Eye movement pattern and consistency predict reading performance of English as Second Language (ESL) Learners

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Introduction

Language proficiency & reading comprehension

- Higher language proficiency is associated with better reading performance in ESL learners (e.g., Rayner et al., 2016).

Eye movement (EM) and reading comprehension

- More proficient L2 readers had longer fixation time on key content (Bax, 2019) and shorter total fixation time (Brunfaut & McCray, 2015).
- More developed visual routine → better performance (e.g., Hsiao et al., 2020).

- Here we aim to examine whether ESL learners' EM pattern and consistency could predict reading performance in addition to English proficiency and potential cognitive ability factors.

Hypothesis

- Readers' EM pattern may be particularly relevant to reading time. EM pattern may mediate the effect of language proficiency on reading time.
- EM consistency may be associated with comprehension accuracy, as higher EM consistency may indicate a higher level of reading expertise/skills.

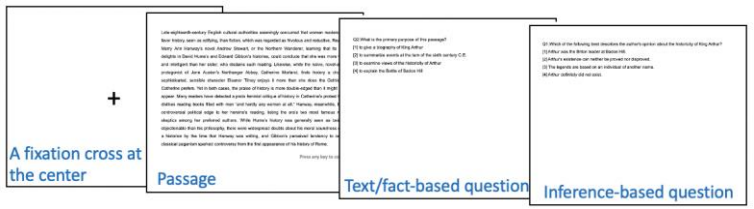
Method

Participants: 50 native Mandarin speakers (25 Female; Age: M = 22.5, SD = 3.88)
Materials: 9 GRE reading samples (typical university learning level; contained similar number of words (M = 218; SD = 9.84))
- Each passage: one text/fact-based question, one inference-based question
Design:
- Regression analysis
  - Independent variables:
    - EM measures: global measure of EM pattern (A-B scale as assessed by EMHMM), entropies, and traditional local measures (fixation duration, horizontal/vertical saccade length); cognitive measures; LexTale score
  - Dependent variables: Comprehension accuracy (ACC); Reading time (RT)

Procedure:

LexTale test → Reading comprehension task (eye tracked) → Cognitive Tests:
1. Verbal n-back
2. Visual-spatial n-back
3. Tower of London Task
4. Multitasking Task
5. Flanker Task
6. Trail-making Task

- Reading comprehension task:

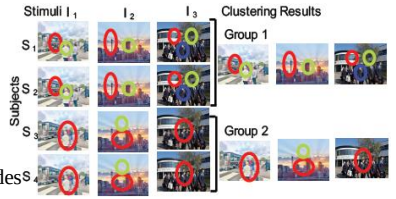


Results

Eye movement analysis:

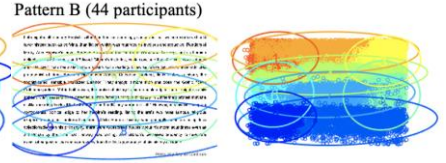
Eye Movement analysis with Hidden Markov Models (**EMHMM**; Chuk et al., 2014) with co-clustering (Hsiao et al., 2021) was used to analyse EM data:

- Each participant's EM was summarized in an HMM in terms of personalized regions of interest (ROIs) and transition probabilities among the ROIs
- We clustered all models to discover 2 common strategies across participants and across stimuli
- Pattern B group had larger proportion of horizontal saccades



Pattern A (5 participants)

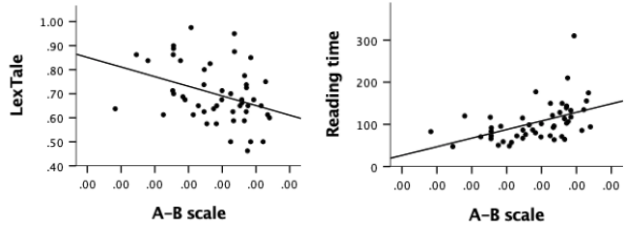
Pattern B (44 participants)



Group 1	To 1	To 2	To 3	To 4	To 5	To 6	To 7	To 8	To 9
Priors	.52	.11	.02	.06	.04	.05	.06	.10	.04
From 1	.83	.16	.00	.01	.00	.00	.00	.00	.00
From 2	.08	.88	.03	.00	.00	.00	.00	.00	.01
From 3	.16	.01	.72	.11	.00	.00	.00	.00	.00
From 4	.00	.00	.02	.77	.12	.02	.04	.01	.01
From 5	.01	.01	.00	.00	.79	.18	.00	.00	.01
From 6	.00	.00	.00	.16	.00	.80	.02	.00	.00
From 7	.01	.00	.00	.01	.00	.00	.81	.16	.00
From 8	.01	.00	.00	.00	.00	.01	.09	.88	.00
From 9	.02	.00	.00	.00	.00	.01	.00	.02	.94

Group 2	To 1	To 2	To 3	To 4	To 5	To 6	To 7	To 8	To 9
Priors	.37	.25	.05	.06	.05	.03	.08	.08	.03
From 1	.79	.15	.01	.04	.00	.00	.01	.00	.00
From 2	.01	.92	.06	.00	.00	.00	.00	.00	.00
From 3	.15	.01	.80	.02	.01	.01	.00	.00	.00
From 4	.00	.00	.03	.93	.01	.00	.01	.00	.00
From 5	.00	.00	.00	.00	.78	.13	.01	.01	.06
From 6	.00	.00	.00	.03	.01	.74	.19	.02	.00
From 7	.00	.00	.00	.00	.07	.00	.90	.01	.00
From 8	.00	.00	.00	.00	.02	.00	.01	.94	.02
From 9	.00	.00	.00	.00	.00	.00	.02	.15	.81

We quantified participants' EM pattern using **A-B scale**: A-B Scale = (A - B) / (|A| + |B|)
- A and B: Participant's data log-likelihood given Pattern A and Pattern B models respectively.
- More positive A-B scale indicated higher similarity towards Pattern A



A-B scale was negatively correlated with LexTale (p = .011), positively correlated with RT (p = .001)

The Mediation of A-B scale on the effect of LexTale on RT

- Unmediated model: LexTale —c = -116.27, p = .037→ Reading RT

- Mediated model: LexTale —a = -0.003, p = .011→ A-B scale —b = 18107.24, p = .004→ Reading RT; LexTale —c' = -57.61, p = .289→ Reading RT

Whether local EM measures can better predict RT and ACC?

- RT: ToL planning time (p < 0.001), horizontal saccade length (p < 0.001).
- ACC: Entropy of the second fixation (p = 0.011), accuracy of working memory as measured in 2-back verbal test (p = 0.021)

→ Traditional EM measures can better predict RT than A-B scale and LexTale

The Mediation of horizontal saccade length on the effect of LexTale on RT

- Mediated model: LexTale —a = 161.71, p <.001→ Horizontal saccade length —b = -.71, p = .004→ Reading RT; LexTale —c' = -1.12, p = .986→ Reading RT

Conclusions

- EM pattern and consistency predicted passage reading performance in addition to language proficiency and general cognitive abilities
- Higher English proficiency predicted faster reading speed through the mediation of this EM pattern; Reading comprehension accuracy could be predicted by a more consistent eye fixation behavior in the beginning of reading engagement

- EM patterns are better predictors for passage reading time than language proficiency.
- Students may be instructed to enhance EM consistency during reading to improve comprehension acc.

References

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Interested in our EMHMM approach for eye movement data analysis?
Visit our website and download the EMHMM MatLab toolbox:
http://abc.psy.hku.hk/emhmm