New Vistas to Study Bhartṛhari: Cognitive Natural Language Processing (NLP)

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1.1 Bhartṛhari's 'Vākyapadīya'

Bhartṛhari: A Grammarian-philosopher, 5^{th} Century CE
'Vākyapadīya'- Vākyakāṇḍa

आख्यातशब्दः सङ्घातो जातिः सङ्घातवर्तिनी ।
एकोऽनवयवः शब्दः क्रमो बुद्ध्यनुसंहृतिः ॥१॥
पदमाद्यं पृथक्सर्वं पदं साकाङ्क्षमित्यपि ।
वाक्यं प्रति मतिर्भिन्ना बहुधा न्यायवादिनाम् ॥२॥

Figure: Sentence-definitions, VP.II.1-2

1.1 Bhartṛhari's 'Vākyapadīya'

First definition: **Ākhyātaśabdaḥ**

Explanation:

1. Bhartṛhari, VP.II.326

   ''ākhyātaśade niyataṃ sādhanaṃ yatra gamyate |
   tadapyekaṃ samāptārthaṃ vākyamityabhidhīyate ||''

2. Ambākartrī by Pt. Raghunatha Sarma

   pidhehīti... atra dvāramiti karmākṣepāt paripūrṇārthatve 'dvāraṃ pidhehi' iti vākyam bhavatyeva |

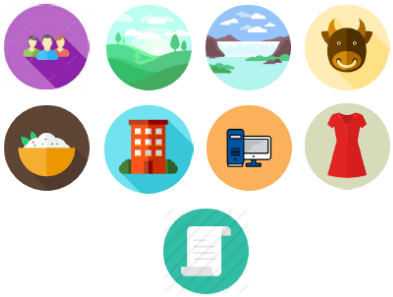
3. Puṇyarāja

   'kriyā vākyārthaḥ'

1.2 Eye-Tracking

Why Eye-Tracking?

- Information passes through the eyes...



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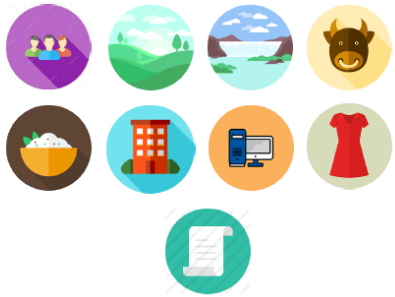

- Various researches have shown that:

  Textual nuances affect gaze. *(Just and Carpenter, 1980; Rayner, 1998)*

  Eye-movements can be used to infer cognitive processes. *(Starr, 2011)*

  Mind processes the word eye fixates on. *(De Groot, 2011)*

  Eye is the window into the brain. *(Majaranta, 2014)*

  Eye-movement is poised between perception and cognition. *(Mishra, 2016)*

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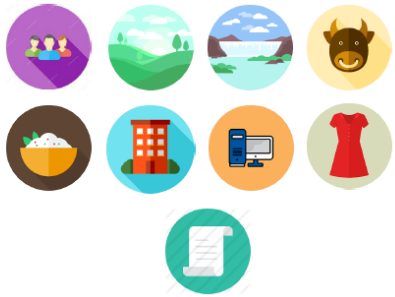

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  Eye is the window into the brain. *(Majaranta, 2014)*

  Eye-movement is poised between perception and cognition. *(Mishra, 2016)*

- Feasibility: Inexpensive eye-tracking hardware available and integrated with handheld gadgets. (`http://www.sencogi.com`) *(Mishra, 2016)*

1.2 Eye-Tracking

Features:

Various efforts done by readers during reading:

- Progression/ Saccades
- Back-tracking/ Regression
- Fixation
- Skip etc.

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2.1 Hypothesis Formulation

Hypothesis:

When lexical complexity is minimized in the texts, Sanskrit readers tend to rely more on *the verbs* for the sentence comprehension.

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Research Question 1:

Do the Sanskrit readers spend more time on, look back more at and rarely skip the verbs than the non-verb words during sentence-comprehension?

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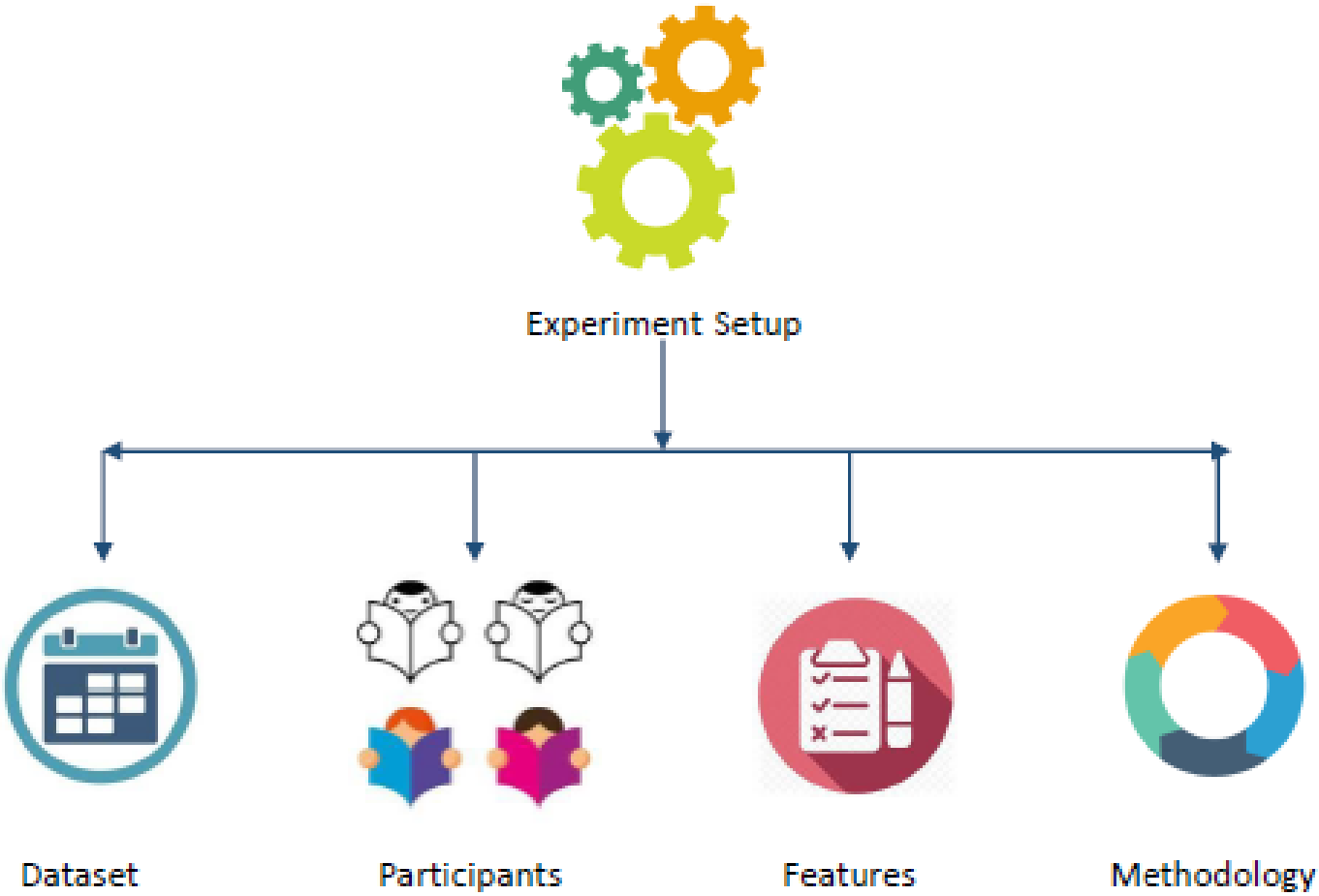
Research Question 1:

Do the Sanskrit readers spend more time on, look back more at and rarely skip the verbs than the non-verb words during sentence-comprehension?

Research Question 2:

Are purely nominal sentences in Sanskrit less comprehensible or less meaningful than the sentences having verb/s?

2.2 Experiment Setup



2.2 Experiment Setup

(i) Dataset Description

Step 1

Dataset Collection- 20 Documents in total, Lexical Complexity Minimization

Step 2

Dataset Modification- Removal and replacements[a], Document Type A, B, C.

[a] This type of modification in the data is motivated by the research conducted by *Marta, 1980*.

Step 3

Dataset Finalization- Shuffled documents, 2 Questions, Dataset 1, 2 and 3

2.2 Experiment Setup

(i) Dataset Description

Step 1

Dataset Collection- 20 Documents in to imization

Dataset Modification- Removal and B, C.

[a]This type of modification in the da d by *Marta, 1980*.

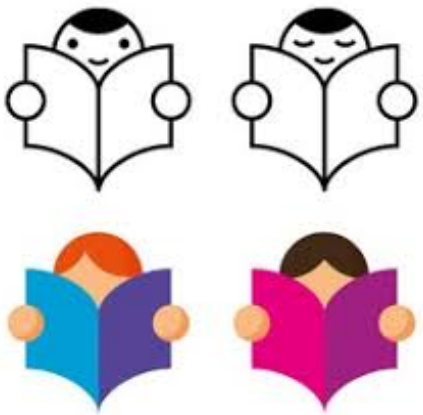
100% agreement

Step 3

Dataset Finalization- Shuffled documents, 2 Questions, Dataset 2 and 3

2.2 Experiment Setup

(ii) Participant Description



20 Participants in total
Adult age-group
Background in Sanskrit
Neurologically healthy
Normal or corrected vision
Multilingual

2.2 Experiment Setup

(iii) Feature Description

1. Dwell Time

Amount of time spent on AOI[a].

2. Regression Count

Total number of regressions on AOI.

3. Skip Count

Total number of times an AOI was skipped.

4. Fixation Count

Total number of fixations.

5. Run Count

Total number of times an AIO was looked at.

[a] AOI= Area of Interest, here, **the verb** in the sentence.

2.2 Experiment Setup

(iv) Methodology

- Experiment Building

  Controlled experiment

- Experiment Conducting

  Instruction

  Sample Documents

  Self-paced and silent reading

  One document at a time

  Multiple-choice question

  Short breaks in between

2.3 Results and Analysis

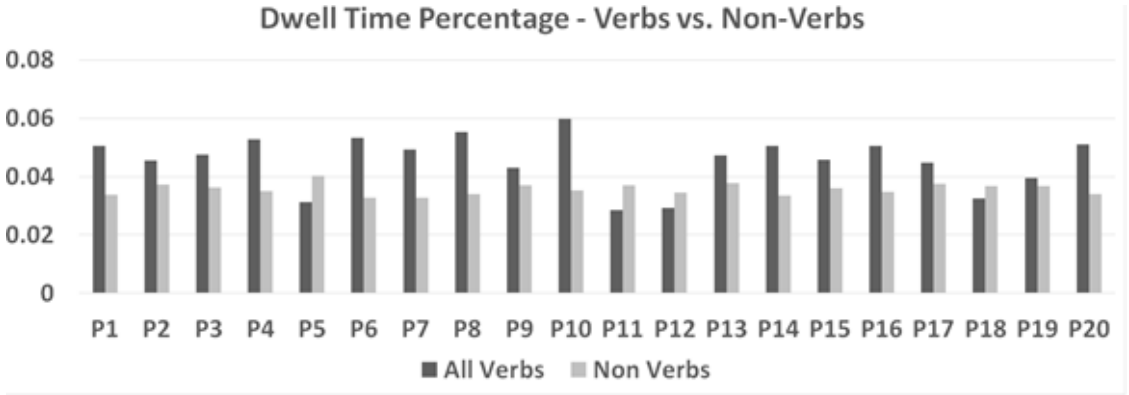


Figure: Dwell Time Percentage on Verbs vs. Non-Verbs in all three Datasets by all participants

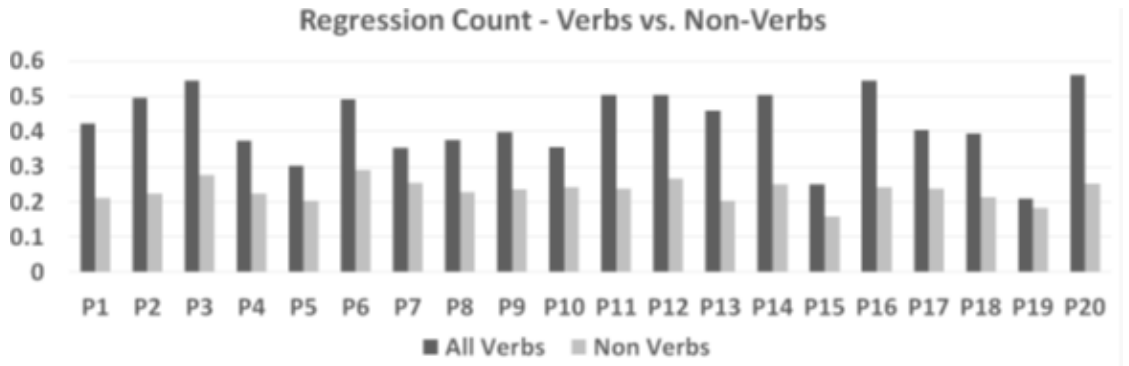


Figure: Regression Count on the Verbs vs. Non-Verbs in all three Datasets by all participants

2.3 Results and Analysis

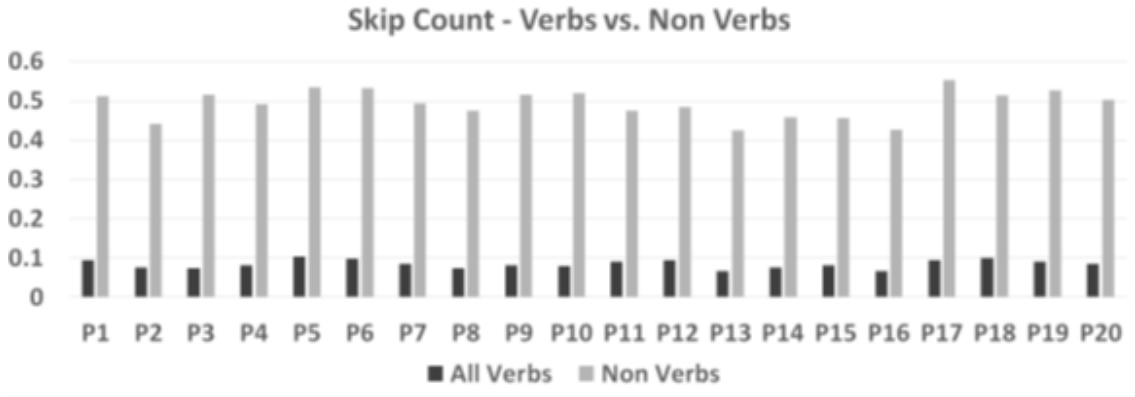


Figure: Skip Count on Verbs vs. Non-Verbs in all three Datasets by all participants

2.3 Results and Analysis

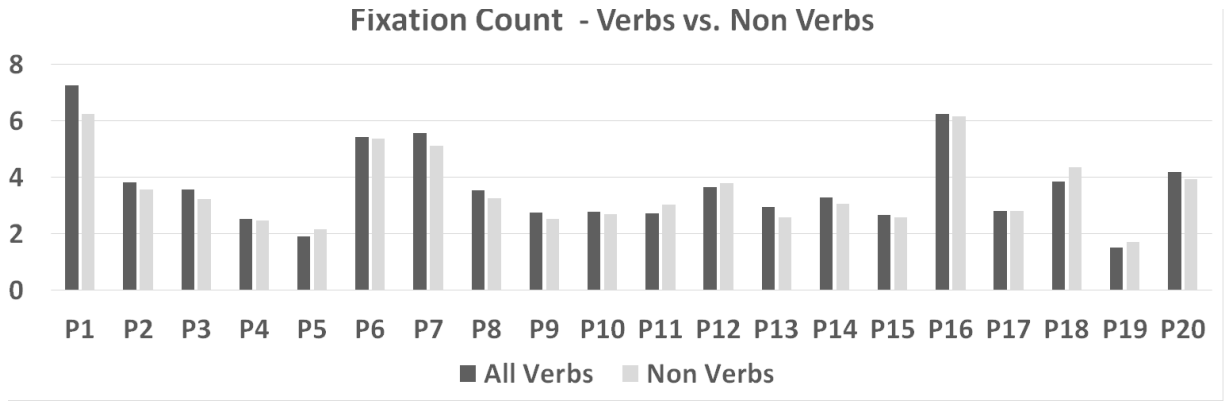


Figure: Fixation Count on Verbs vs. Non-Verbs in all three Datasets by all participants

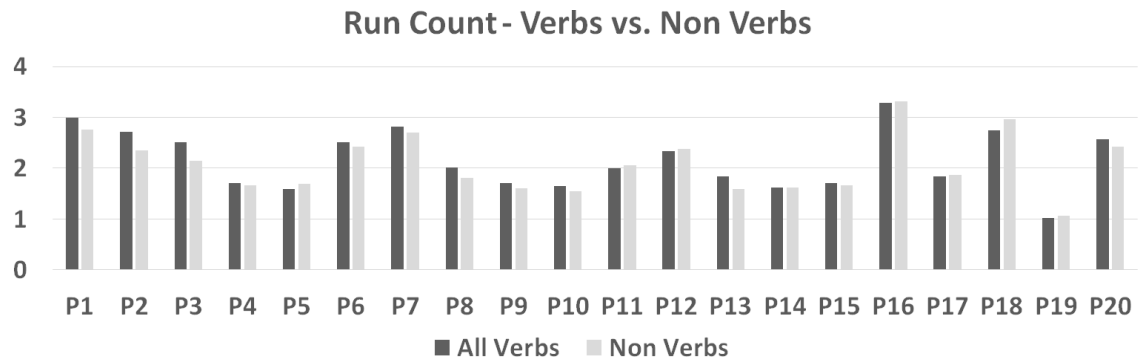


Figure: Run Count on the Verbs vs. Non-Verbs in all three Datasets by all participants

2.3 Results and Analysis

Evaluation of the Work

Meaningfulness of the texts

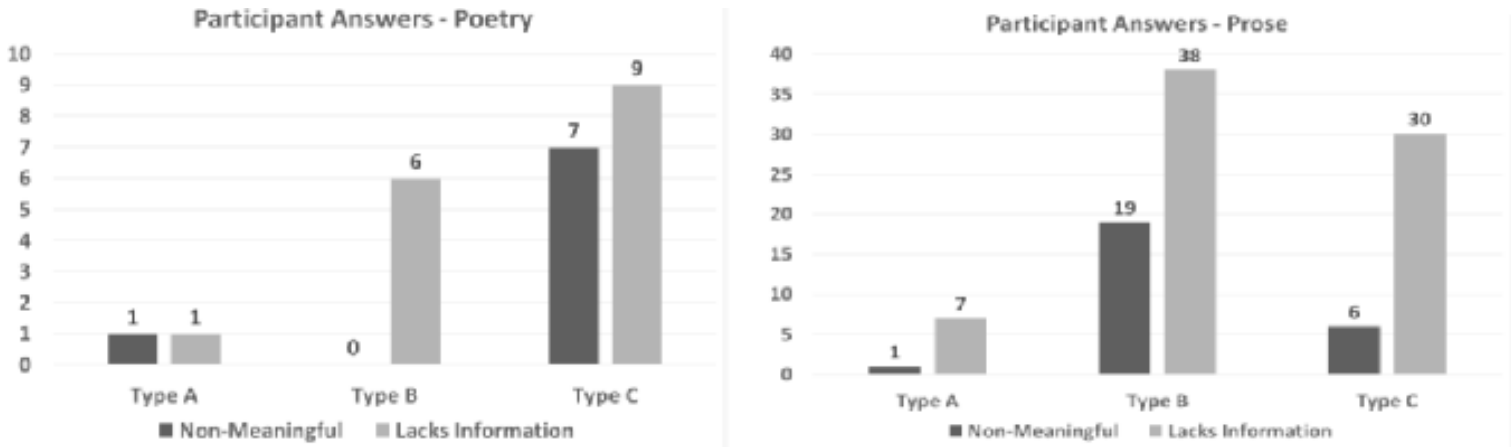


Figure: Meaninglessness of Poetry and Prose texts (A vs. B Vs. C) as reported by Participants

2.3 Results and Analysis

Evaluation of the Work

Inter-Annotator Agreement and Accuracy on both questions by all participants

Overall Agreement: Q1- 0.45 to 0.95 and Q2- 0.5 to 0.95; Accuracy: 0.6 to 1

	Q1	Q2	
	IAA	IAA	ACC
P1	0.7	0.5	0.6
P2	0.8	0.9	0.95
P3	0.8	0.9	0.9
P4	0.95	0.95	0.95
P5	0.45	0.85	0.9
P6	0.9	0.55	0.6
P7	0.85	0.7	0.8

Table: Dataset 1

	Q1	Q2	
	IAA	IAA	ACC
P8	0.85	0.9	0.95
P9	0.75	0.6	0.75
P10	0.75	0.8	1
P11	0.5	0.75	0.85
P12	0.7	0.8	0.85
P13	0.85	0.95	1

Table: Dataset 2

	Q1	Q2	
	IAA	IAA	ACC
P14	0.8	0.8	0.75
P15	0.65	0.65	0.75
P16	0.85	0.9	0.95
P17	0.9	0.8	0.7
P18	0.75	0.85	0.85
P19	0.5	0.9	0.9
P20	0.8	0.7	0.8

Table: Dataset 3

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Limitations and Future Work

Limitations

- Technical

  Only Written-language Cognition

  Under the controlled environment

Limitations and Future Work

Limitations

- Technical
  - Only Written-language Cognition
  - Under the controlled environment
- Human-related
  - Literate population
  - Visually impaired population
  - Other

Limitations and Future Work

Limitations

- Technical
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  - Other
- Methodology-related
  - Dataset
  - Participants
  - Analysis

Limitations and Future Work

Future Work

- *Author:* Bhartṛhari, Kauṇḍabhaṭṭa...
- *Definition:* Definition 1, 2...
- *Technique:* Eye-Tracking, EEG, fMRI, Off-line methods...
- *Language:* Sanskrit, First Language...
- *Purpose:* Language Cognition, Computational, WSD, CWI, solutions for people having reading disabilities...
- *Methodology:* Lexical Complexity Minimization, Single-verb sentences, Large data size, More number of participants, Reading aloud, Different kind of texts, Comparative study etc.

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Conclusion

Pilot Study

Verbs in a Sanskrit sentence hold *the most prominent position* in the semantics of the sentence, without which a sentence seems to be incomplete.

State-of-the-art Study

We uncover this *new avenue* to study Bhartṛhari's in a more meaningful way.

The sizable data from these experiments will allow us to extract some *cognitive features* which can be used in various NLP applications.

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Google Images

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All participants

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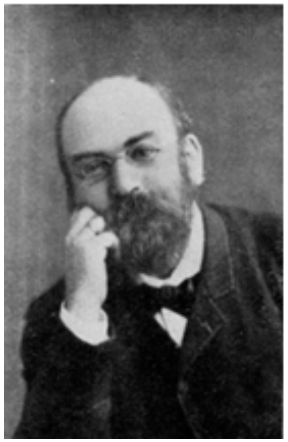
Thank you!

Extra Slides...

History of Eye-tracker



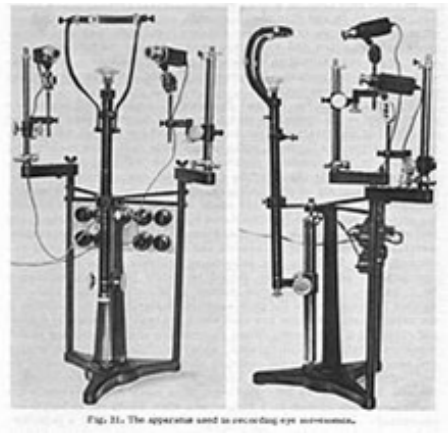


Figure: Louis Emile Javal, (1839-1907)

Invented Eye-tracker in 1879.

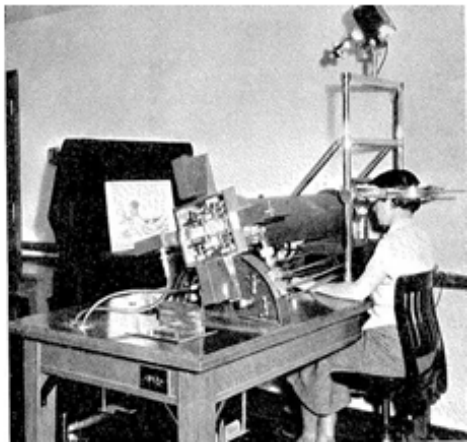


Figure: Edmund Huey, (1870-1913)

First Eye-tracker for reading in 1903.

Eye-Tracking

Working of Eye-Tracker:

- Two PCs,
  Infrared Illuminator,
  Head and Chin Rest.
- Eye-Calibration Process.

Figure: SR Eyelink 1000 Plus Eye-Tracker

Figure: Monocular Eye-tracking

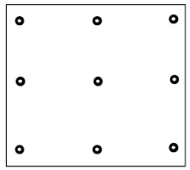


Figure: 9-Grid Eye-Calibration

Eye Tracking

Before the Eye-tracking experiment:

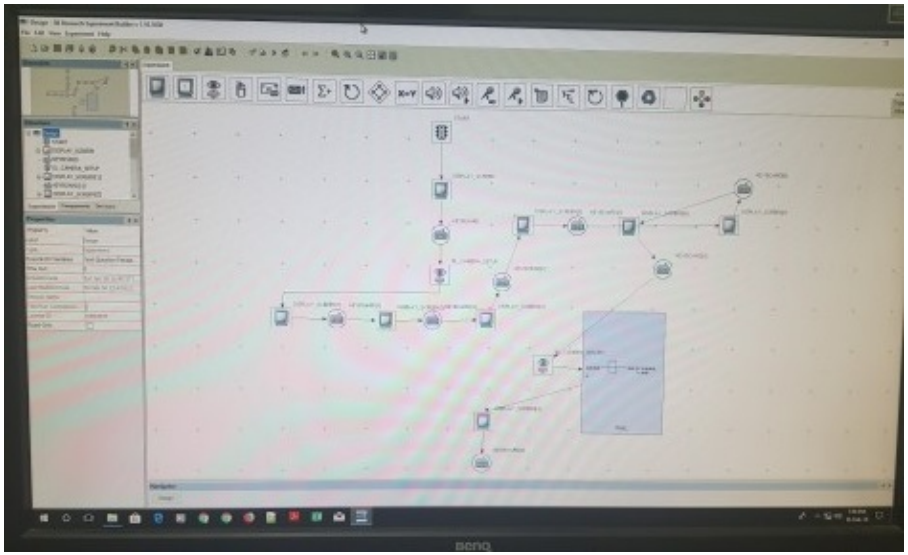


Figure: Experiment Building Procedure

Figure: Camera Setup Screen on Host PC

Eye-Tracking

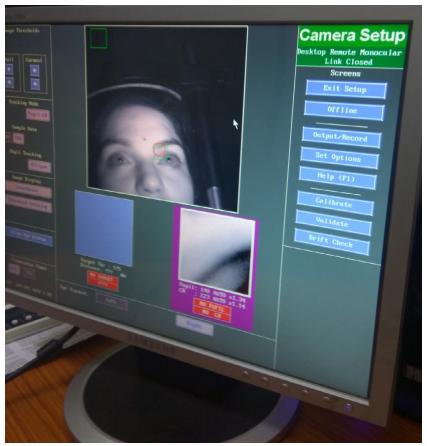


Figure: Camera Setup Screen- Host PC

Working of Eye-Tracker:

- Eye-Calibration Process.
- Various efforts during reading are measured.

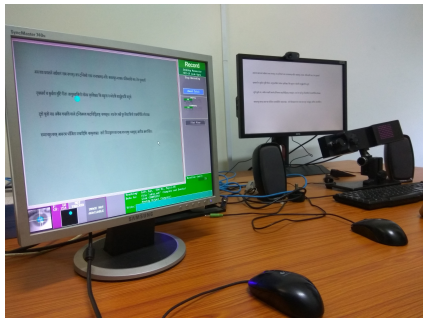


Figure: Video during reading

Figure: Gaze-text mapping

Eye-Tracking

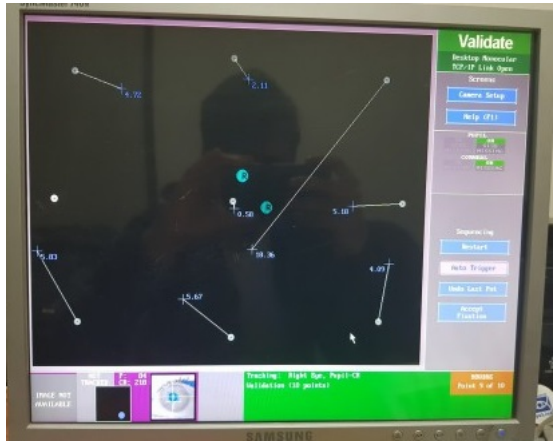


Figure: Eye-drifts

Working of Eye-Tracker:

- Eye-Calibration Process.
- Various efforts during reading are measured.

Figure: Eye-calibration Fail

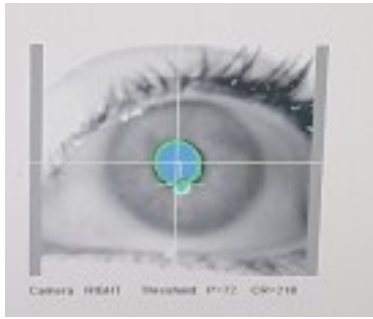


Figure: Perfect Eye-calibration

Eye-Tracking

Drift correction procedure of the Eye-movement data:

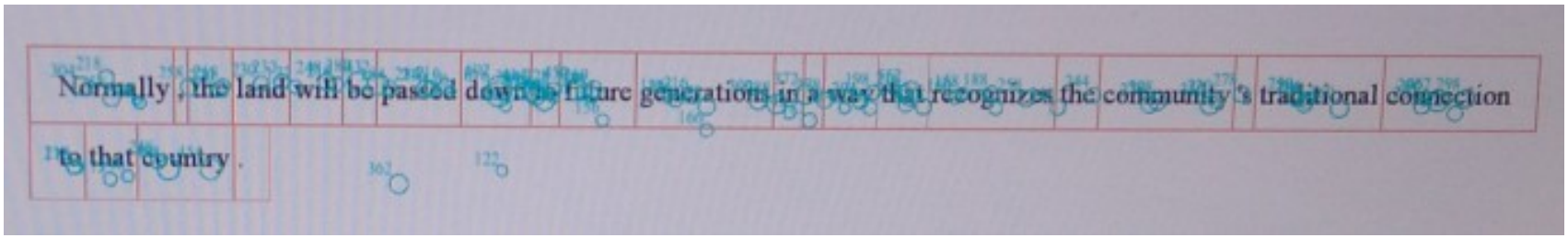


Figure: Various efforts during reading

Eye-Tracking

Various Efforts during reading- **Features**:

Saccades (→), Regressions (↶), Fixations (▪), Skip (↷) Blinks...

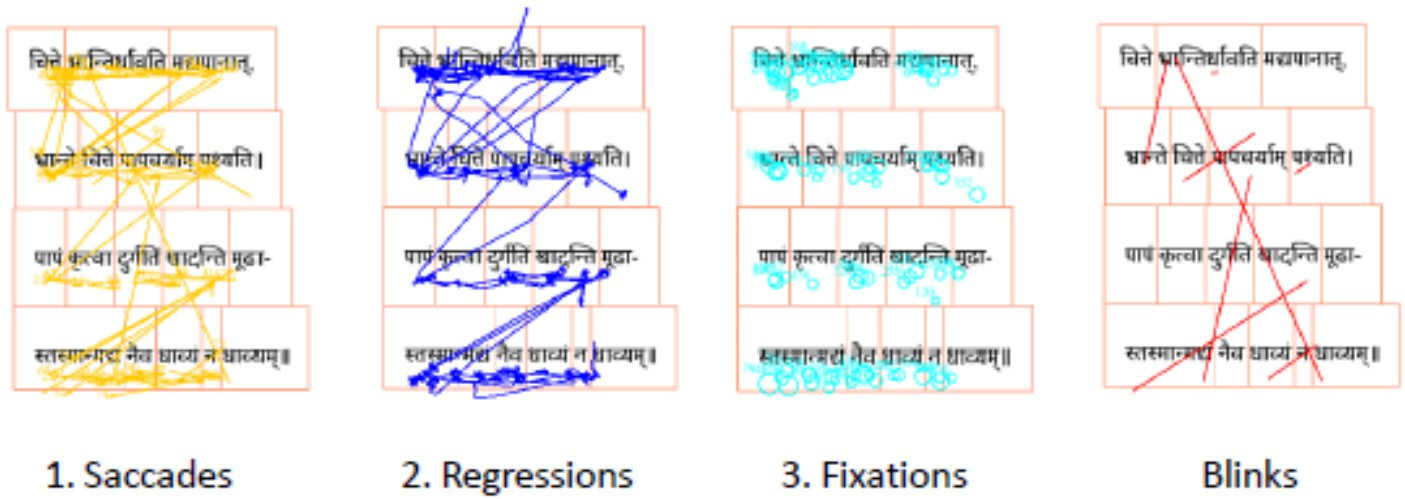


Figure: Various efforts during reading

Dataset Example

Prose documents: Original, Purely nominal and No-Karta sentences

अस्त्यत्र धरातले वर्धमानं नाम नगरम्। तत्र दन्तिलो नाम नानाभाण्ड-पतिः सकलपुर-नायकः प्रतिवसति स्म। तेन पुरकार्यं नृपकार्यं च कुर्वता तुष्टिं नीताः तत्पुरवासिनो लोका नृपतिश्च। किं बहुना न कोऽपि तादृक्केनापि चतुरो दृष्टो श्रुतो वा। अथैव गच्छति काले दन्तिलस्य कदाचिद्विवाहः सम्प्रवृत्तः। तत्र तेन सर्वे पुर-निवासिनो राजसंनिधि-लोकाश्च सम्मानपुरःसरम् आमन्त्र्य भोजिता वस्त्रादिभिः सत्कृताश्च। ततो विवाहानन्तरं राजा सान्तःपुरः स्वगृहम् आनीय अभ्यर्चितः।

Figure: Document Type A

अत्र धरातले वर्धमानं नाम नगरम्। तत्र दन्तिलो नाम नानाभाण्ड-पतिः सकलपुर-नायकः। तेन पुरकार्यं नृपकार्यं च कुर्वता तुष्टिं तत्पुरवासिनो लोका नृपतिश्च। किं बहुना न कोऽपि तादृक्केनापि चतुरो। अथैव गच्छति काले दन्तिलस्य कदाचिद्विवाहः। तत्र तेन सर्वे पुर-निवासिनो राजसंनिधि-लोकाश्च सम्मानपुरःसरम् वस्त्रादिभिः। ततो विवाहानन्तरं राजा सान्तःपुरः स्वगृहम्।

Figure: Document Type B

अस्त्यत्र धरातले वर्धमानं नाम। तत्र नानाभाण्ड-पतिः सकलपुर-नायकः प्रतिवसति स्म। तेन पुरकार्यं नृपकार्यं च कुर्वता तुष्टिं नीताः तत्पुरवासिनो। किं बहुना न अपि तादृक् अपि चतुरो दृष्टो श्रुतो वा। अथैव गच्छति काले दन्तिलस्य कदाचिद् सम्प्रवृत्तः। तत्र पुर-निवासिनो राजसंनिधि-लोकाश्च सम्मानपुरःसरम् आमन्त्र्य भोजिता वस्त्रादिभिः सत्कृताश्च। ततो विवाहानन्तरं सान्तःपुरः स्वगृहम् आनीय अभ्यर्चितः।

Figure: Document Type C

Dataset Example

Poetry documents: Original, Synonym verb and Distant-meaning verb

सन्तप्तायसि संस्थितस्य पयसो नामापि न ज्ञायते
मुक्ताकारतया तदेव नलिनीपत्रस्थितं राजते।
स्वात्यां सागरशुक्तिमध्यपतितं तन्मौक्तिकं जायते
प्रायेणाधममध्यमोत्तमगुणः संसर्गतो जायते॥६७॥

Figure: Document Type A

सन्तप्तायसि संस्थितस्य पयसो नामापि न बुध्यते
मुक्ताकारतया तदेव नलिनीपत्रस्थितं शोभते।
स्वात्यां सागरशुक्तिमध्यपतितं तन्मौक्तिकं भवति
प्रायेणाधममध्यमोत्तमगुणः संसर्गतो उत्पद्यते॥६७॥

Figure: Document Type B

सन्तप्तायसि संस्थितस्य पयसो नामापि न नमन्ति
मुक्ताकारतया तदेव नलिनीपत्रस्थितं पश्यति।
स्वात्यां सागरशुक्तिमध्यपतितं तन्मौक्तिकं खादति
प्रायेणाधममध्यमोत्तमगुणः संसर्गतो स्थीयते॥६७॥

Figure: Document Type C

Regressions

Regressions of the same participant on three types of documents

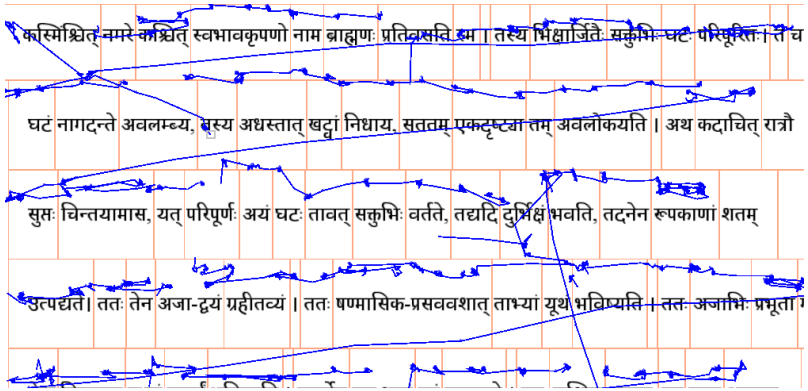


Figure: Document Type A

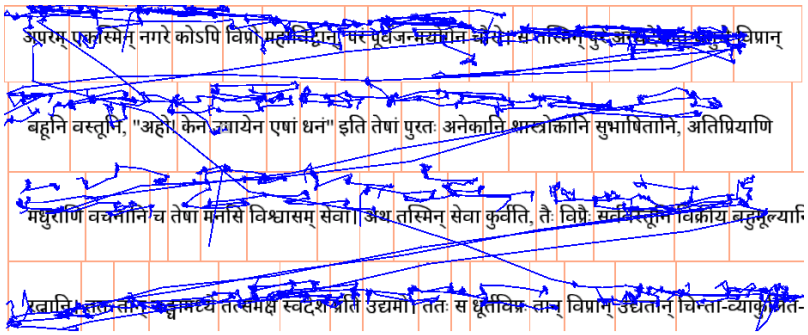


Figure: Document Type B

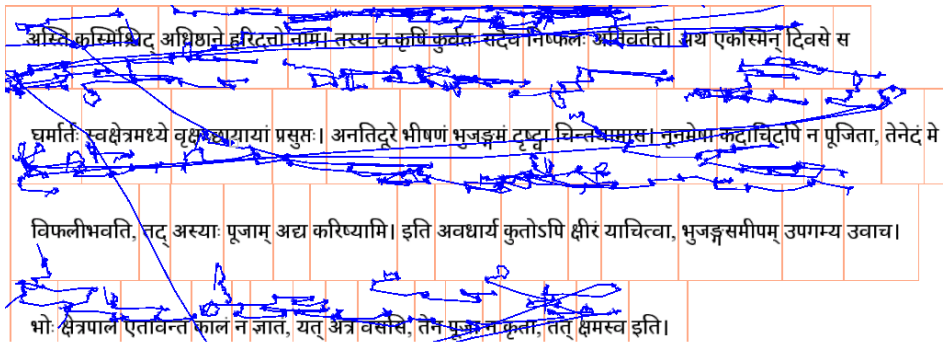


Figure: Document Type C

Fixations

Fixations on the modified data by two different participants

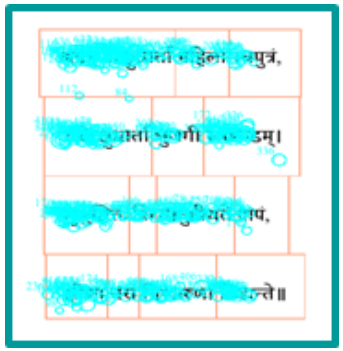


Figure: Poetry Type C

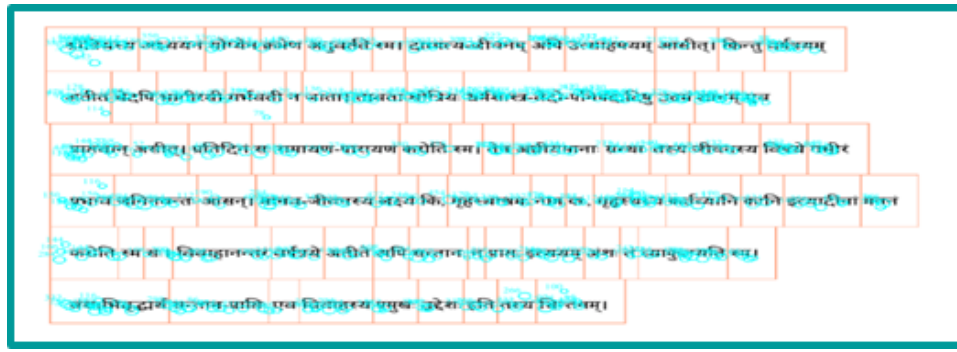


Figure: Prose Type B

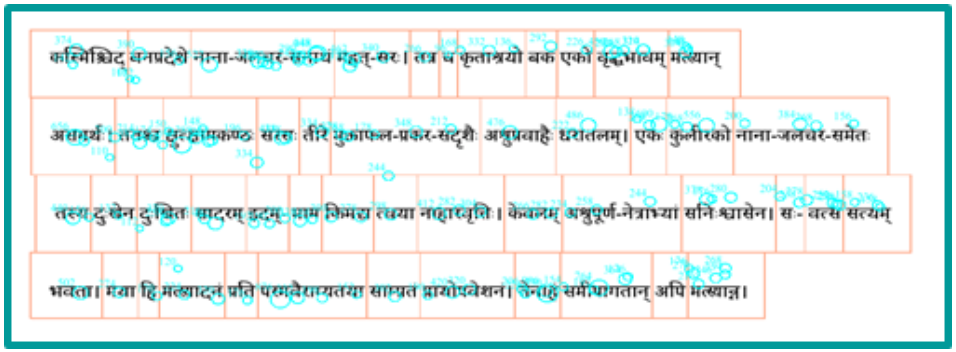


Figure: Prose Type B

Figure: Poetry Type C

Saccades

Saccades across the Original Vs. Modified data by the same participant

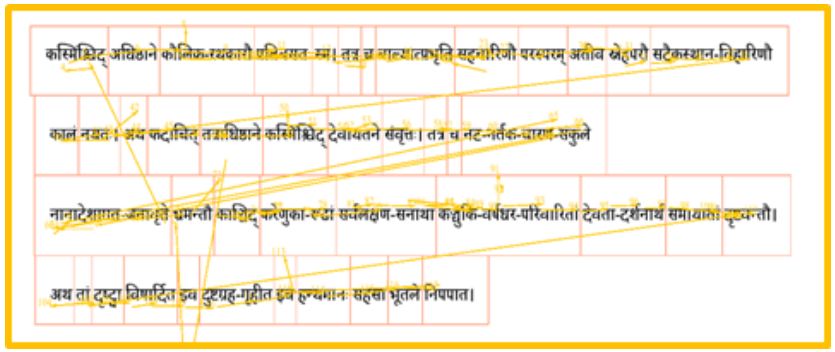


Figure: Document Type A

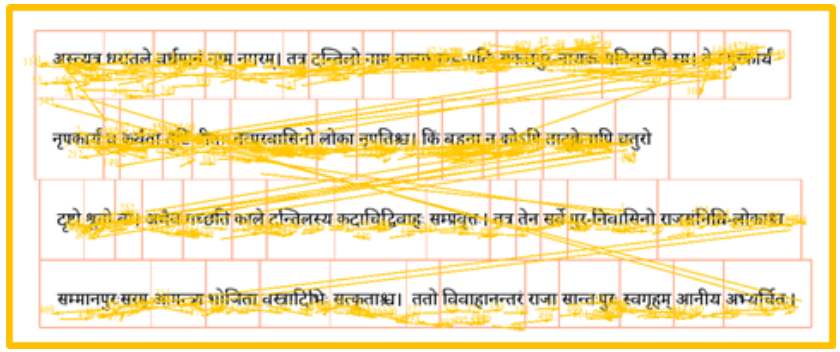


Figure: Document Type B

Results and Analysis

Evaluation of the Work

Mean Difference and p-values from T-Test for Regression Count (ROC) and Skip Count (SC)

	ROC		SC	
	M_D	P	M_D	P
P1	0.159	0.000	0.061	0.038
P2	0.234	0.000	0.078	0.012
P3	0.250	0.000	0.180	0.000
P4	0.126	0.001	0.112	0.001
P5	0.062	0.050	0.029	0.194
P6	0.183	0.001	0.064	0.029
P7	0.091	0.029	0.089	0.005

Table: Dataset 1

	ROC		SC	
	M_D	P	M_D	P
P8	0.141	0.001	0.129	0.000
P9	0.147	0.001	0.134	0.000
P10	0.112	0.005	0.143	0.000
P11	0.194	0.000	0.025	0.237
P12	0.163	0.003	0.012	0.364
P13	0.211	0.000	0.106	0.001

Table: Dataset 2

	ROC		SC	
	M_D	P	M_D	P
P14	0.188	0.000	0.058	0.053
P15	0.072	0.033	0.058	0.053
P16	0.244	0.001	0.077	0.015
P17	0.129	0.003	0.055	0.059
P18	0.120	0.030	-0.030	0.189
P19	0.021	0.247	0.044	0.106
P20	0.253	0.002	0.059	0.049

Table: Dataset 3

Extra slides!