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Predicting reading speed from eye-movement measures

Ádám Nárai, Kathleen Kay Amora,
Zoltán Vidnyánszky, Béla Weiss

weiss.bela@ttk.hu

Brain Imaging Centre
Research Centre for Natural Sciences
(BIC, RCNS)
Budapest, Hungary

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Motivation

- Reading has a pivotal role in our society
  - Long-term goal: investigating dyslexics
- Reading processes are sensitive to
  - Low-level visual features (e.g. letter-spacing, font type)
  - Linguistic characteristics (e.g. word frequency and length)
  - High-level cognitive processes (e.g. attention)
- These effects are reflected in eye-movements
  - fixations, saccades and glissades (corrective eye-movements)
- Reading speed as a measure of reading competence
- **How eye-movement measures affect reading speed?**

Literature overview

- Søvik et al., 2000: (12 year-old children, N=20)
  - fixation duration (-)
  - number of backward saccades (-)
- Krieber et al., 2017: (14 year-old adolescents, N=21)
  - fixation duration (-)
  - number of saccades (-)
  - saccade amplitude (+)
- Rayner et al., 2010: (typical and poor adult readers, N=32)
  - fixation duration (-)
  - number of forward/backward fixations (-)
  - saccade amplitude (+)

Experiment

- 24 young adults with normal reading abilities
- SMI iView X™ Hi-Speed 1250 eye-tracker
- 64-channel EEG (not analyzed here)
- Silent reading of 32 Hungarian paragraphs
- Text presented line-by-line in three conditions:
  - Normal spacing (~0.31°)
  - Minimal spacing (0.707 times the normal spacing)
  - Double spacing (2 times the normal spacing)

A hód valaha egész földrészünkön benépesítette a folyó menti ligeterdőket, de élőhelyeinek megfogyatkozása és a túlzott mértékű MS: ×0,707

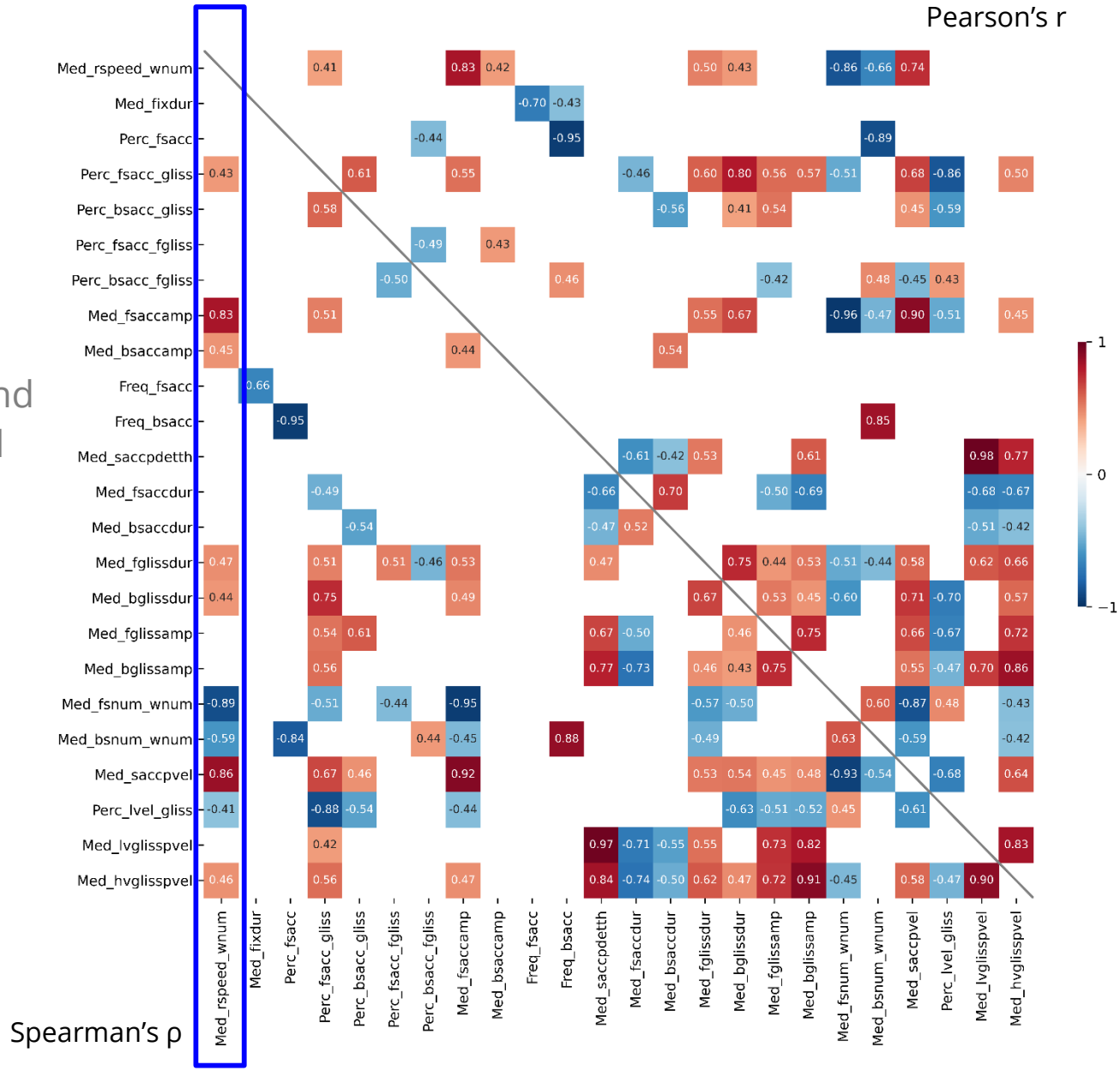
A hód valaha egész földrészünkön benépesítette a folyó menti ligeterdőket, de élőhelyeinek NS: ×1

A hód valaha egész földrészünkön benépesítette DS: ×2

(Weiss et al., 2016)

Measures

- 23 global eye-movement measures
  - Based on fixation, saccade and glissade properties extracted using an adaptive algorithm (Nyström et al., 2010)
  - estimated on subject level
  - Median, percentage or frequency measures
- Reading speed (word/sec)
- Correlations imply multicollinearity

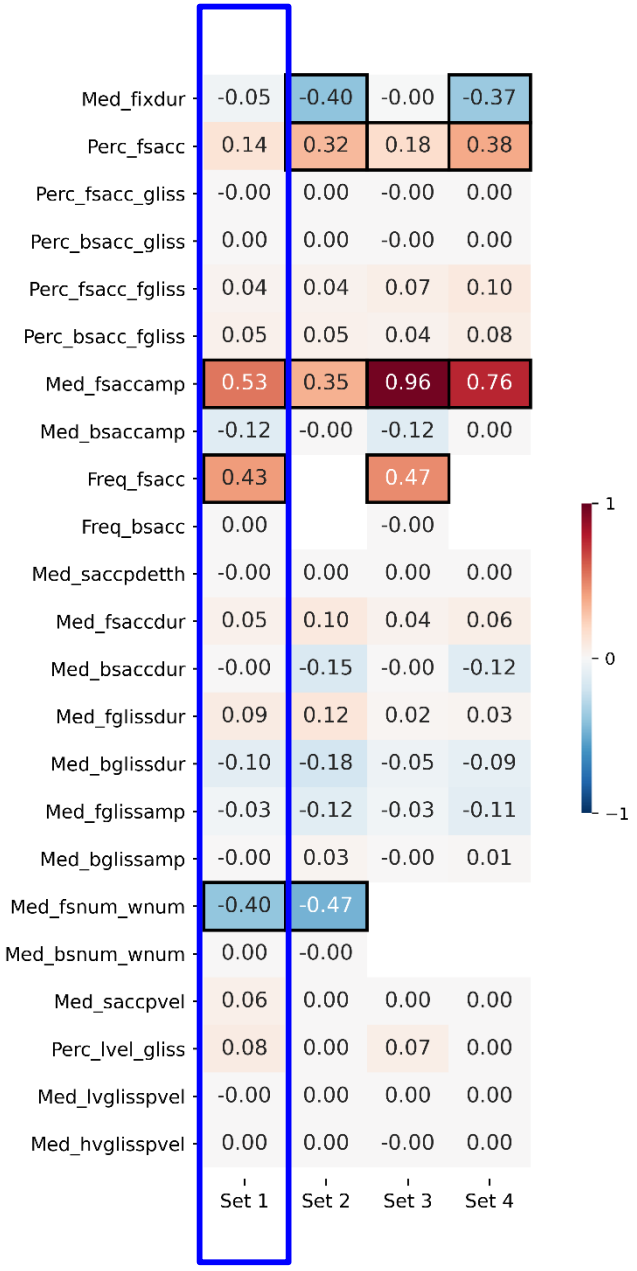


Modeling

- Linear regression model with elastic net regularization
  - ElasticNetCV class from scikit-learn
    - 10-fold cross-validation
    - L1 ratio: 20 values from 0.1 to 1 equally spaced on a logarithmic scale
    - Alpha: 20 values set automatically
  - Dependent variable: reading speed (z-scored)
  - Independent variables: subsets of the 23 global eye-movement measures (z-scored)
  - Performance measure: predicted R^2 (median from a 10-fold cross-validation)
  - Significance testing of regression weights: permutation approach (1000 random permutations)

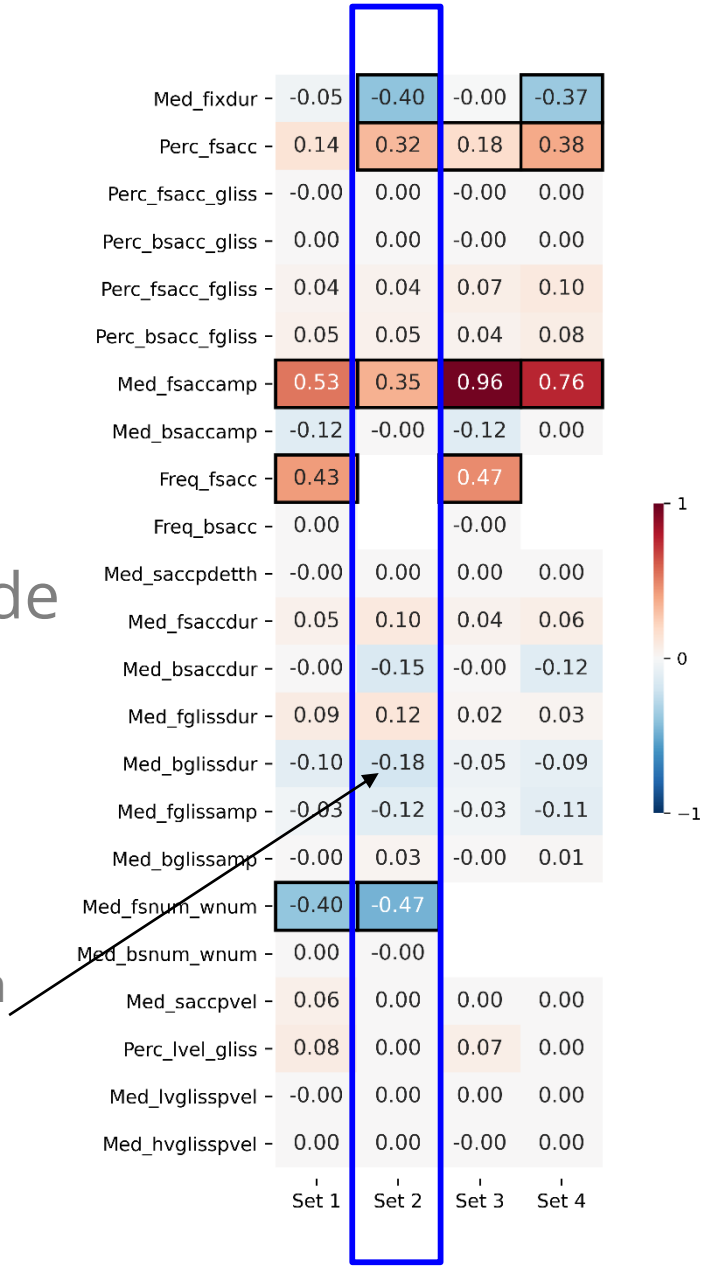
Results

- Using all 23 eye-movement measures
- $R^2_{CV} = 0.88$
- Significant regression weights
  - Median forward saccade amplitude (Med_fsaccamp)
  - Frequency of forward saccades (Freq_fsacc)
  - Median forward saccade number normalized to word number (Med_fsnum_wnum)



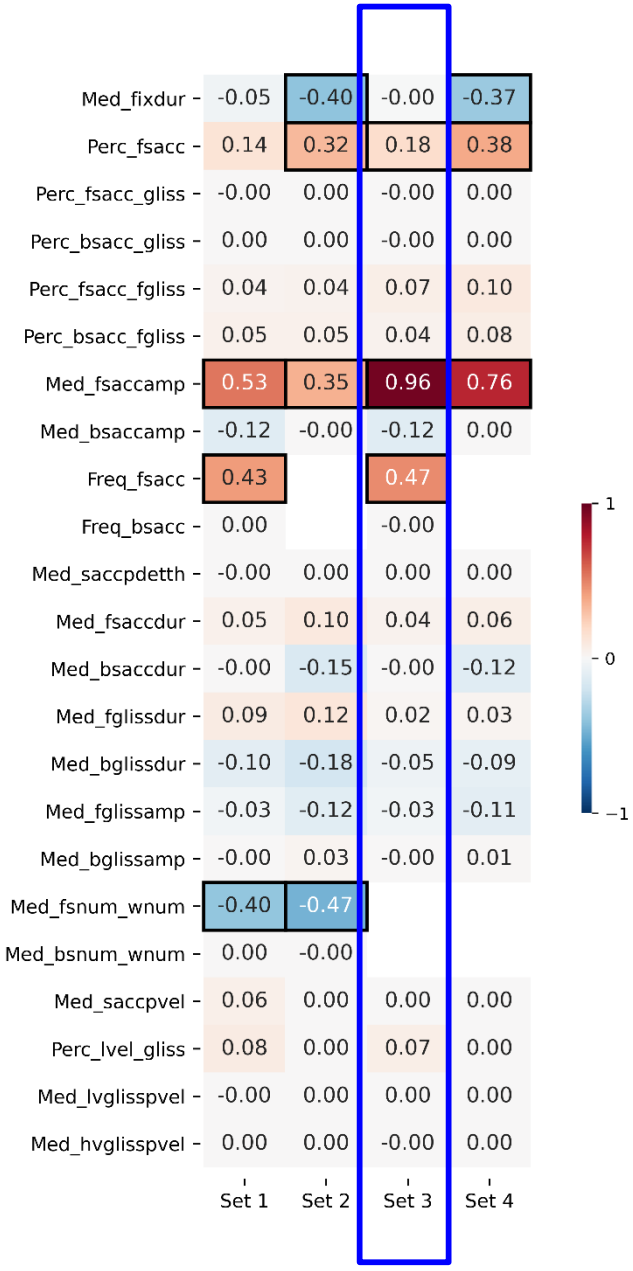
Results

- Effect of leaving out saccade frequency measures
- $R^2_{CV} = 0.51$
- Regression weights replacing saccade frequency
  - Median fixation duration (Med_fixdur)
  - Percentage of forward saccades (Perc_fsacc)
  - Marginal (p=0.051) negative effect of median backward glissade duration (Med_bglissdur)



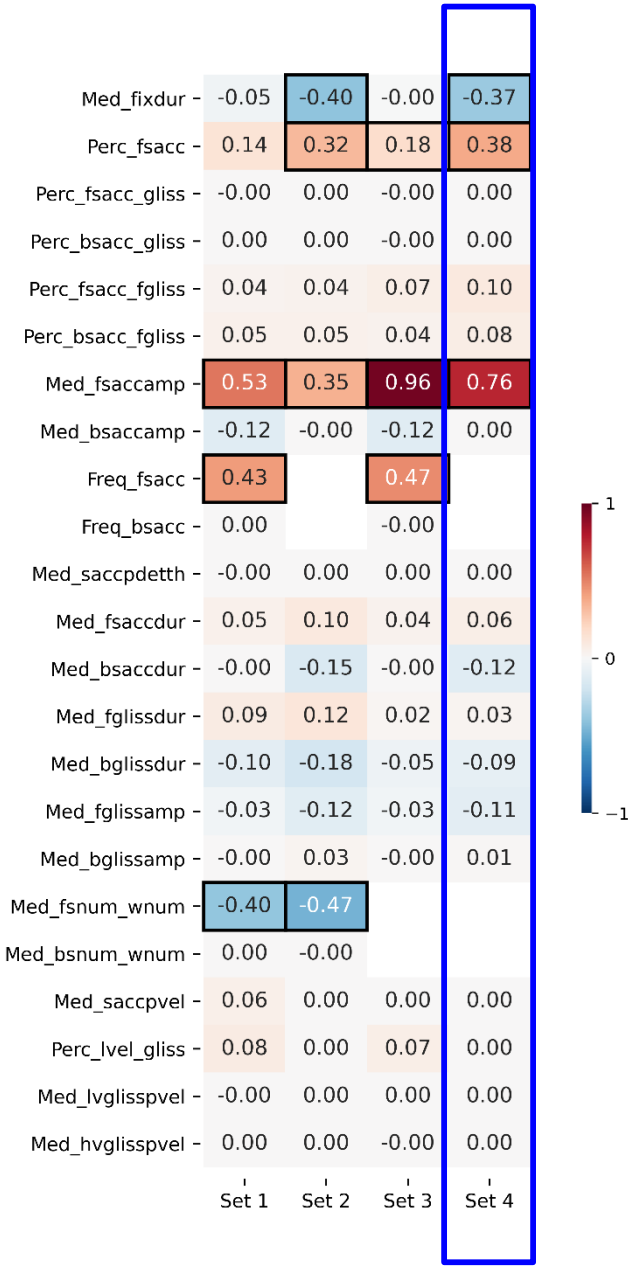
Results

- Effect of leaving out saccade number measures
- $R^2_{CV} = 0.79$
- Regression weights replacing saccade number
  - Median forward saccade amplitude (Med_fsaccamp)
  - Percentage of forward saccades (Perc_fsacc)



Results

- Leaving out both saccade frequency and saccade number measures
- $R^2_{CV} = 0.44$
- Combined effect



Conclusions

- Primarily three features of progressive saccades (amplitude, frequency, number per word) drive reading speed
- Saccade frequency measures mask fixation duration and forward saccade percentage effects
- Normalized saccade number reduces the effect of saccade amplitude
- Potential importance of glissade measures

- Further work
  - Effects of letter spacing modulation on regression weights (MS and DS conditions)
  - How does the regression model depend on reading abilities?

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Thank you!

weiss.bela@ttk.hu

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