Eye Tracking and Reading Proficiency

Grant Eckstein

Brigham Young University

NATO-BILC

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BYU
BRIGHAM YOUNG
UNIVERSITY

ICAMRA
INTERDISCIPLINARY COUNCIL
on the ASSESSMENT of
MULTILINGUAL READING ABILITY
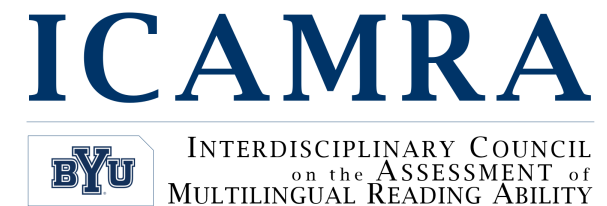
ICAMRA Research Team

Jennifer Bown
Russian

Michael Child
Portuguese

Troy Cox, Center for Language Studies

Grant Eckstein
Linguistics

Larissa Grahl

Anastasia Rybakova

Dennis Eggett
Statistics

Steve Luke
Psychology

Rachel Liu
Chinese

Robert Reynolds
Office Digital Humanities

Logan Blackwell

Background

What is Reading?

- The most complex cognitive activity humans engage in on a daily basis (Rayner & Pollatsek, 1989)

- "the process of simultaneously extracting and constructing meaning through interaction and involvement with written language" (Snow, 2002, p. 11).

- Reading comprehension involves 3 elements:
  - the reader who is doing the comprehending
  - the text that is to be comprehended
  - the activity in which comprehension is a part

Each and every two seconds a reader must

- focus on and access eight to ten word meanings

- parse a clause for information and form a meaning unit

- figure out how to connect a new meaning unit into a growing text model

- check interpretation of the information according to their purposes, feelings, attitudes and background expectations, as needed

- monitor their comprehension, make appropriate inferences as needed, shift strategies and repair misunderstandings, as needed

- resolve ambiguities, address difficulties and critique text information, as needed

What is Reading Proficiency?

- The active, automatic far-transfer process of using one's internalized language and culture expectancy system to efficiently comprehend an authentic text for the purpose for which it was written.

    – Clifford and Cox (2013, p. 50)

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Purpose, Text, and Task Alignment by Level

Level	Author Purpose	Text Type	Reader Task
Int.	**Orient** by communicating main ideas.	Simple, short sentences with simple vocabulary. Text organization is loose without much cohesion	Orient oneself by identifying main topics, ideas, or facts.
Adv.	**Instruct** or inform by communicating organized factual information	Connected factual discourse with compound and complex sentences dealing with factual information. Sequenced within cohesive paragraphs.	Understand not only central facts, but also supporting details.
Sup.	**Evaluate** situations, concepts, and conflicting ideas; present and support arguments and/or hypotheses, accompanied by wit, sarcasm, etc.	Multiple paragraph block of discourse on variety of unfamiliar and abstract topics. Author's voice is evident.	Learn by relating ideas and conceptual arguments. Comprehend literal and figurative meaning of text

Measuring Reading Proficiency

Indirect measures

• Multiple choice reading tests

• Book reports

• Comprehension checks (written/oral)

• Lexical decision tasks

Direct Measures

• Reading aloud protocols

• Eye-tracking

Eye-Tracking

How Eye Trackers Work

Eye trackers use an infrared camera and light source to track the darkest (pupil) and the lightest (corneal reflection) areas of the camera image. The infrared light is invisible to the human eye.

Eye trackers vary in their temporal and spatial precision. The best trackers measure eye position every millisecond. It is spatially accurate to within 2-5 millimeters (a single letter depending on font).
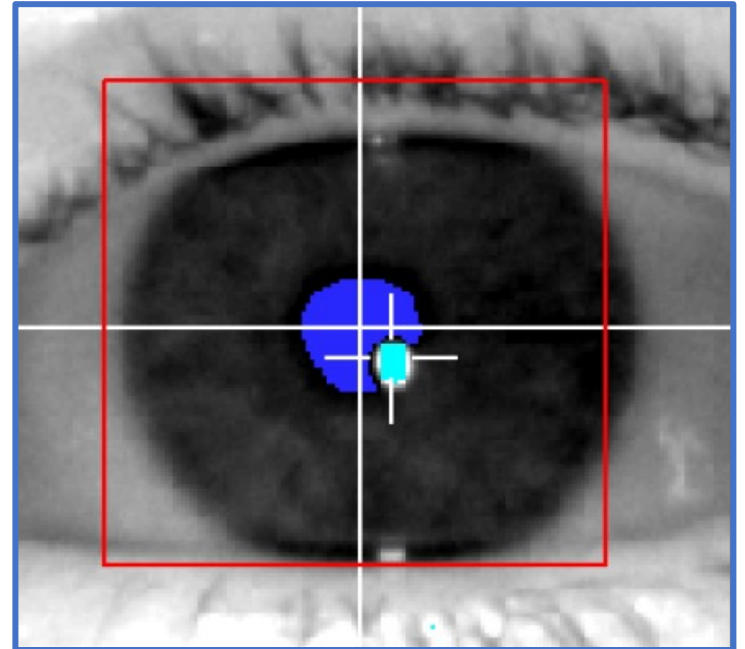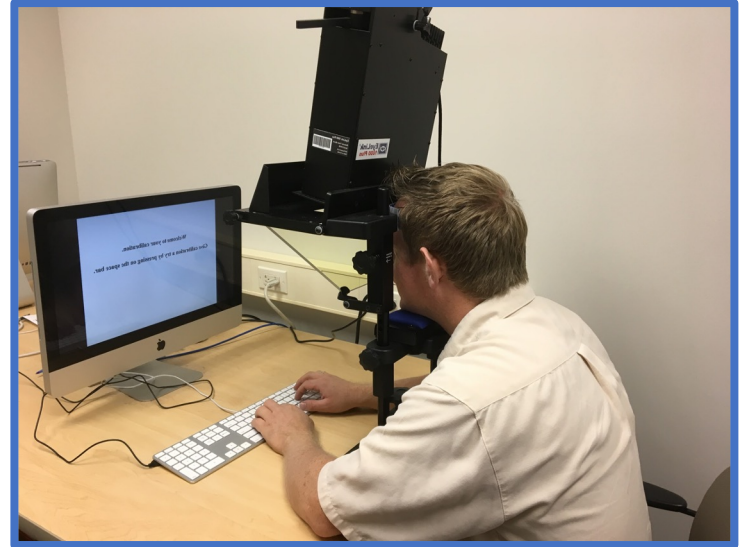
What Eye Trackers Record

- Eye trackers record two basic things
  - Eye stabilizations called FIXATIONS
  - Eye movements called SACCADES

Saccade

1 2 3 4 5 6 9

We are such stuff as nightmares are made on.

7 8
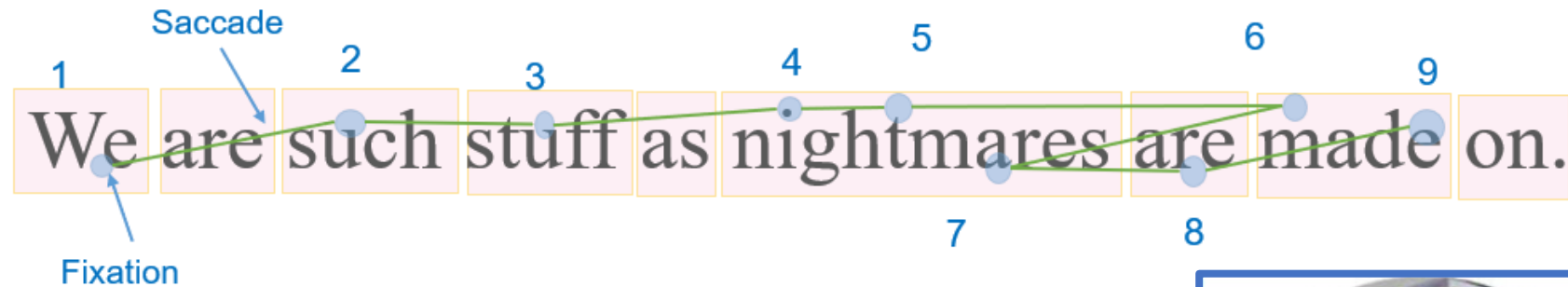
Fixation

Eyes move from point to point because the most sensitive light-receptive cells are concentrated at the center of the retina, called the fovea. We see detail only when an image falls in this region.

Fovea
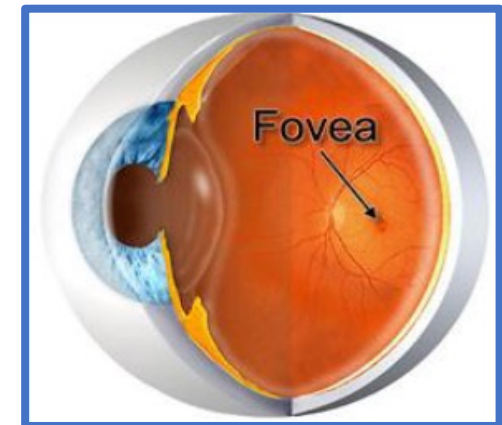
fixation point

Around the fixation point only four to five letters are seen with 100% acuity.

32-25%   45% 75%100% 75% 45%   32-25%

Acuity

Prompt: Explain your background and process as a writer.   Student 1

I am a good writer in the sense of thinking critically in my essay. When I start off my essays it's a habit for me to write down onto paper first and then later on transfer that information onto the computer. The reason I do this is because I can concentrate better without distraction and I am actually thinking about my essay and no other things on the web. So by doing this first I am able to brainstorm more ideas. Sometime when I start off my essay writing on my computer, I have the intention or interest to search the web. When I do this I can no longer concentrate on my essay. As a good writer I also need time. Everyone pace is different when writing essays. Some people can grasp the essay topic and ideas right after the instructor gives it out and some students (like me) take a longer time to process the information down and then start writing. I am not a good writer in the sense of making my paper the best but what I contribute to my essays.

It is always hard for me to narrow my ideas into a shorter sentence so for that I am a detail writer. I like giving and going into depth in my writing. When there is an idea that I really want to express but cannot find a word for it I like to describe what it is. For example, if I wanted to talk about my family and finding a specific vocabulary word to describe them would be impossible. In my opinion one word cannot describe my family. If I have the choice to pick multiple of words to describe them it would be a long one. But by describing my family in a lot of words can help the reader to have an idea of how I am describing my family. In my writing I try to make the reader understand what I am writing about and that can work sometime and other time it may not go as planned.

Fact or Fiction? The creatures of Scotland

Over the decades, several theories about the beast of Loch Ness have been proposed. One theory is that the beast is simply an unknown water mammal, a giant fish. Or it may be the relative of an ancient animal.

Or maybe not. These are just the theories of a few passionate believers. Theories that most scientists reject. The water of Loch Ness is freezing and so dark that few plants live, let alone fish. What would the creature eat? And how could there be just one creature? There would have to be a family that breeds and raises its young. Is it really likely that a group of giant animals lives in the lake, invisible to all but a few witnesses?

Perhaps no person has been as interested in these questions as Tim Dinsdale. An engineer, he led seven Loch Ness expeditions between 1960 and 1987.

DATA_FILE	RECORDING	reading_set	reading_orde	TRIAL_INDEX	TRIAL_LAB	IA_ID	IA_LABEL	text	IA_SKIP	IA_FIRST_FIX	IA_FIRST_RU	IA_FIXATION	IA_FIRST_RU	IA_SE	IA_SEC	TRIAL	IA_DWELL_TI	IA_R	IA_R	IA_R	IA_F	IA_REGRESSI	IA_R	TRIAL_DWELL_TIME
eye106.edf	eye106	3	1	13	Trial: 47	1	Caribou	Caribou	0	399	1	1	399	.	.	169	399	0	0	0	0	399	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	2	Caribou	Caribou	0	162	2	2	405	.	.	169	405	0	0	0	0	405	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	3	are	Caribou	0	267	1	1	267	.	.	169	267	0	0	0	0	267	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	4	large	Caribou	0	205	1	1	205	.	.	169	205	0	0	0	0	205	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	5	members	Caribou	0	337	2	2	618	.	.	169	618	0	0	0	0	618	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	6	of	Caribou	1	.		0	.	.	.	169	0	.	.	.	.		0	46368
eye106.edf	eye106	3	1	13	Trial: 47	7	the	Caribou	0	345	1	1	345	.	.	169	345	0	0	0	0	345	1	46368
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eye106.edf	eye106	3	1	13	Trial: 47	9	family.	Caribou	0	509	1	1	509	.	.	169	509	0	0	0	0	509	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	10	They	Caribou	0	273	1	1	273	.	.	169	273	0	0	0	0	273	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	11	are	Caribou	0	142	1	1	142	.	.	169	142	0	0	0	0	142	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	12	similar	Caribou	0	267	1	1	267	.	.	169	267	0	0	0	0	267	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	13	to	Caribou	0	261	1	1	261	.	.	169	261	0	0	0	0	261	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	14	reindeer,	Caribou	0	353	3	3	808	.	.	169	808	0	0	0	0	808	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	15	except	Caribou	0	430	1	1	430	.	.	169	430	0	0	0	0	430	1	46368
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eye106.edf	eye106	3	1	13	Trial: 47	17	live	Caribou	0	376	1	1	376	.	.	169	376	0	0	0	0	376	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	18	in	Caribou	0	232	1	1	232	.	.	169	232	0	0	0	0	232	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	19	a	Caribou	1	.		0	.	.	.	169	0	.	.	.	.		0	46368
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eye106.edf	eye106	3	1	13	Trial: 47	21	part	Caribou	0	323	1	1	323	.	.	169	323	0	0	0	0	323	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	22	of	Caribou	0	142	1	1	142	.	.	169	142	0	0	0	0	142	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	23	the	Caribou	0	219	1	1	219	.	.	169	219	0	0	0	0	219	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	24	world	Caribou	0	201	1	1	201	.	.	169	201	0	0	0	0	201	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	25	and	Caribou	0	342	1	1	342	.	.	169	342	0	0	0	0	342	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	26	have	Caribou	0	217	1	1	217	.	.	169	217	0	0	0	0	217	1	46368
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eye106.edf	eye106	3	1	13	Trial: 47	28	domesticated.	Caribou	0	290	2	2	523	.	.	169	523	0	0	0	0	523	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	29	Domesticated	Caribou	0	251	2	2	448	.	.	169	448	0	0	0	0	448	1	46368
eye106.edf	eye106	3	2	13	Trial: 47	30	means	Caribou	0	170	2	3	472	1	133	169	605	1	1	0	0	472	2	46368
eye106.edf	eye106	3	1	13	Trial: 47	31	that	Caribou	0	148	1	1	148	.	.	169	148	0	0	0	0	148	1	46368
eye106.edf	eye106	3	1	13	Trial: 47	32	people	Caribou	0	248	1	1	248	.	.	169	248	0	0	0	0	248	1	46368

Eye Tracking Theory

- The eye-mind hypothesis relies on two assumptions
  - What one fixates upon is indeed what one is considering
  - Duration of fixation reflects the cognitive effort required to process what is being viewed

Previous Research

Bilingual Reading: Cop et al., 2015

- 19 Unbalanced bilinguals (Dutch [L1], English [L2]) and 14 English monolinguals read the entire Agatha Christie novel The Mysterious Affair at Styles in 4 reading sessions
  - Bilinguals read half in English, half in Dutch
  - Data collected on sentence level reading
- General differences between bilingual L1 and L2 reading
  - In L2, longer sentence reading times, more fixations/sentence, longer fixation durations, shorter saccade lengths, and lower probability of skipping a word
- No major differences between Bilingual L1 and monolingual English readers

MECO L2 Corpus: Kuperman et al. (2022)

- 543 unbalanced bilingual university speakers of 11 different L2s (Indo-European, Uralic, Semitic, and Turkic) read 12 English texts at intermediate level
  - ACCUPLACER reading test practice passages
  - Data collected on word level reading
- Comprehension questions (4 yes/no) and a battery of language proficiency, vocabulary, and motivation tests were also administered
- General differences between L1 and L2 English reading
  - In all L2s, longer and more fixations, fewer skips, more regressions, and lower reading rate compared to L1
  - Wide variability in eye-movement measures between samples of participants
  - Weak correlation between eye-movements and comprehension accuracy (more common to obtain L1-like comprehension than L1-like reading fluency)

MECO Corpus: Siegelman et al. (2022)

- 543 unbalanced bilingual university speakers of 11 different L2s (Indo-European, Uralic, Semitic, and Turkic) read 12 texts at intermediate level
    - Wikipedia-style encyclopedic entries; five translated from English
    - Data collected on word level reading
- Comprehension questions (4 yes/no) and a battery of language proficiency, vocabulary, and motivation tests were also administered
- General differences across L2 reading
    - Wide variability in eye-movement measures across languages
    - Skipping rate explained greatest amount of variance across languages
    - No discussion of comprehension

ET Proficiency: Berzak et al., (2018)

- 37 L1 English speakers and 145 ESL speakers (Chinese, Japanese, Portuguese, Spanish) read 156 stand-alone sentences in English
  - Wall Street Journal Penn Treebank (100 characters max)
  - Data collected on word level reading
  - EyeScore calculated (normalized difference between L2 features and average L1 features)
- English Proficiency: Michigan English Test and self-report of TOEFL
- General Results
  - Correlations of about .5 between EyeScore and proficiency on MET and TOEFL on test data; same for predicting proficiency on novel learners
  - First proof-of-concept for using eye-tracking to measure linguistic ability

Eckstein et al. (in review)

- 35 university-level L1 speakers of English studying French as an L2
  - 16 beginning French (classroom instruction)
  - 18 intermediate French (in-country experience)
- 80 sentences from translations of WikiHow article
  - 40 English; 40 French — 20 Normal; 20 jumbled
- General results
  - French took longer to process than English (irrespective of transposing)
  - Beginning students read normal French more slowly than intermediate students
  - Transposed letters in French may be easier to read than transposed letters in English

Present Research (in progress)

Our Study

- Little is known about literacy development in a second language
- Assessing reading proficiency in L2 is currently difficult because

  (1) we have few direct measures of the reading process,

  (2) identifying reading-level-appropriate texts for assessment use is time- and resource-intensive, and

  (3) text readability measures are based on word frequency and syntactic complexity rather than reading behavior
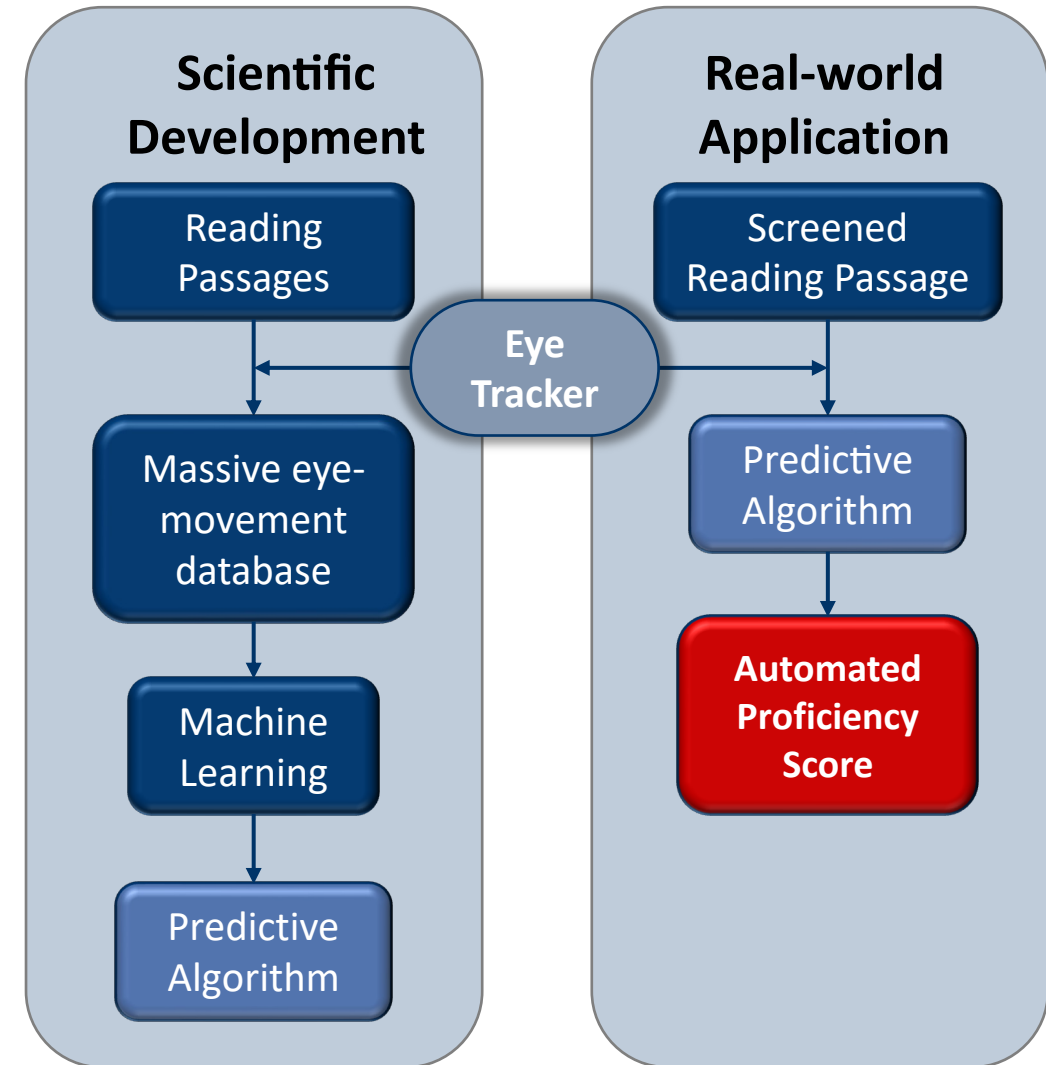
Research Questions

- What is the relationship between L2 reading proficiency level and measures of reading fluency?
  - first fixation duration, gaze duration, and total dwell time
- How does text difficulty affect eye movements of L2 readers at Intermediate, Advanced, and Superior levels of proficiency?
- How do eye movements differ when reading in L1 versus L2?
- How does the L2 of the reader affect eye movements at each proficiency level?

Our Methods

- **Participants**
  - About 30 language learners and 30 native speakers in each target language (Chinese, Portuguese, Russian, English)
  - College age adults with various language proficiencies (novice to superior on ACTFL scale)

- **Stimuli**
  - Scaled reading passages at intermediate, advanced, and superior levels (about 500 words per level for a total of 17 passages [12, 4, 1] in each language)
  - Intermediate and advanced passages were translated into each language whereas superior was culturally unique

- **Procedures**
  - Screening survey, in-person reading proficiency exam in L2, eye-tracking component
  - During eye-tracking, 9-point calibration, practice items, and counter-balanced presentation of readings were used
  - Each reading was followed by a single multiple-choice comprehension question

- **Variables**
  - Each word was an AOI*
  - First fixation duration, gaze duration (first pass reading time), and total time*

- **Analysis**
  - Linear mixed-effect model
  - Fixed effects: Language, Reader proficiency, Text level
  - Random grouping variables: Participant, Text

* We chose these variables to measure preliminary global fluency rather than examining more nuanced measures related to word order, frequency, etc., which we plan to pursue in the future.

Reading Proficiency Test

From an essay on art and culture

When we look around us today, we see tremendous sums of public and private money poured into artistic and cultural activities at every level. We see a vast network of institutions serving a large and eager but often bewildered public. And, not least, we also see a great deal of unmistakable talent and imagination at work.

Yet how directionless and stymied, how baffled in their purposes most of this activity and talent seem. In fact, after viewing the art scene all these years, it is impossible for me not to ask: What's wrong here?

Let me put it another way: Why is so much of our art so empty and mean-spirited? Why do so many vaunted reputations turn to ashes so quickly? Why don't all the talent, effort, and money produce more of quality and permanence? Why is so much of the criticism lavished upon our art so pusillanimous in confronting failures? And why are our values, tastes, and intellectual loyalties

---

In the three opening paragraphs, the author _____.

says it is impossible for today's artists to fail in the art scene

claims cultural activities are underfunded at every level

expresses dismay with today's art and cultural activities

argues that large institutions interfere with artists' talent

I don't know.

Next

Eye-tracking Instrument

- 34 reading passages (17 in each language).
  - Intermediate (12 passages), advanced (4 passages) and superior (1 passage).
  - Total word count among the three levels: 500 words.
- Each passage was immediately followed by one multiple-choice comprehension question, with five possible options: three distractors, one "I don't know" option, and one correct answer.

Just a reminder that your appointment is scheduled for Monday, May 26 at 2:00 p.m. Please confirm your meeting by clicking the button below. If you are unable to make this appointment, please call us to reschedule. Please come prepared with your form of payment or insurance card.

Thanks!

What is the purpose of this message?

to help someone apply for insurance

to remind someone of a doctor appointment

to cancel a doctor consultation

to remind someone to pay a medical bill

I don't know.

Procedures

Pre-Visit Intake

In-Person Reading Proficiency Testing

In-Person Eye-tracking Visit

- Demographic information
- Language Background Questionnaire

■ English Reading Proficiency Test
■ L2 Reading Proficiency Test

Eye-tracking lab
Two blocks: English and L2
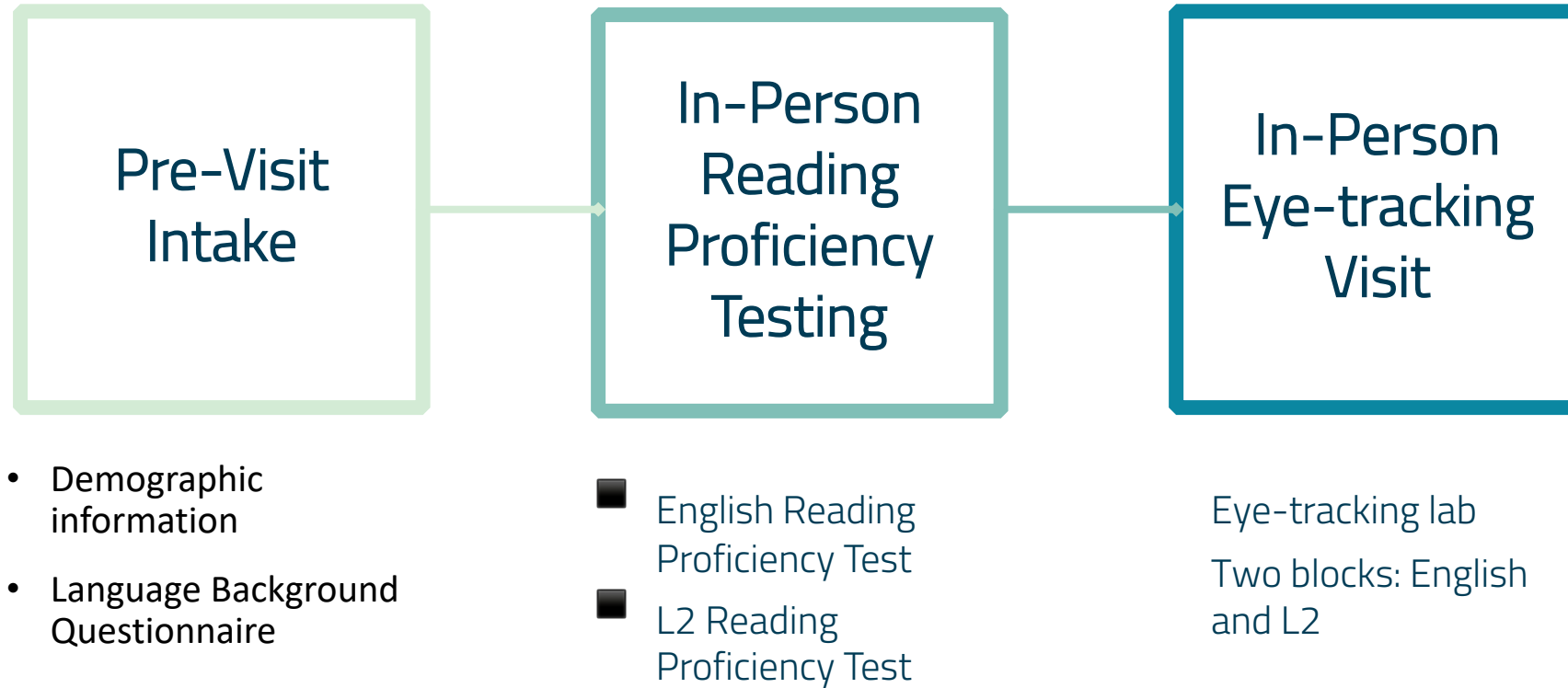
Data Measurements

- First fixation duration = the length of the first fixation made on a word or area of interest (AOI). ③

- Gaze duration = the sum of all fixations made on a word or AOI before the reader exits to the right or to the left. ③ + ④

- Total time = the sum of all fixations made on a word or AOI during a trial. ③ + ④ + ⑥ + ⑨
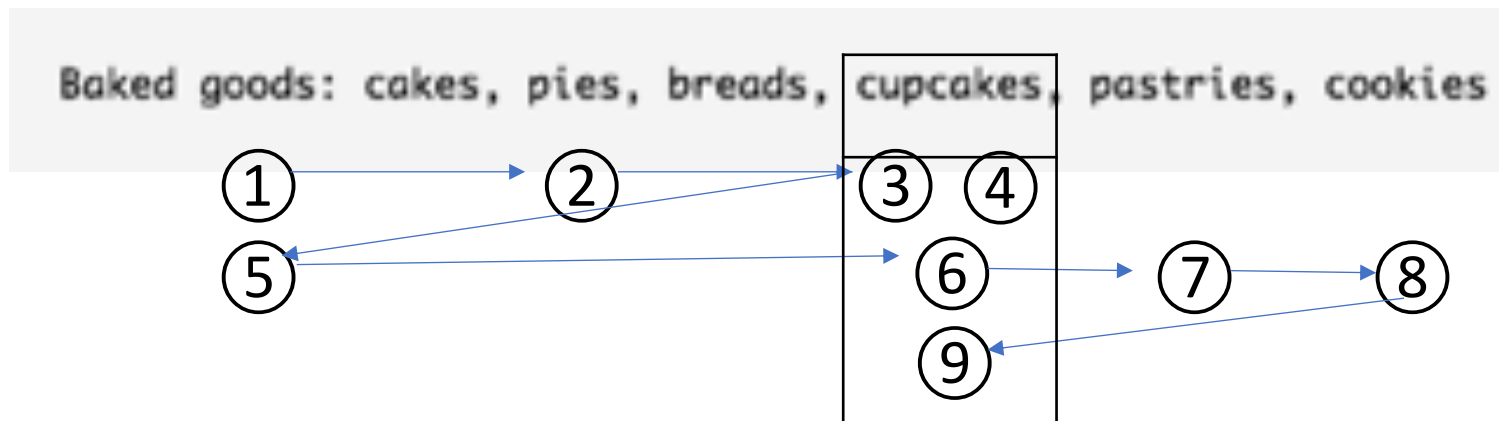
Present Results

Grahl et al., 2018

- 37 English (L1) speakers of Portuguese (L2)
- Proficiency level did not significantly affect reading behaviors in either language
- Participants read slower in Portuguese (L2) than English (L1)
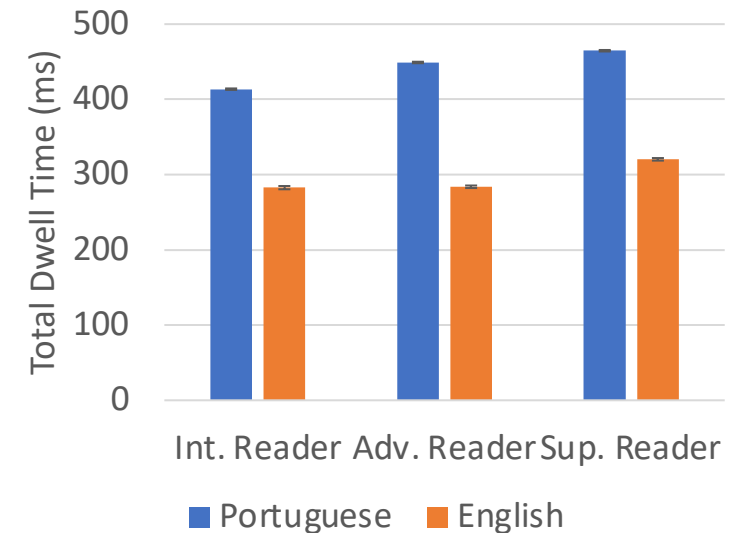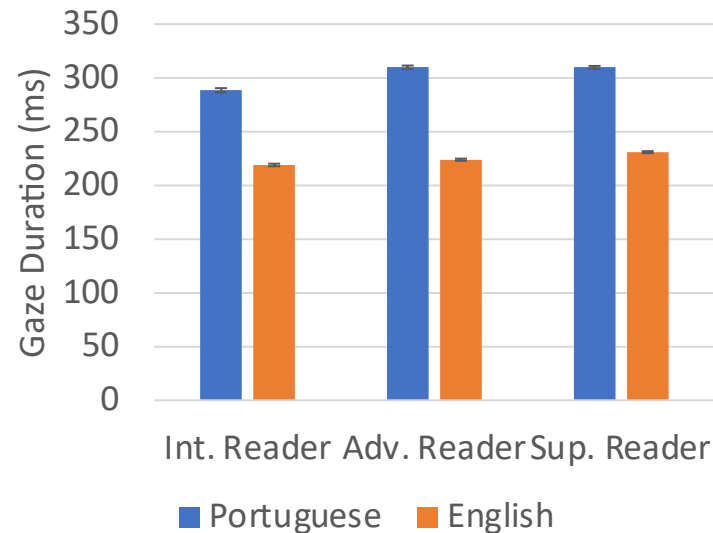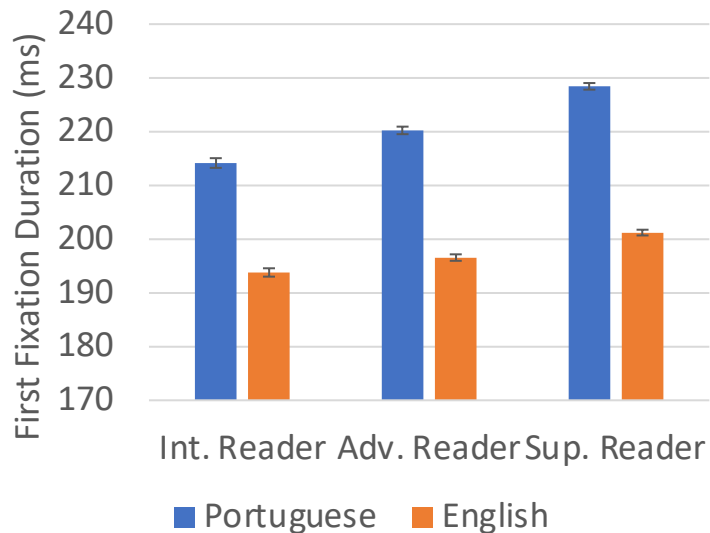
Rybakova et al., 2019

- 32 English (L1) speakers of Russian (L2)

- Proficiency level did not significantly affect reading behaviors in either language

- Participants read slower in Russian (L2) than English (L1)
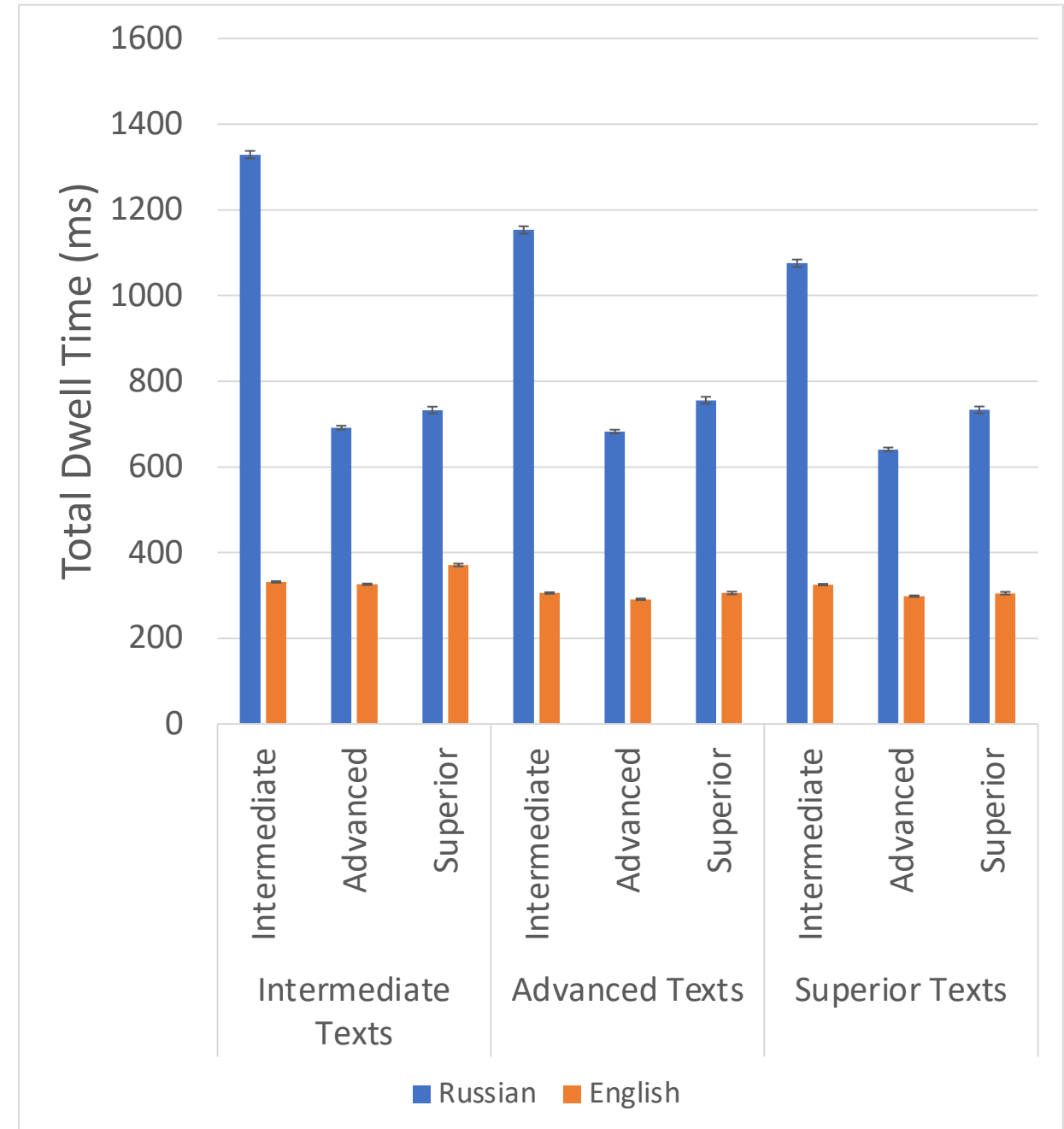
Applications

For Teachers

- Reading is a complex, multi-faceted task
- Reading in an L2 is slower
  - longer and more fixations, fewer skips, more regressions, and lower reading rate compared to L1
- Slower reading does not mean worse comprehension
- In L2, reading speed can vary depending on language proficiency, but results are not conclusive
- Text difficulty may not affect reading behavior

For Teachers

- Teach readers about the mechanics of reading

- Empathize with reading in an L2 (slower, harder)

- Teach reading strategies
  - Pre-, During, Post-
  - Text purpose

- Provide texts and vocabulary that match students' interests and language proficiency

- Practice faster reading on easier texts
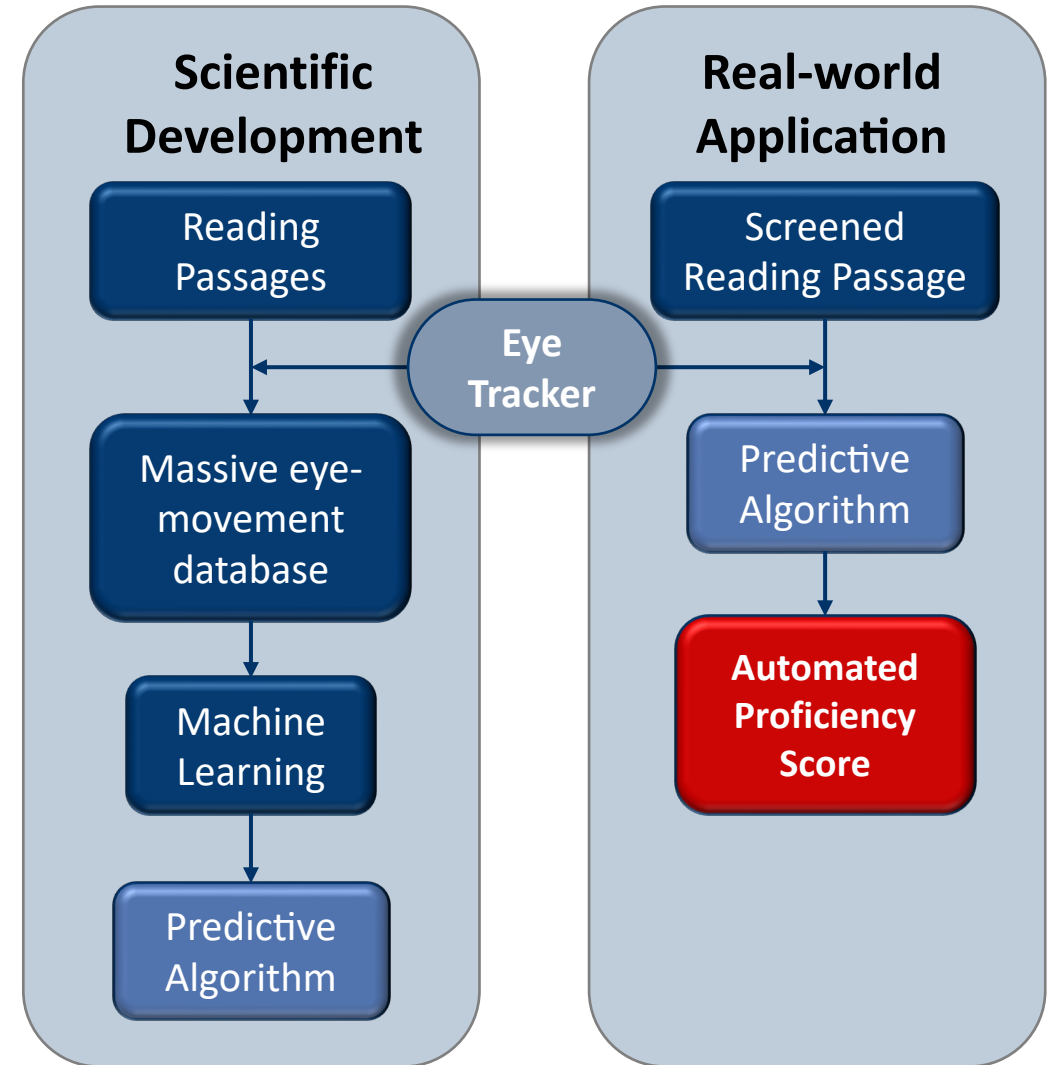
Future Research

Decision Trees
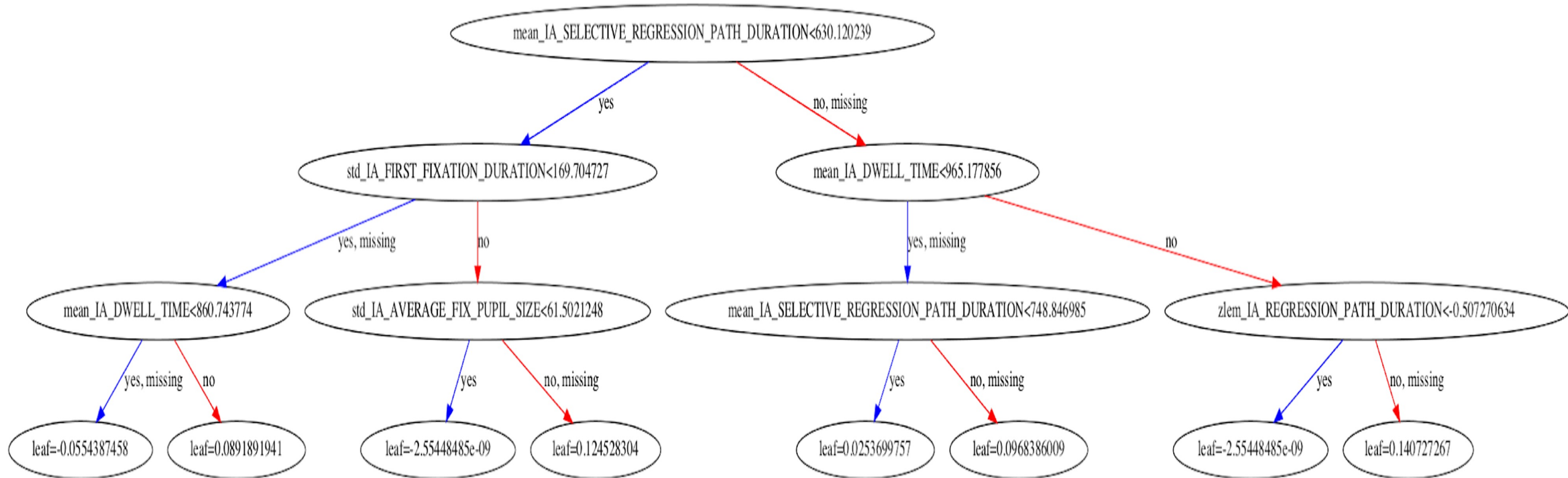
Possible Applications

- Military
- Law
- Industry
- Government
- Language learning
- Translation
- Cognitive science
- Text assessment

Scientific Development

- Reading Passages
- Massive eye-movement database
- Machine Learning
- Predictive Algorithm

Eye Tracker

Real-world Application

- Screened Reading Passage
- Predictive Algorithm
- Automated Proficiency Score

Future Projects

- Create a data corpus of eye tracking measures to establish L2 reading benchmarks

- Apply machine learning to
  - Assess L2 reading proficiency
  - Automatically assess text readability level

References

- Berzak, Y., Katz, B., & Levy, R. (2018). Assessing language proficiency from eye movements in reading. *arXiv preprint arXiv:1804.07329.*

- Cop, U., Drieghe, D., & Duyck, W. (2015). Eye movement patterns in natural reading: A comparison of monolingual and bilingual reading of a novel. *PLoS ONE*, *10*(8), 1–38. https://doi.org/10.1371/journal.pone.0134008

- Kuperman, V., Siegelman, N., Schroeder, S., Acartürk, C., Alexeeva, S., Amenta, S., . . . Usal, K. (2022). Text reading in English as a second language: Evidence from the Multilingual Eye-Movements Corpus. *Studies in Second Language Acquisition,* 1-35. doi:10.1017/S0272263121000954

- Siegelman, N., Schroeder, S., Acartürk, C., Ahn, H.-D., Alexeeva, S., Amenta, S., Bertram, R., Bonandrini, R., Brysbaert, M., Chernova, D., Da Fonseca, S. M., Dirix, N., Duyck, W., Fella, A., Frost, R., Gattei, C. A., Kalaitzi, A., Kwon, N., Lõo, K., ... Kuperman, V. (2022). Expanding horizons of cross-linguistic research on reading: The Multilingual Eye-movement Corpus (MECO). *Behavior Research Methods*. Advance online publication. https://doi.org/10.3758/s13428-021-01772-6

Thank You

- Questions?

- Grant_eckstein@byu.edu