

# Improving Equivalent Scores for Clinical Neuropsychology: A new method for regression model selection

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# Test scores in clinical neuropsychology

In a working memory test a patient scores 5.

# Test scores in clinical neuropsychology

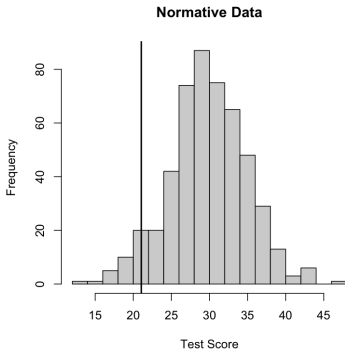
In a working memory test a patient scores 5.

In clinical neuropsychology, scores are almost always compared to *thresholds* to facilitate interpretation.

Typically, if the score is *below* the thresholds (i.e. “cut-offs ”), it is interpreted as a probable impairment.

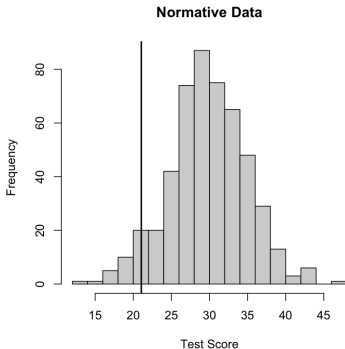
# Demographic variables and normative data

Most methods for cognitive impairment are based on *normative data* that take into account age, education, and sex.



# Demographic variables and normative data

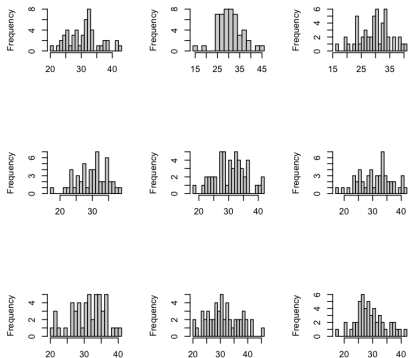
Most methods for cognitive impairment are based on *normative data* that take into account age, education, and sex.



Threshold typically delimits 5% of worse performances (at sample or population level)

# Demographic variables and normative data

Demographic variables can be taken into account by dividing into bins.



# Equivalent Scores

**Equivalent Scores** is one of the most widespread method to calculate thresholds in clinical neuropsychology in Italy, originally developed by E. Capitani (Spinnler & Tognoni, 1987).

# Equivalent Scores

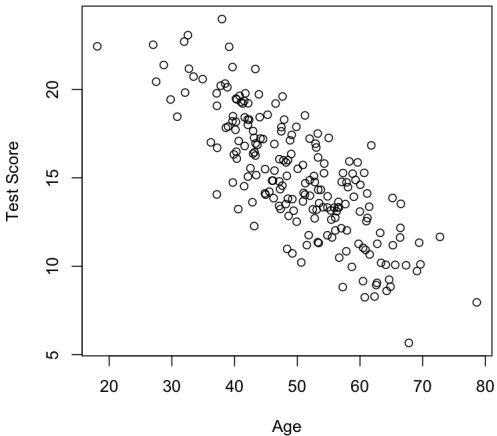
**Equivalent Scores** is one of the most widespread method to calculate thresholds in clinical neuropsychology in Italy, originally developed by E. Capitani (Spinnler & Tognoni, 1987).

the method consists of:

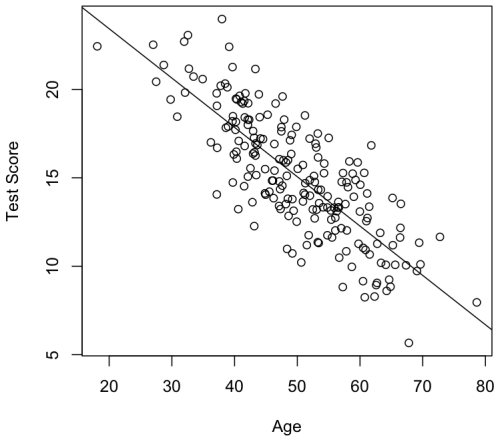
- a first part using regression to calculate adjusted scores that consider age, education, and sex.
- a second part to derive thresholds for clinical inference (based on tolerance limits).



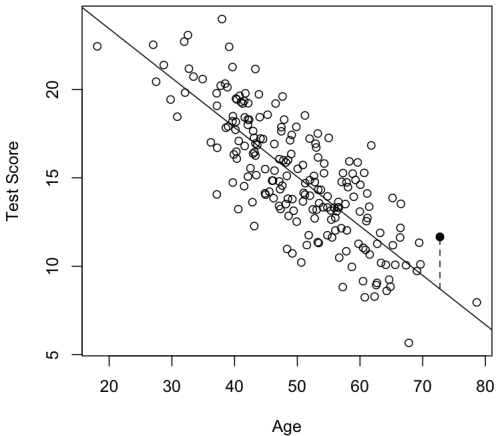
# Regression Method



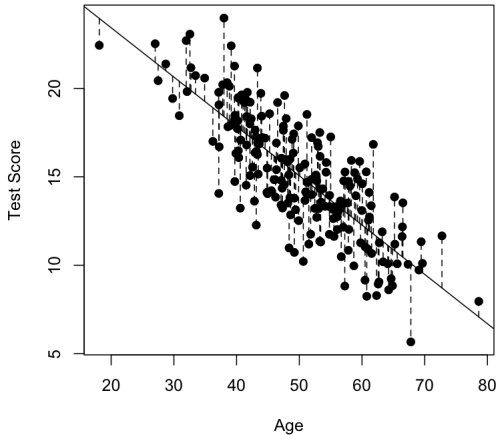
# Regression Method



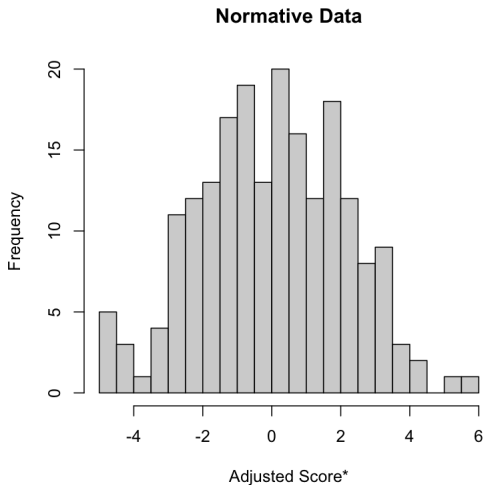
# Regression Method



# Regression Method

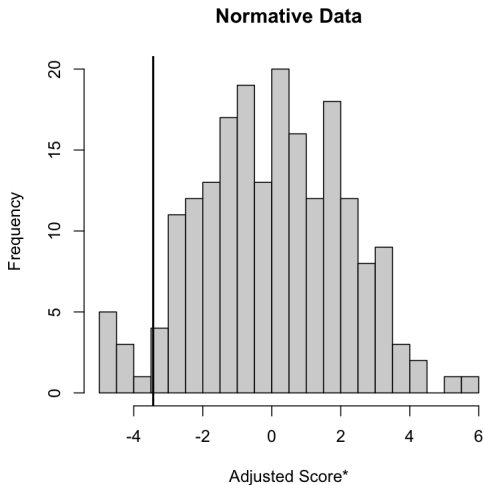


# Regression Method



\* Intercept is added to go back to original scale

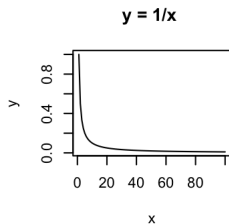
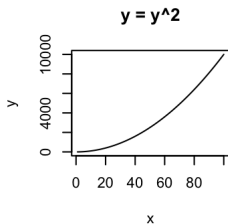
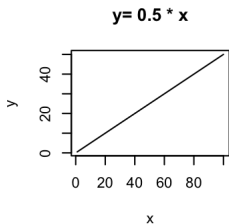
# Regression Method



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# Regression Modeling: two issues

- 1 what predictors should be included in the model? (Age, Education, Sex)
- 2 what is the better transformation of predictors? (log, quadratic, inverse etc.)



# Equivalent Scores - regression method (*Capitani1987*)

Capitani 1987 (Spinnler & Tognoni 1987).

- 1 fit separate simple regression models for *Age* and *Education* trying different transformations from a list (e.g. log, inverse, quadratic, etc.)
- 2 fit a multiple regression with best transformations for *Age* and *Education* identified in 1. (best = higher  $R^2$ ), and *Sex*.
- 3 drop terms with  $p > 0.05$ , Bonferroni corrected (i.e.,  $p < 0.017$ )



# An alternative method (*Arcara2024*)

Arcara 2024 (*in prep.*)

- 1 fit all possible multiple regressions including *Age*, *Education* and *Sex* with all possible transformations for *Age* and *Education* (from a list). Calculate **AIC** for all models.
- 2 from each starting model in 1. , use a *stepwise* backward selection (`step` function in R) to find the best model (lowest AIC) and select among all reduced models, select the model with the lowest AIC.
- 3 drop iteratively terms with  $p > 0.05$ , Bonferroni corrected (i.e.,  $p < 0.05/\text{number of terms}$ )

# Testing the methods

Methods can be compared by using the generative model assumed for ES and simulating normative data.

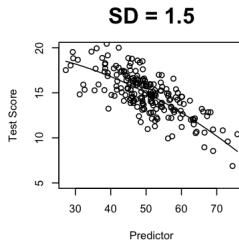
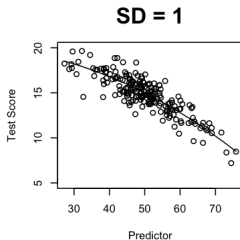
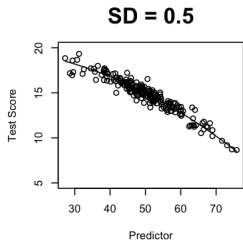
- simulate data with known transformations of Age and Education and calculate *Ground Truth* (GT) cut-offs.

# Parameters (1): Normative data Sample Size

Normative Data Sample size  
[100 300 500 700]

# Parameters (2): True Adjusted Score variability

True Adjusted score Standard Deviation  
[0.5 1 1.5]



# Simulation

1000 simulation for each condition of the three parameters.

- *Normative data* (Train Set)
- *New participants* (i.e. Test Set of 1000 new participants for each Normative Data sample)

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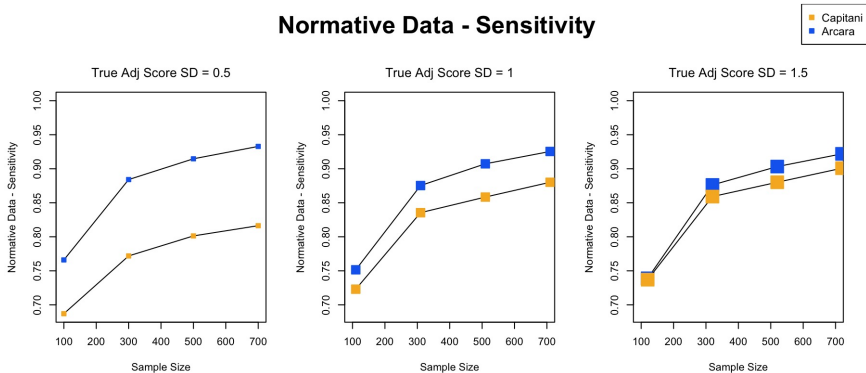
- *Normative data* (Train Set)
- *New participants* (i.e. Test Set of 1000 new participants for each Normative Data sample)

For each simulation performance is tested in classifying correctly below/above cut-off considering GT classifications (Sensitivity, Specificity, and others)

NOTE: as data are simulated with healthy participants, about 0.05 (at population level) are expected to fall below cut-off.

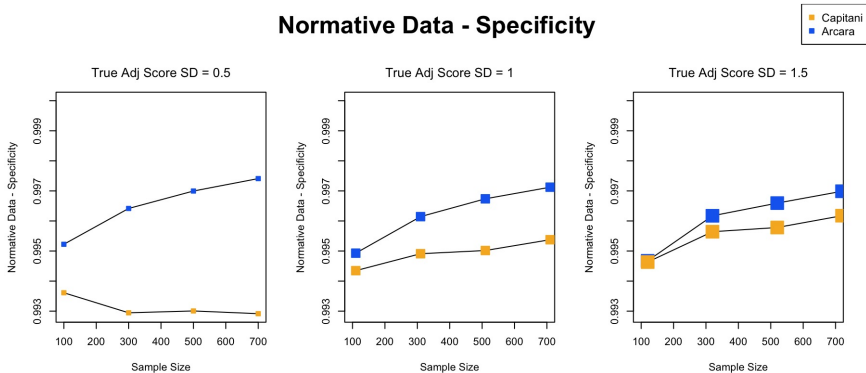
# Sensitivity - Normative Data

## Normative Data - Sensitivity



# Specificity - Normative Data

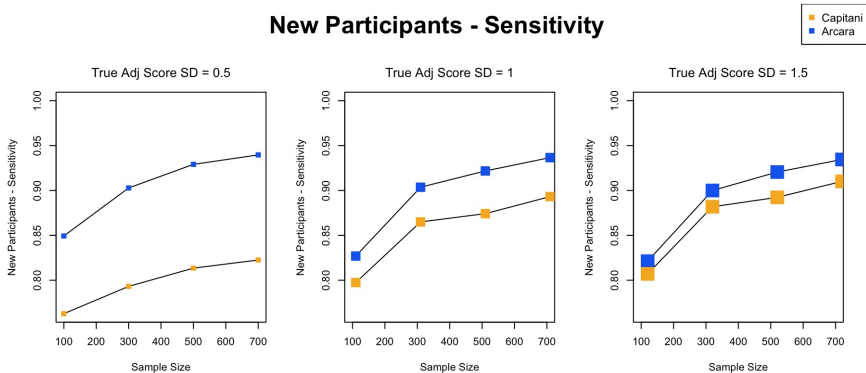
## Normative Data - Specificity





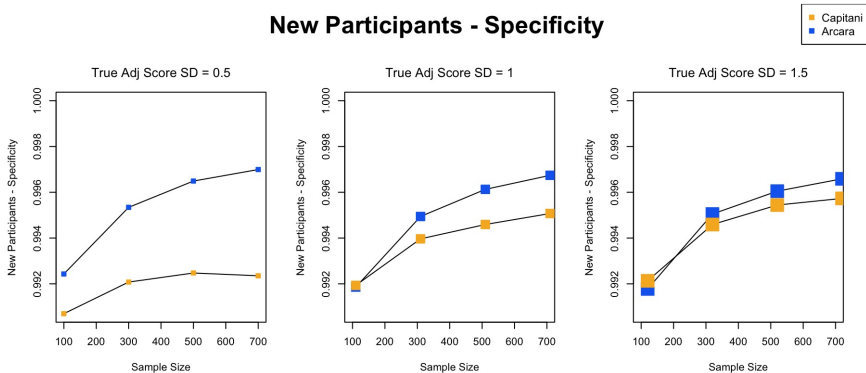
# Sensitivity - New Participants

## New Participants - Sensitivity



# Specificity - New Participants

## New Participants - Specificity



# Additional checks

(not shown, but trust me)

- better performance in guessing correctly the Ground Truth transformation.
- better performance with different conditional distributions of age and education.
- better performance with different proportion of participants below/above cut-off.
- the better method includes all three steps.

# Discussion

A simulation approach can help in develop better methods for clinical neuropsychology.

The new proposed method outperforms the existing method across a wide range of parameters and conditions

The Equivalent Score method (as many other methods in Clinical Neuropsychology) can be improved.

# Future Directions

Many aspects left:

- what about reliability of scores? (with Andrea Spoto)
- what about heteroschedasticity and other realistic scenarios?
- rising awareness into issues and limitations of cut-offs.

## Resources

- All code and scripts are available at <https://github.com/giorgioarcara/Reg-Method-Norm-Data-Sim>.
- All supplementary materials available at <https://osf.io/yma69/>.
- Manuscript soon on Psyarxiv.
- ShinyApp for easy application of the method (with cautionary notes)

**Arcara 2024 Regression method for normative data**

1. Upload a csv file

Filename:

Click this button to upload a csv file. It should include four columns: **Age**, **IQ**, **ESQ**, and **ESQ-adj**. **ESQ-adj** should use "1" as missing an estimate.

2a. Set min Score value

2b. Set max Score value

Insert into the minimum admissible score, and the maximum admissible score (necessary for the method)

Click this button whenever the results

4. Export csv

Click this button to export the results. A csv file will be saved on your computer.

Regression function:  $ESQ = \text{score}(Age)^{-0.228 \cdot IQ} + \text{log}(ESQ-adj) + 13.8$

Age effect plot

Education effect plot

Adj score = Observed score - [score(Age)<sup>-0.228·IQ</sup> + log(ESQ-adj) + 13.8]

ESQ-adj	ESQ	ESQ	ESQ	
Adjusted Score	48.78	50.47	50.08	52.17

This shiny app accompanies the article Arcara G. (2024) 'Improving Equivalent Scores: a new regression method'

**Instructions:** The CSV file supplied should have: **Age** as a predictor and should include the following columns:  
**Age**: education's numerical variable  
**ESQ-adj**: as a numerical variable  
**ESQ**: as a factor  
**ESQ-adj**: as a numerical variable

**NOTE:**  
 If you use the regression method, please cite: Arcara G. (2024) Improving Equivalent Scores: A new method for regression model selection  
 If you also use the EQ, please cite: Arcara, G. M., & Caputo, F. G. (2023). Norms and standardizations in neuropsychology via equivalent scores: software solutions and practical guides. *Neuropsychological Reviews*, 4(2), 481-494.

# Thanks!

Any suggestion (on additional analyses or other) is more than welcome.

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