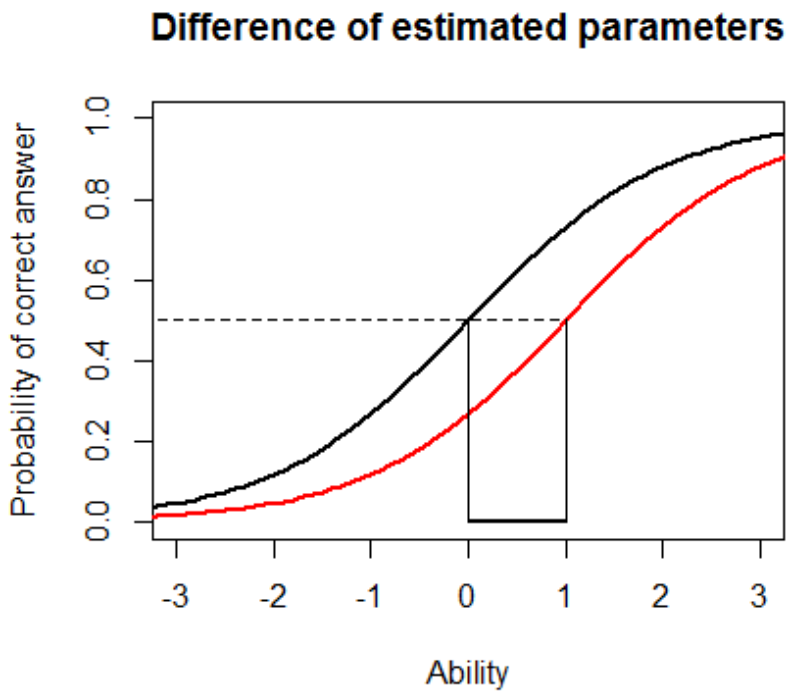
= probability of correct answer of student i to item j

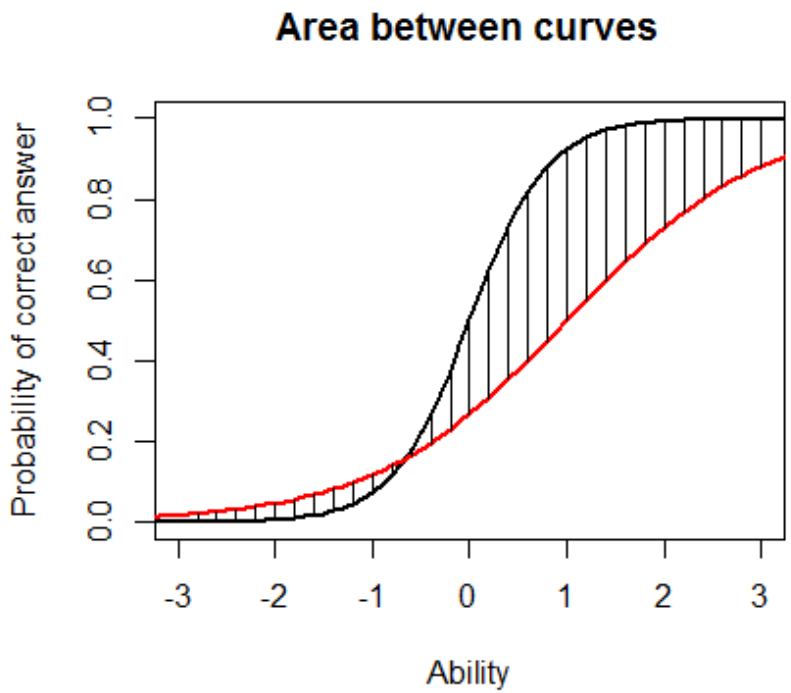
X_i total score, G_i group



IRT-based Methods for DIF Detection

- Lord's Wald statistic: Difference between parameters
- Raju: Area between the curves (difference or absolute difference)
- Likelihood ratio test



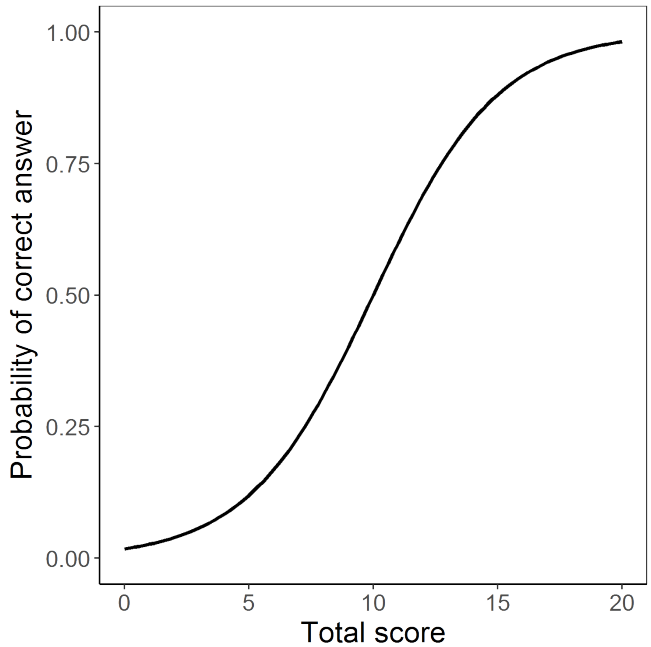


Generalized logistic regression for DIF detection

$$\mathrm{P}(Y_{ij} = 1|X_i, G_i) = \frac{e^{\beta_{0j}+\beta_{1j}X_i}}{1 + e^{\beta_{0j}+\beta_{1j}X_i}}$$

= probability of correct answer by ith subject on jth item

X_i total score, G_i group membership



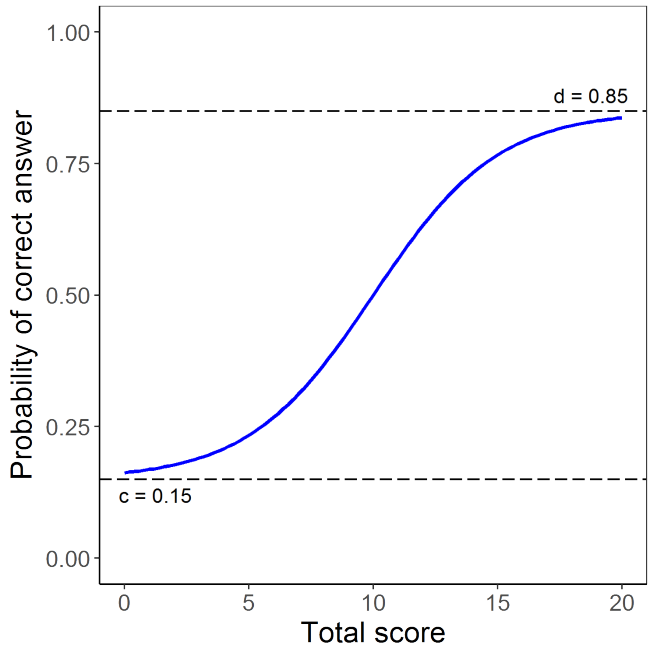
Drabinová & Martinková (2017)

Generalized logistic regression for DIF detection

$$\mathrm{P}(Y_{ij} = 1|X_i, G_i) = c_j + (d_j - c_j)\,\frac{e^{\beta_{0j}+\beta_{1j}X_i}}{1 + e^{\beta_{0j}+\beta_{1j}X_i}}$$

$=$ probability of correct answer by ith subject on jth item

X_i total score, G_i group membership



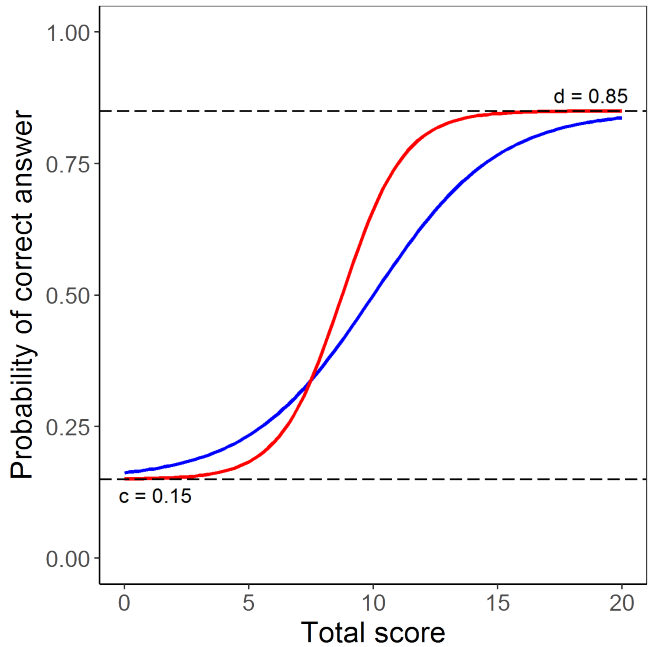
Drabinová & Martinková (2017)

Generalized logistic regression for DIF detection

$$\mathrm{P}(Y_{ij} = 1|X_i, G_i) = c_j + (d_j - c_j) \frac{e^{\beta_{0j}+\beta_{1j}X_i+\beta_{2j}G_i+\beta_{3j}X_iG_i}}{1 + e^{\beta_{0j}+\beta_{1j}X_i+\beta_{2j}G_i+\beta_{3j}X_iG_i}}$$

$=$ probability of correct answer by ith subject on jth item

X_i total score, G_i group membership



Drabinová & Martinková (2017)

Technical details

We use:

- Z-scores instead of total score
- IRT parameterization
- Non-linear least squares for parameter estimation
- DIF testing based on F or LR test
- Multiple comparison corrections

Drabinová, Martinková & Zvára (2017): `difNLR`: Detection of Dichotomous DIF by Non-linear Regression. R package Version 1.1.1
https://CRAN.R-project.org/package=difNLR

Technical details

We use:

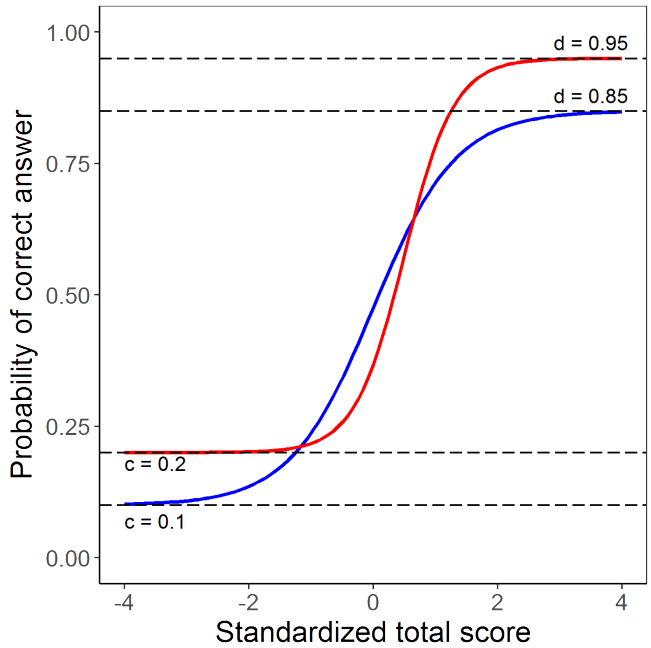
- Z-scores instead of total score
- IRT parameterization
- Non-linear least squares for parameter estimation
- DIF testing based on F or LR test
- Multiple comparison corrections

Method is implemented in `R` library `difNLR` (Drabinová, Martinková & Zvára, 2017)

Drabinová, Martinková & Zvára (2017): `difNLR`: Detection of Dichotomous DIF by Non-linear Regression. R package Version 1.1.1
https://CRAN.R-project.org/package=difNLR

Different asymptotes for groups

- Model allows for differences in guessing between groups



Drabinová & Martinková (2017): Detection of Differential Item Functioning with Non-Linear Regression: Non-IRT Approach Accounting for Guessing. *Journal of Educational Measurement*, 54(4), pp. 498-517, 2017. dx.doi.org/10.1111/jedm.12158

Monte Carlo simulation study

Design

- 5 levels of sample size (500+500, 500+1,000, 1,000+1,000, 1,000+2,000, 2,000+2,000)
- 20 items
- Answers generated using 3PL model
- DIF caused by difference in difficulty, discrimination and guessing parameters
- 0%, 5%, or 15% DIF proportion
- DIF size based on (weighted) area between characteristic curves

Monte Carlo simulation study

Design

- 5 levels of sample size (500+500, 500+1,000, 1,000+1,000, 1,000+2,000, 2,000+2,000)
- 20 items
- Answers generated using 3PL model
- DIF caused by difference in difficulty, discrimination and guessing parameters
- 0%, 5%, or 15% DIF proportion
- DIF size based on (weighted) area between characteristic curves

DIF detection

- Mantel-Haenszel, Logistic Regression, Lord (3PL IRT), **NLR**
- Benjamini-Hochberg multiple comparison correction

Monte Carlo simulation study

Results - NLR

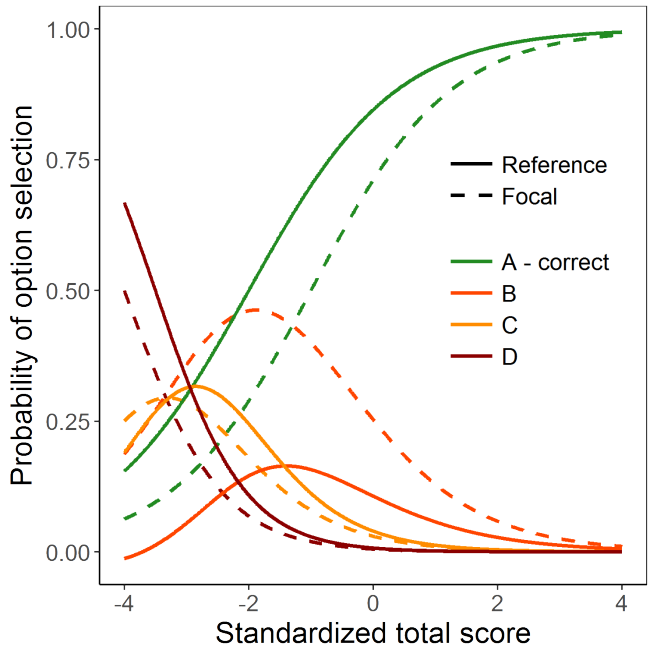
- Less convergence issues than for Lord (3PL IRT)
- Good control of rejection rates in almost all scenarios
- Comparable power to other DIF detection methods
- **Accounts for guessing**
- **Allows for testing group difference in guessing**

Drabinová & Martinková (2017): Detection of Differential Item Functioning with Non-Linear Regression: Non-IRT Approach Accounting for Guessing. *Journal of Educational Measurement*, 54(4), pp. 498-517, 2017. dx.doi.org/10.1111/jedm.12158

Differential Distractor Functioning

Differential Distractor Functioning (DDF)

Two subjects with the same underlying ability but from different groups have different probability to choose given distractor in multiple-choice item



Martinková & Drabinová, in progress.

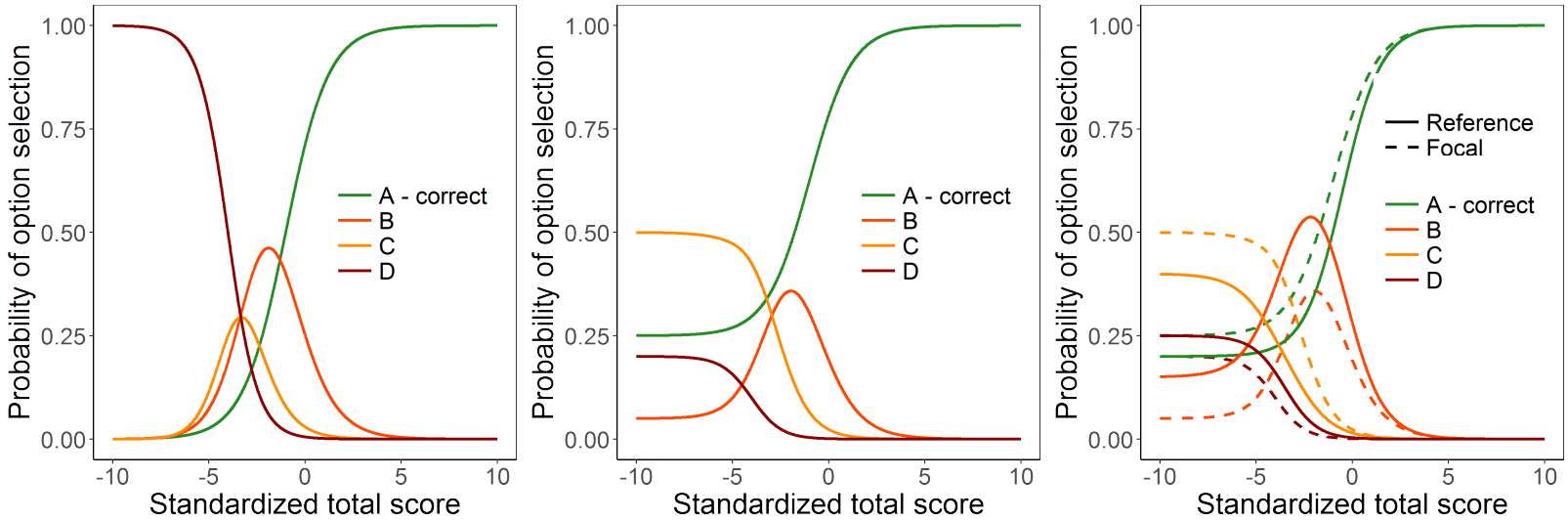
DDF for detection of differential attractiveness of distractors

Extending multinomial regression model

- To better describe attractiveness of distractors

Extending DDF model

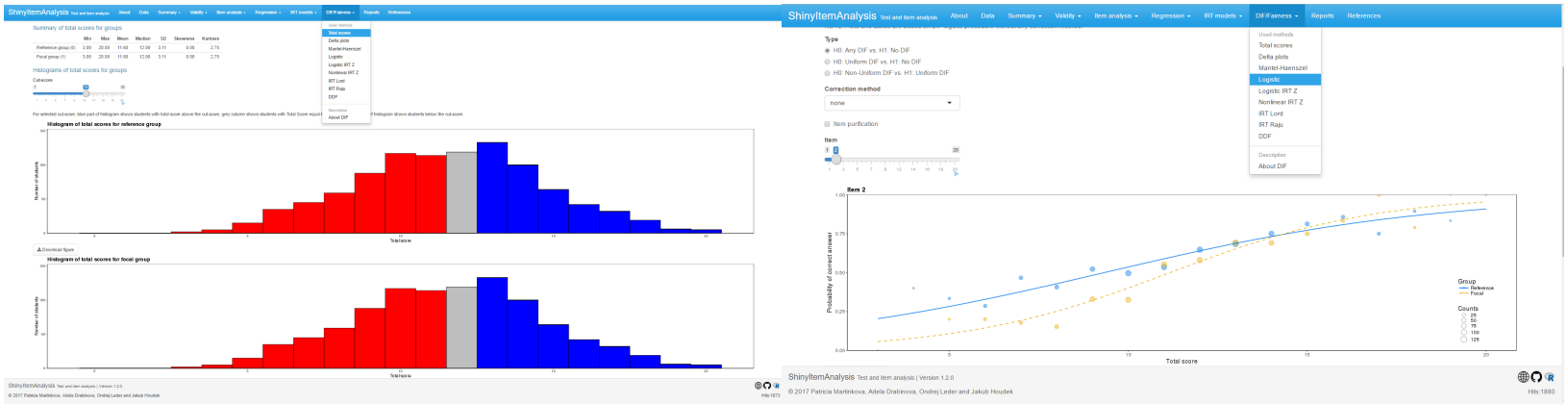
- To account for differential attractiveness of distractors in multiple-choice items



Martinková & Drabinová, in progress.

ShinyItemAnalysis: Why DIF should be analyzed routinely?

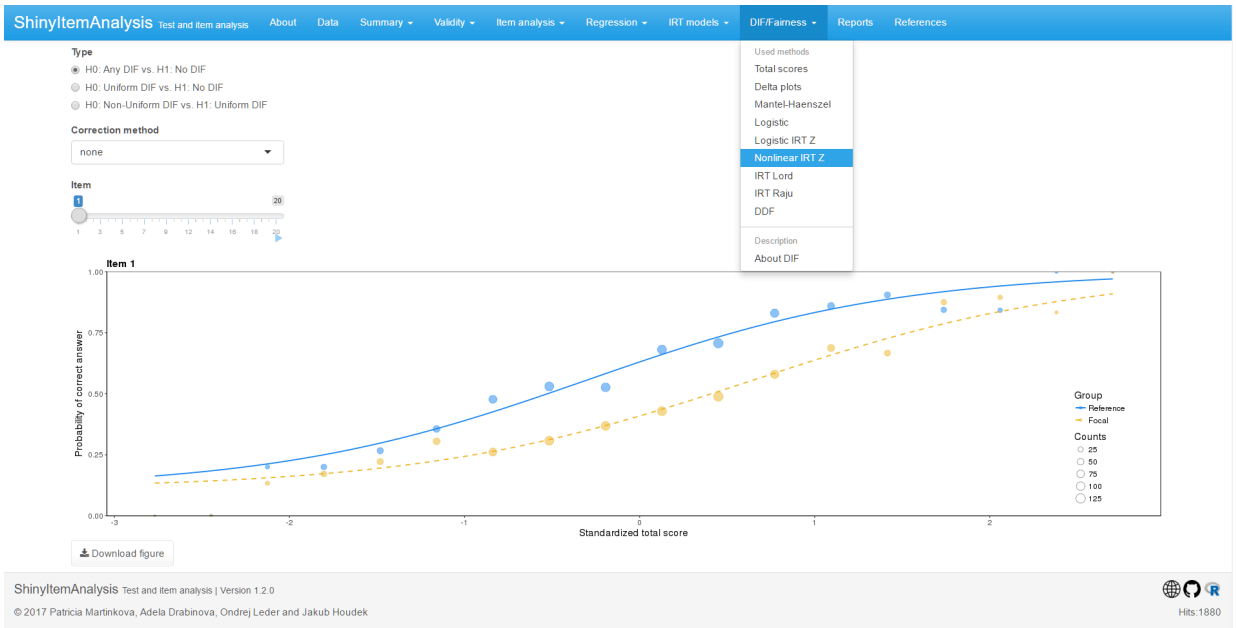
- Simulated GMAT data: total scores may have exactly the same distribution, yet there may be DIF present in some items!



Martinková et al. Checking Equity: Why DIF Analysis should be a Routine Part of Developing Conceptual Assessments. *CBE Life Sciences Education*, 16(2), rm2. doi 10.1187/cbe.16-10-0307

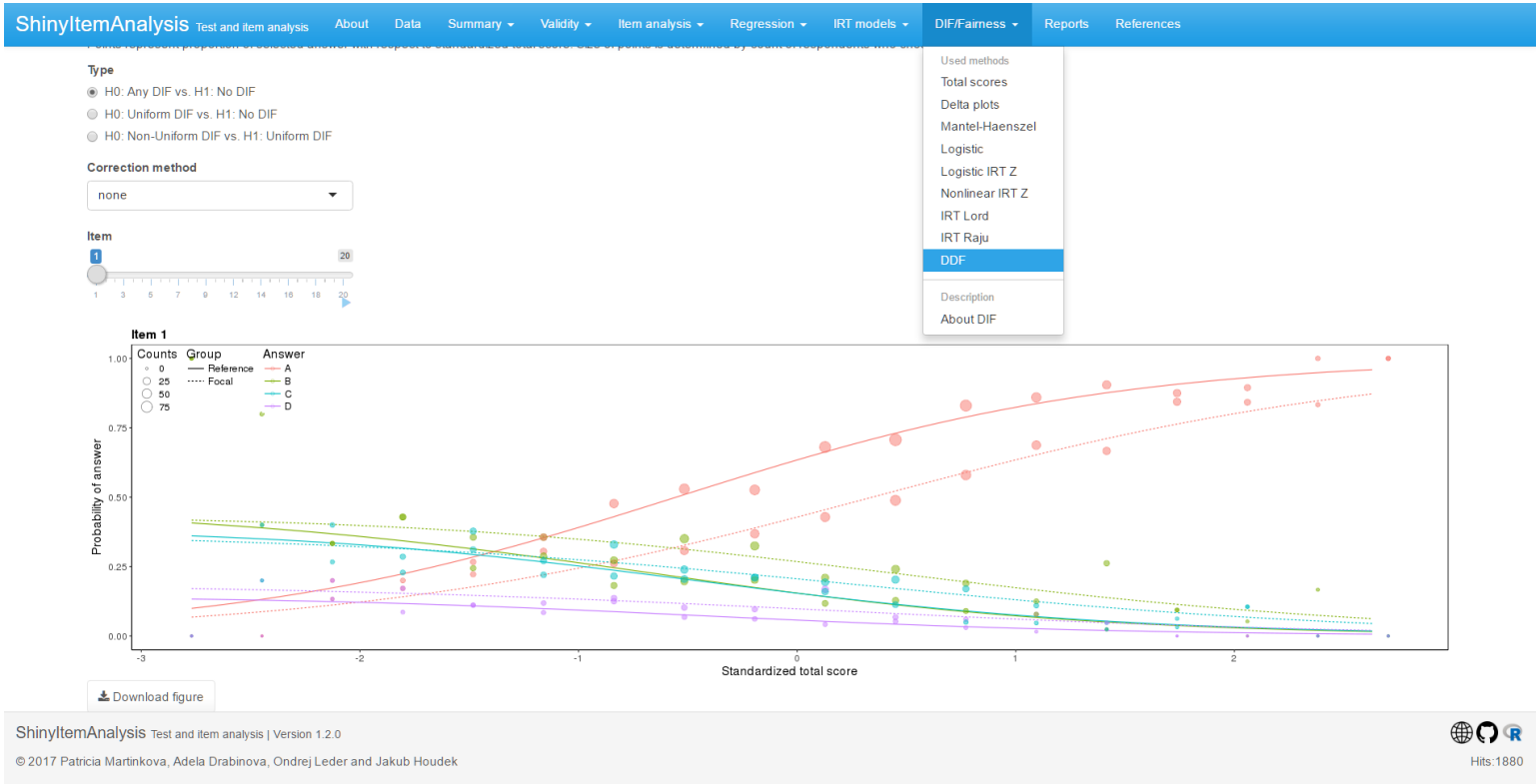
ShinyItemAnalysis: DIF detection with non-linear regression

- Method demonstrated on MSAT-B dataset from Drabinová & Martinková (2017)



Drabinová & Martinková (2017): Detection of Differential Item Functioning with Non-Linear Regression: Non-IRT Approach Accounting for Guessing. *Journal of Educational Measurement*, 54(4), pp. 498-517, 2017. dx.doi.org/10.1111/jedm.12158

ShinyItemAnalysis: DDF with multinomial regression



Conclusion

DIF/DDF analysis should be used routinely in test development

- to check for fairness with respect to groups
- to inform teaching

Conclusion

DIF/DDF analysis should be used routinely in test development

- to check for fairness with respect to groups
- to inform teaching

DIF detection methods

- Mantel-Haenszel test
- Logistic regression
- IRT/based methods: Lord (Wald test), Raju

Conclusion

DIF/DDF analysis should be used routinely in test development

- to check for fairness with respect to groups
- to inform teaching

DIF detection methods

- Mantel-Haenszel test
- Logistic regression
- IRT/based methods: Lord (Wald test), Raju

New method for DIF detection was introduced

- allows for group differences in guessing and inattention
- current research focuses on differences in option selection (DDF)
- may provide better understanding to misconceptions held by groups

Thank you for your attention!

www.cs.cas.cz/martinkova

References

- McFarland, Price, Wenderoth, Martinková, Cliff, Michael, Modell and Wright (2017). Development and Validation of the Homeostasis Concept Inventory. *CBE Life Sciences Education*, vol. 16 no. 2 ar35. doi 10.1187/cbe.16-10-0305
- Martinková, Drabinová, Liaw, Sanders, McFarland & Price (2017). Checking Equity: Why DIF Analysis should be a Routine Part of Developing Conceptual Assessments. *CBE-Life Sciences Education*, 16(2), rm2. doi 10.1187/cbe.16-10-0307
- Drabinová & Martinková (2017). Detection of Differential Item Functioning with Non-Linear Regression: Non-IRT Approach Accounting for Guessing. *Journal of Educational Measurement*, 54(4), pp. 498-517, 2017. dx.doi.org/10.1111/jedm.12158
- Martinková, Štěpánek, Drabinová et al. (2017). Semi-real-time analyses of item characteristics for medical school admission tests. *FedCSIS 2017 Proceedings*, M. Ganzha, L. Maciaszek, M. Paprzycki (eds). ACSIS, Vol. 11, pages 189–194, 2017. doi 10.15439/2017F380
- Martinková, Drabinová & Houdek (2017): ShinyItemAnalysis: Analýza přijímacích a jiných znalostních či psychologických testů. TESTFÓRUM, č.9, str. 16-35. doi 10.5817/TF2017-9-129
- Martinková, Drabinová, Leder & Houdek (2017). `ShinyItemAnalysis`: Test and Item Analysis with Shiny. R package Version 1.2.3 https://shiny.cs.cas.cz/ShinyItemAnalysis/ https://CRAN.R-project.org/package=ShinyItemAnalysis
- Drabinová, Martinková & Zvára (2017): `difNLR`: Detection of Dichotomous DIF by Non-linear Regression. R package Version 1.1.1 https://CRAN.R-project.org/package=difNLR