Robust quantile estimation of the Brief Test of Adult Cognition by Telephone (BTACT) battery

Serenity Budd
Advisor: Dr. Adam Sima

Virginia Commonwealth University
Department of Biostatistics

August 28, 2020

Origin and purpose of BTACT

Cognitive test battery

- A set of tests designed to comprehensively assess an individual's cognitive functioning.

Administered over the telephone

- Low cost, can be implemented in large survey studies.
- Able to test a wider variety of people, such as people with mobility issues.

Pros of BTACT compared to similar instruments

- Can implement in a wider range of ages.
- Tests a wider range of cognitive functions.

BTACT tests

- There are six BTACT tests that assess memory, intelligence, and reasoning.
  1. Immediate word list recall
  2. Digits backward span
  3. Category fluency
  4. Number series
  5. Backward counting
  6. Delayed word list recall

Traumatic brain injury (TBI)

- Potentially leads to lasting cognitive impairment.
- Need to assess cognitive functioning at multiple points to inform intervention strategies.

Use of BTACT in TBI studies

- A person's age, sex, and education level affect their level of cognitive functioning.
- Compare a person's scores to those from a healthy population after accounting for age, sex, and education level.

Standardized scores

- Standardization sample: represent the population for which the test is intended.
- Standardized scores explain how a person performed compared to the distribution of scores from the sample.
- For BTACT, that population is the cognitively healthy adult population in the United States.

Traditional method: z-score

Method

- Categorized age into decades (e.g. $50 - 59$).
- Created strata with categorized age, sex, and binary education level.
- Calculated mean and SD of each strata.
- $Z = \frac{\text{Score} - \text{Stratum Mean}}{\text{Stratum SD}}$

Limitations

- Assumed no difference between people within a decade.
- Assumed scores were normally distributed.

Previous application of quantile regression

Alzheimer's & Dementia: Diagnosis, Assessment & Disease Monitoring 2 (2016) 12-18

Cognitive & Behavioral Assessment

Using quantile regression to create baseline norms for neuropsychological tests

Ben Sherwood[a], Andrew Xiao-Hua Zhou[b,*], Sandra Weintraub[c], Lan Wang[d]

[a]*Department of Biostatistics, Johns Hopkins University, Baltimore, MD, USA*
[b]*Department of Biostatistics, University of Washington, Seattle, WA, USA*
[c]*Department of Psychiatry and Behavioral Sciences and Neurology – Ken and Ruth Davee Department, Northwestern University, Chicago, IL, USA*
[d]*School of Statistics, University of Minnesota, Minneapolis, MN, USA*

Abstract

Introduction: The Uniform Data Set (UDS) contains neuropsychological test scores and demographic information for participants at Alzheimer's disease centers across the United States funded by the National Institute on Aging. Mean regression analysis of neuropsychological tests has been proposed to detect cognitive decline, but the approach requires stringent assumptions.
Methods: We propose using quantile regression to directly model conditional percentiles of neuropsychological test scores. An online application allows users to easily implement the proposed method.
Results: Scores from 13 different neuropsychological tests were analyzed for 5413 cognitively normal participants in the UDS. Quantile and mean regression models were fit using age, gender, and years of education. Differences between the mean and quantile regression estimates were found on the individual measures.
Discussion: Quantile regression provides more robust estimates of baseline percentiles for cognitively normal adults. This can then serve as standards against which to detect individual cognitive decline.

Table 1: Comparison of linear regression and quantile regression methods

	Linear Regression	Quantile Regression
Models	Conditional mean	Conditional quantile
Linear in predictors	✓	✓
Continuous response variable	✓	✓
Accommodates heteroscedasticity	✗	✓
Distribution-free	✗	✓

Midlife in the United States

Purpose

- Investigate how behavioral, psychological, and social factors affect the age-related differences in mental health.

Sampling method

- Nationally representative random-digit-dial sample of non-institutionalized English-speaking adults.

Cognitive Project

- Participants were asked to participate in the BTACT interview.

MIDUS data sets

MIDUS 2

- Data collection: 2004 – 2006.
- Age range: 35 – 86 years old.
- Longitudinal follow-up of the original MIDUS cohort.

MIDUS Refresher

- Data collection: 2011 – 2014.
- Age range: 25 – 74.
- Designed to replenish the original MIDUS cohort.

Variables

- BTACT test scores
  1. Immediate word list recall
  2. Digits backward span
  3. Category fluency
  4. Number series
  5. Backward counting
  6. Delayed word list recall
- Age (years)
- Sex (male/female)
- Education (graduated from college/ has not graduated from college)

Training & test sets

- Split each data set into a training (70%) and test set (30%).
- Merged the training data sets together.
- Training, Test-MIDUS 2, Test-Refresher.

Determine shape of age

- Used polynomial spline models as a flexible shape for age.
- Knots at 25^{th}, 50^{th}, 75^{th} percentiles.

Interaction terms

- Interaction terms were evaluated by AIC.
- AIC(Model i, quantile q) - AIC(Model 1, quantile q)
- Smaller AIC difference means Model i is better than Model 1 for quantile q.

Choose model 1, fit main effects only

Figure 1: Centered AIC table for category fluency models

Figure 2: Predicted category fluency scores

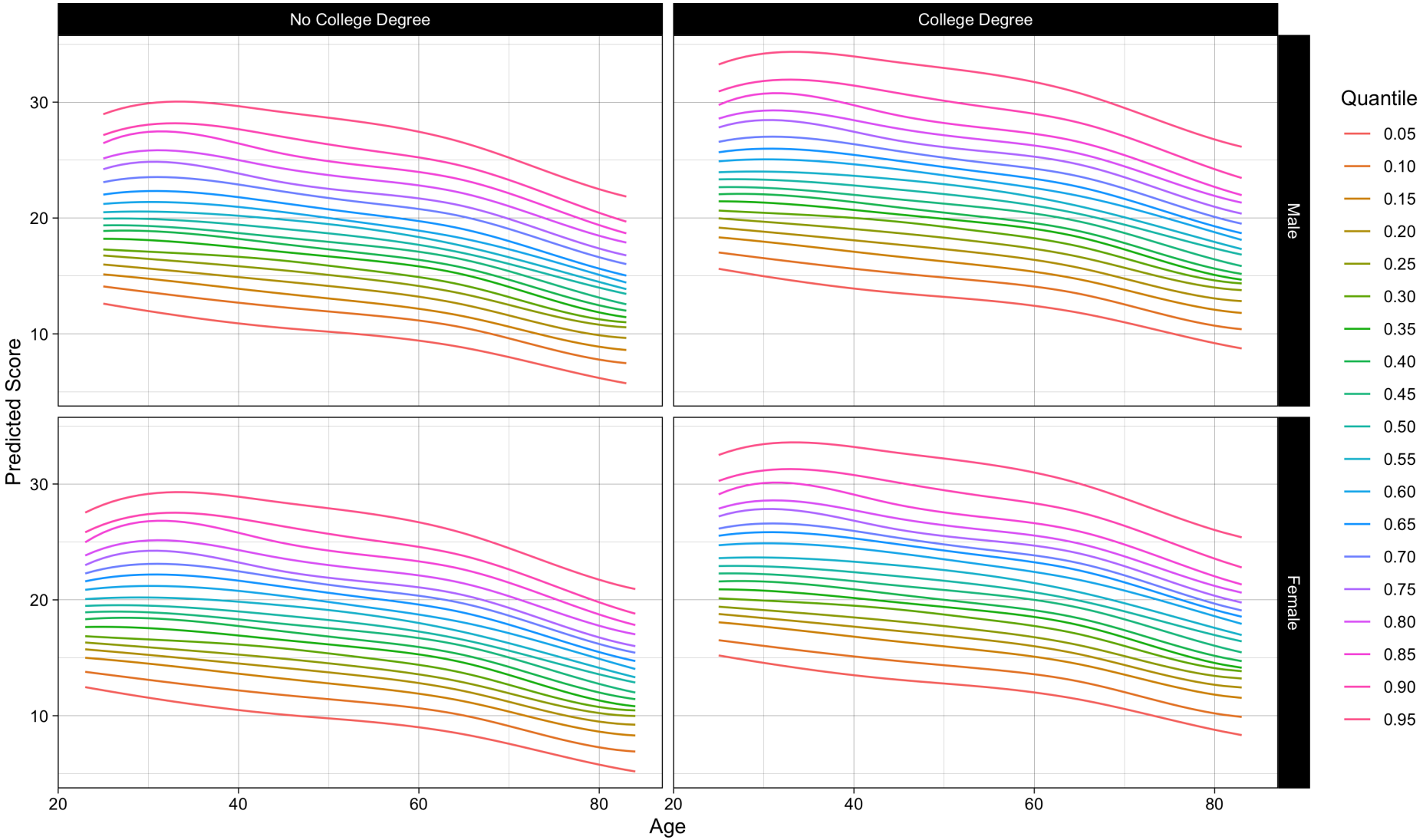


Figure 3: Predicted category fluency score for a woman without a college degree

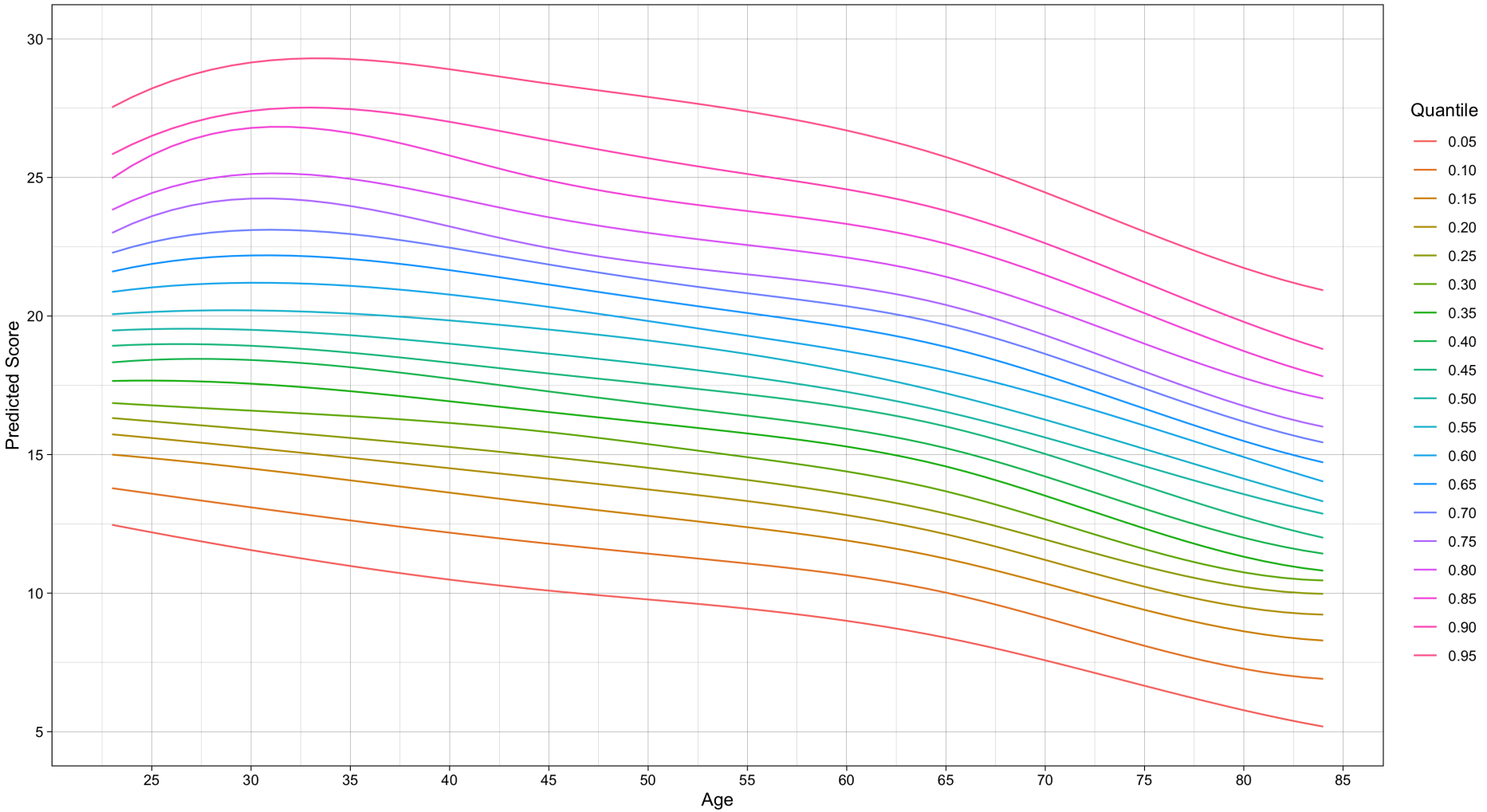


Figure 4: Predicted category fluency score for a woman without a college degree
— Predicted mean category fluency score using z-score method

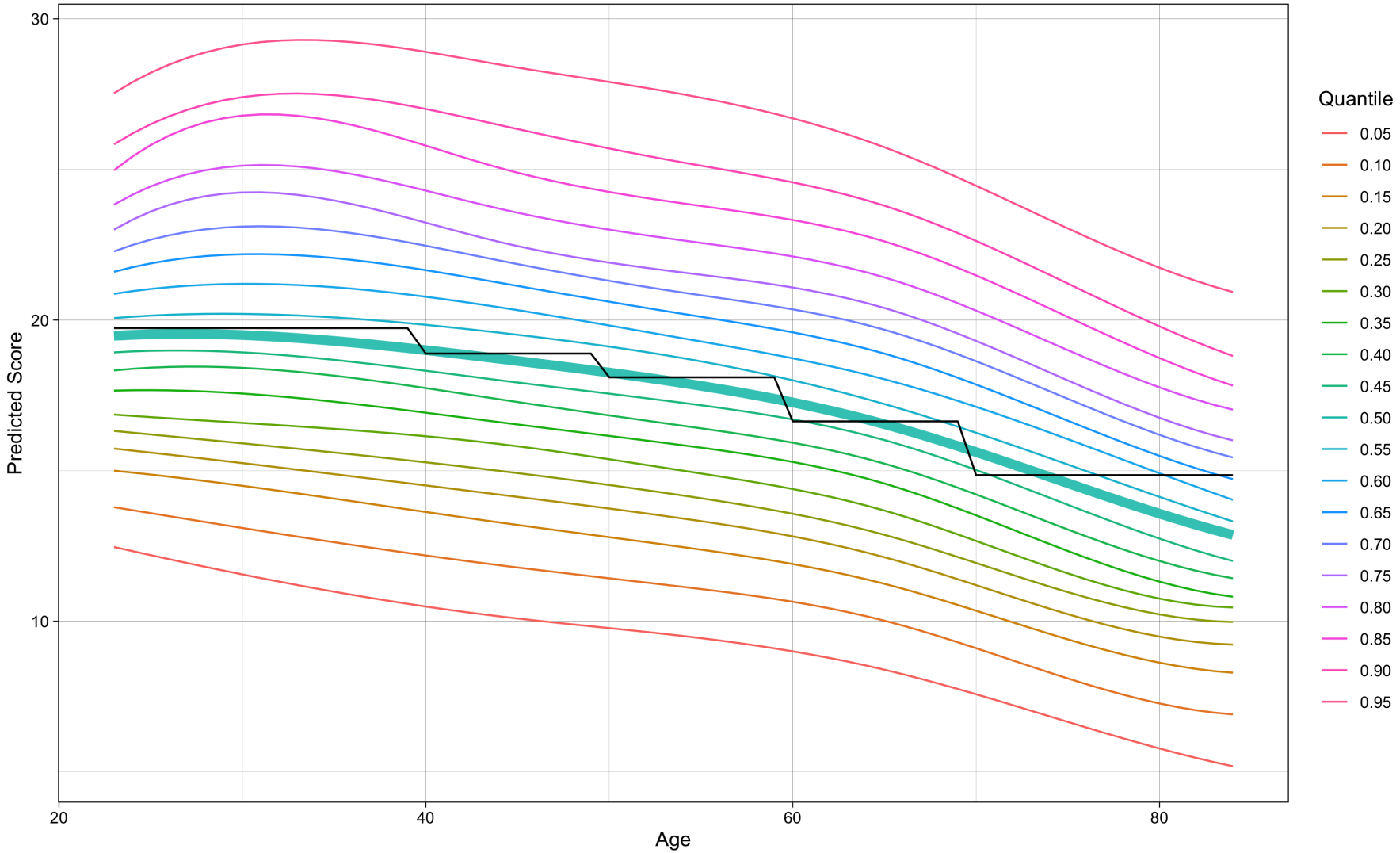


Figure 5: Predicted median category fluency score

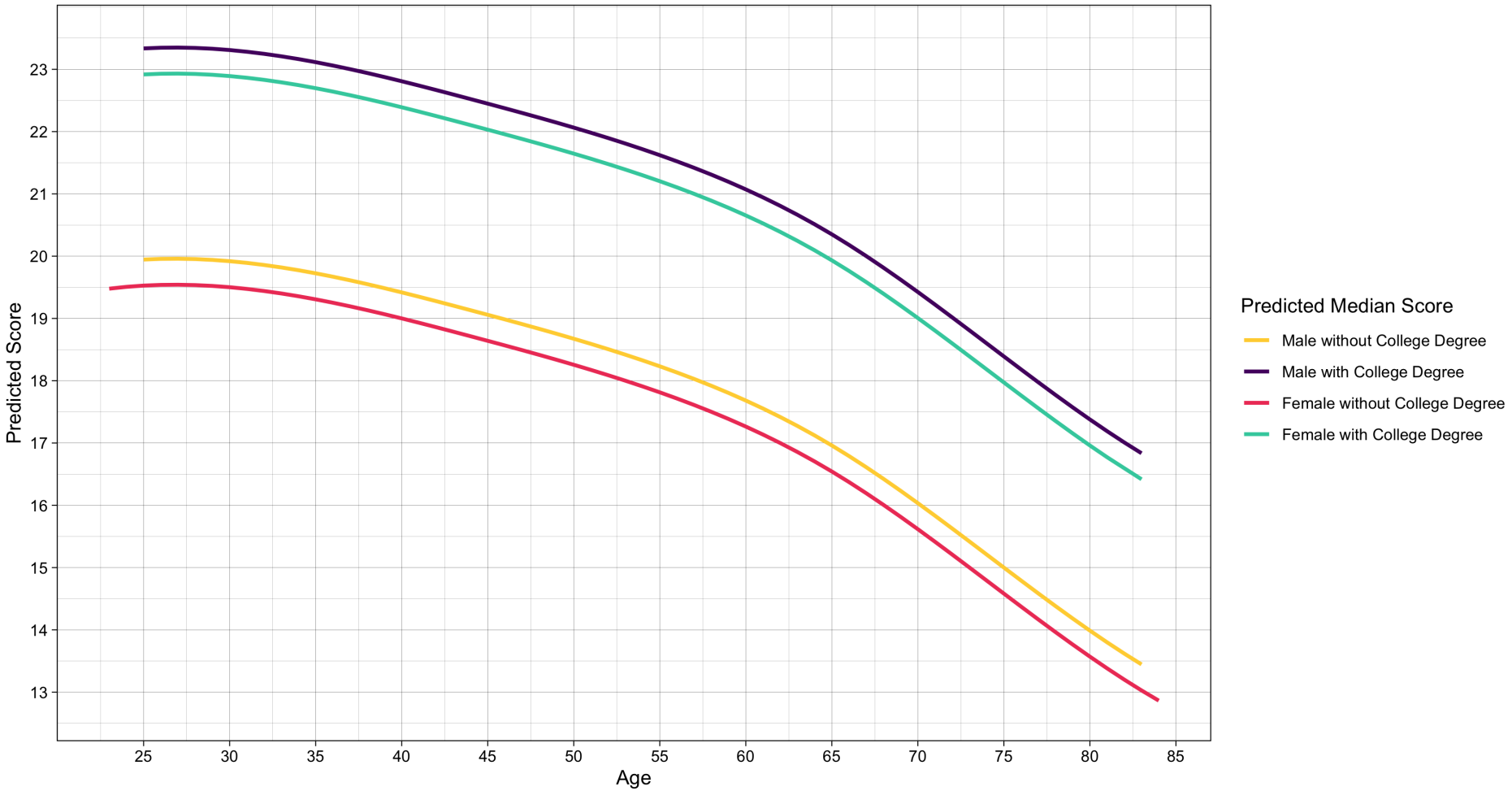
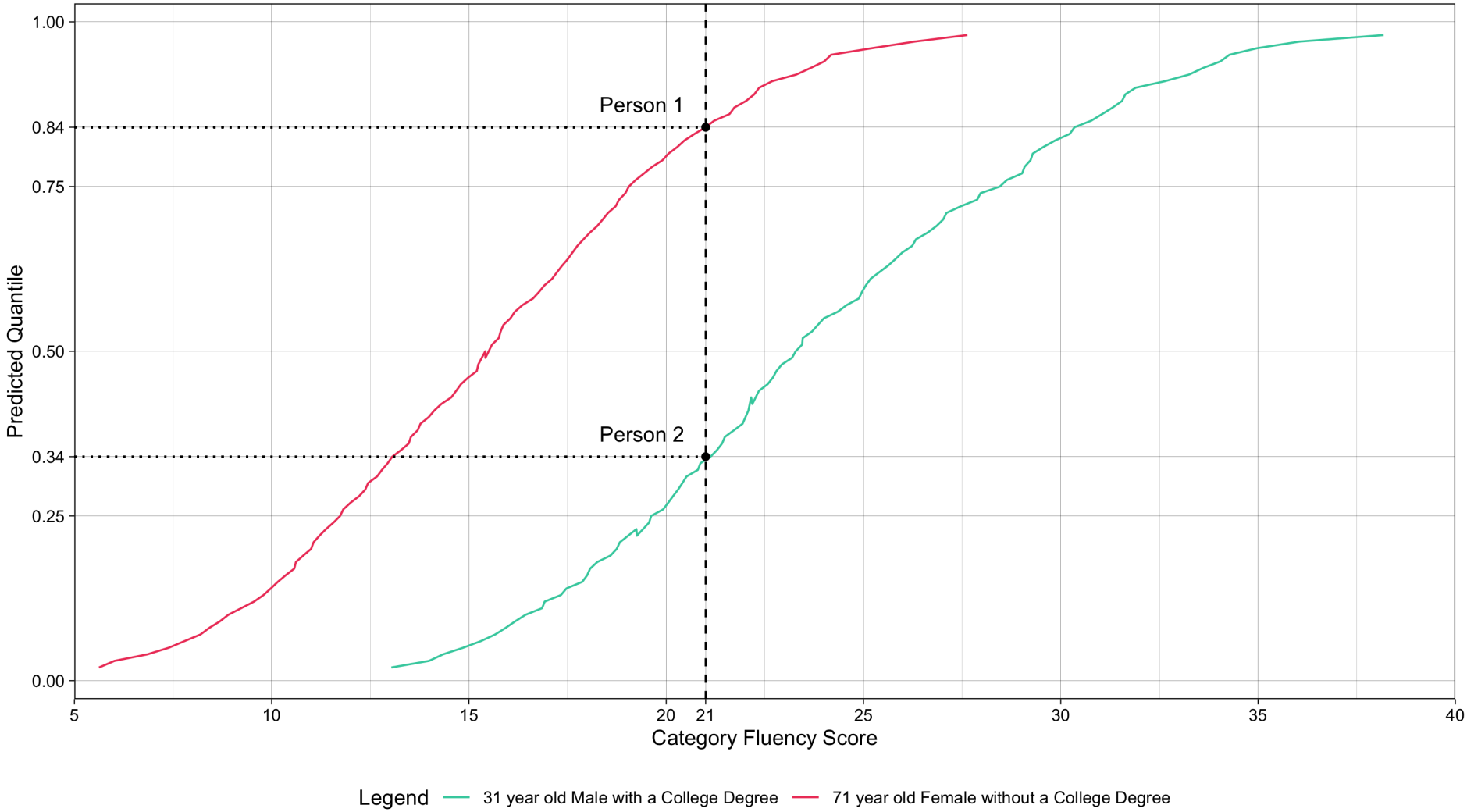


Figure 6: Conditional distribution functions of category fluency scores



Methods

- Use the quantile regression models to predict category fluency scores for both the training and test sets.
- Convert z-score to quantile using properties of the normal distribution.
- We expect $q \cdot 100\%$ of any sample to have predicted quantiles less than or equal to $q \cdot 100\%$.
- Determine if the percent of observations with a predicted quantile $\leq q$ is equal to $q \cdot 100$.

Figure 7: Percent of predicted quantiles less than or equal to expected quantile

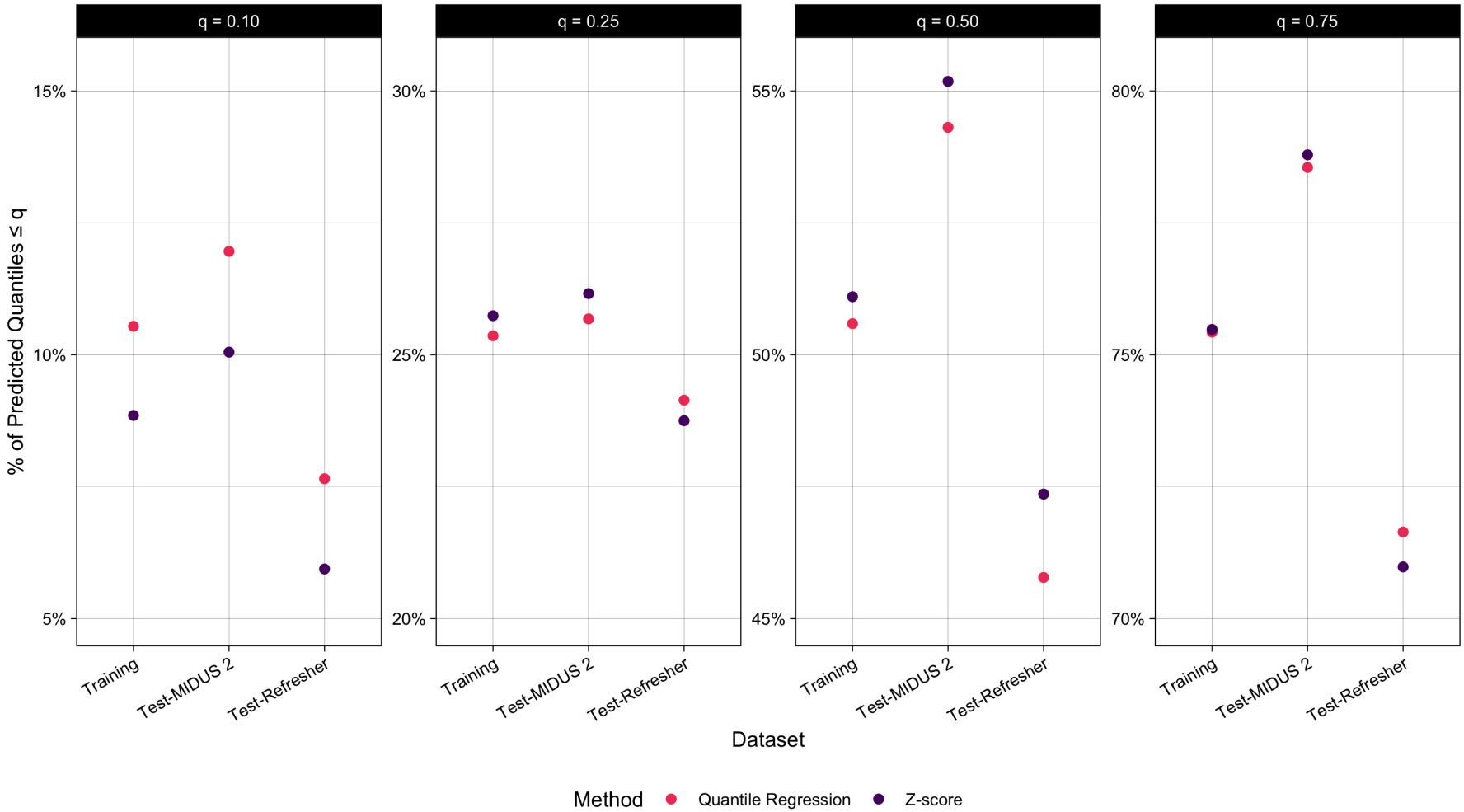


Table 2: Times quantile regression outperforms z-score on all datasets & quantiles

Measure	n (%)
Word List Immediate	9 (75.0)
Backward Digitspan	9 (75.0)
Category Fluency	10 (83.3)
Number Series	9 (75.0)
Backward Counting	8 (66.7)
Word List Delayed	9 (75.0)
All	54 (75.0)

Pros of the quantile regression approach

- Used age as continuous predictor.
- Able to get the whole distribution, i.e. get predicted score for every quantile.
- Typically, predicted quantiles are closer to intended quantiles than existing z-score method.

Limitations

- Assumed the distribution of each test score was continuous for quantile regression.
- Test scores were predicted outside the original range (e.g. negative scores for a test with a positive range).

Future Research & Applications

- Predict a range of quantiles for each test.
- Use to estimate cognitive ability of any adult, specifically those with TBI.

L. Crocker and J. Algina.

Norms and Standard Scores, page 431–455.

Cengage Learning, 2008.

K. Dams-O'Connor, K. T. L. Sy, A. Landau, Y. Bodien, S. Dikmen, E. R. Felix, J. T. Giacino, L. Gibbons, F. M. Hammond, T. Hart, D. Johnson-Greene, J. Lengenfelder, A. Lequerica, J. Newman, T. Novack, T. M. O'Neil-Pirozzi, and G. Whiteneck.

The Feasibility of Telephone-Administered Cognitive Testing in Individuals 1 and 2 Years after Inpatient Rehabilitation for Traumatic Brain Injury.

Journal of Neurotrauma, 35(10):1138–1145, 2018.

M. Geraci.

Linear quantile mixed models: The lqmm package for laplace quantile regression.

Journal of Statistical Software, 57(13):1–29, 2014.

L. Hao and D. Q. Naiman.

Quantile regression.

Sage Publications, 2007.

R. Koenker.

Quantile regression.

Cambridge University Press, 2005.

M. E. Lachman, S. Agrigoroaei, P. A. Tun, and S. L. Weaver.

Monitoring Cognitive Functioning: Psychometric Properties of the Brief Test of Adult Cognition by Telephone.

Assessment, 21(4):404–417, 2014.

R. N. Rodriguez and Y. N. Yao.

Five things you should know about quantile regression.

SAS Institute Technical Paper, 2017.

C. Ryff, D. Almeida, J. Ayanian, N. Binkley, D. S. Carr, C. Coe, R. Davidson, J. Grzywacz, A. Karlamangla, R. Krueger, M. Lachman, G. Love, M. Mailick, D. Mroczek, B. Radler, T. Seeman, R. Sloan, D. Thomas, M. Weinstein, and D. Williams.

Midlife in the United States (MIDUS Refresher), 2011-2014, 2017.

C. Ryff, D. M. Almeida, J. Ayanian, D. S. Carr, P. D. Cleary, C. Coe, R. Davidson, R. F. Krueger, M. E. Lachman, N. F. Marks, D. K. Mroczek, T. Seeman, M. M. Seltzer, B. H. Singer, R. P. Sloan, P. A. Tun, M. Weinstein, and D. Williams.

Midlife in the United States (MIDUS 2), 2004-2006, 2017.

C. D. Ryff and M. E. Lachman.

Midlife in the United States (MIDUS 2): Cognitive Project, 2004-2006, 2017.

C. D. Ryff and M. E. Lachman.

Midlife in the United States (MIDUS Refresher): Cognitive Project, 2011-2014, 2018.

B. Sherwood, A. X.-H. Zhou, S. Weintraub, and L. Wang.

Using quantile regression to create baseline norms for neuropsychological tests.

Alzheimer's & Dementia: Diagnosis, Assessment & Disease Monitoring, 2(1):12–18, 2016.

P. A. Tun and M. E. Lachman.

Telephone assessment of cognitive function in adulthood: the Brief Test of Adult Cognition by Telephone.

Age and Ageing, 35(6):629–632, aug 2006.

Thank you!

Questions?