

Eye-tracking data analysis using hidden semi-Markovian models to identify and characterize reading strategies

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also with contributions by Sophie Achard, Benoit Lemaire, Yann Guédon

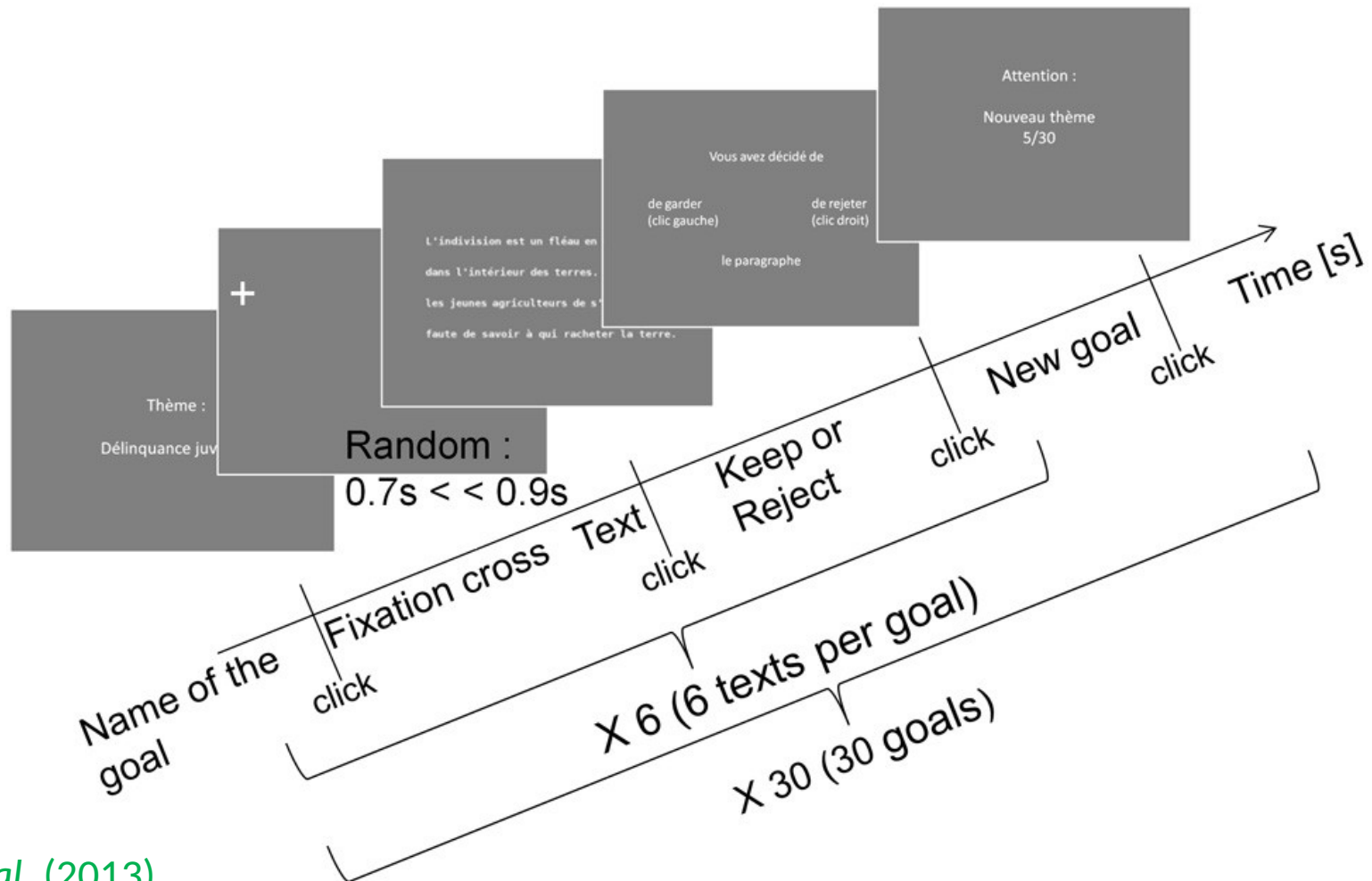
Project supported by PERSYVAL-Lab

Outline

- Aim of the study, experiment and data
- Model
- Results and interpretation
- Conclusion and perspectives

Protocol

- Presentation of a goal topic (e.g. “bird hunting”) and then a text.
- Question asked: is the text about that topic?



Data

SUBJ	TEXT_NO	TEXT	X	Y	FDUR	SACAMP	WINC	READMODE	WFREQ	COSINST
4.0000	9.0000	chasse_ciseaux-f1	232.2000	299.6000	162.0000	-139.4323	2.0000	0.0000	8296.0800	0.0000
4.0000	9.0000	chasse_ciseaux-f1	371.6000	296.6000	290.0000	-88.9892	0.0000	2.0000	-1.0000	0.1356
4.0000	9.0000	chasse_ciseaux-f1	460.4000	290.8000	179.0000	-134.0481	2.0000	0.0000	-1.0000	0.1356
4.0000	9.0000	chasse_ciseaux-f1	594.3000	284.5000	237.0000	-266.8162	1.0000	1.0000	41.5500	0.8865
4.0000	9.0000	chasse_ciseaux-f1	332.6000	336.5000	185.0000	-39.6989	0.0000	2.0000	49.2600	0.1649
4.0000	9.0000	chasse_ciseaux-f1	293.0000	339.3000	100.0000	153.6422	2.0000	0.0000	49.2600	0.1649
4.0000	9.0000	chasse_ciseaux-f1	446.6000	342.9000	186.0000	-103.1363	2.0000	0.0000	163.7200	0.1194
4.0000	9.0000	chasse_ciseaux-f1	549.6000	337.6000	178.0000	129.3031	2.0000	0.0000	282.7700	0.0837
4.0000	9.0000	chasse_ciseaux-f1	678.9000	338.5000	156.0000	-360.7417	2.0000	0.0000	67.9100	0.4000
4.0000	9.0000	chasse_ciseaux-f1	322.5000	394.3000	154.0000	72.3224	1.0000	1.0000	14662.3000	0.0000
4.0000	9.0000	chasse_ciseaux-f1	394.8000	396.1000	172.0000	-101.0179	-1.0000	3.0000	7.8400	0.3204
4.0000	9.0000	chasse_ciseaux-f1	293.8000	398.0000	157.0000	-101.0218	1.0000	1.0000	8296.0800	0.0000
4.0000	9.0000	chasse_ciseaux-f1	394.8000	395.9000	171.0000	-132.4000	2.0000	0.0000	7.8400	0.3204
4.0000	9.0000	chasse_ciseaux-f1	527.2000	395.8000	248.0000	-239.3214	-4.0000	4.0000	-1.0000	0.0368
4.0000	9.0000	chasse_ciseaux-f1	287.9000	399.0000	234.0000	257.2000	4.0000	0.0000	8296.0800	0.0000
4.0000	9.0000	chasse_ciseaux-f1	545.1000	399.1000	141.0000	80.5453	1.0000	1.0000	-1.0000	0.0368
4.0000	9.0000	chasse_ciseaux-f1	625.6000	401.8000	167.0000	-87.9260	1.0000	1.0000	99.3200	-0.0082
4.0000	9.0000	chasse_ciseaux-f1	713.3000	395.5000	104.0000	-401.5383	2.0000	0.0000	375.6800	0.0000

- Subject, text, topic
- Sequences of coordinates x,y of fixations
- Fixation durations, (signed) number of words between fixations
- Word frequencies, length, semantic proximity to target topic

Example of a scanpath

X	Y	FDUR	WNC
232.2000	299.6000	162.0000	2.0000
371.6000	296.6000	290.0000	0.0000
460.4000	290.8000	179.0000	2.0000
594.3000	284.5000	237.0000	1.0000
332.6000	336.5000	185.0000	0.0000
293.0000	339.3000	100.0000	2.0000
446.6000	342.9000	186.0000	2.0000
549.6000	337.6000	178.0000	2.0000
678.9000	338.5000	156.0000	2.0000
322.5000	394.3000	154.0000	1.0000
394.8000	396.1000	172.0000	-1.0000
293.8000	398.0000	157.0000	1.0000
394.8000	395.9000	171.0000	2.0000
527.2000	395.8000	248.0000	-4.0000
287.9000	399.0000	234.0000	4.0000
545.1000	399.1000	141.0000	1.0000
625.6000	401.8000	167.0000	1.0000
713.3000	395.5000	104.0000	2.0000

Dans le Pas-de-Calais, les chasseurs réclament le droit de continuer à chasser dans les huttes. La France risque pourtant une lourde amende si elle contrevient aux directives européennes qui protègent les oiseaux migrateurs.

Types of text

- S: strongly related, U: unrelated, M: moderately related to topic
- Example: Target topic “Bird hunting”

S

In the north of France, hunters claim the right to carry on hunting in huts. However, France could face heavy fines if European directives protecting migratory birds are not respected.

U

The French and Japanese space agencies decided to constitute working groups on natural risk monitoring. One of them will be in charge for better use of space data.

M

Fat balls coated with seeds are quite much appreciated by chickadees, which storm them as soon as the weather gets colder.

NB. “M”-texts may be more or less close to S or U...

Issues to be addressed

- Segmentation of scanpaths into interpretable zones, in terms of cognitive phases in information acquisition and processing (speed reading, careful reading, taking a decision, ...)
→ **reading strategies**
- Characterization of the effect of different sources of variability (individual effects, text effects) on the reading strategy (global / local strategies)
- Characterization of the effect of global (**text type**) and local text characteristics (word frequency, length, **semantic proximity** to target topic, ...) on reading strategies.

Hidden semi-Markov chain models

- Purpose: segmentation, variability in global reading strategies
- Statistical model for time series X_1, \dots, X_n
- Here time step t = fixation. The considered variable X_t (“observation”) should characterize the fixation.

Here: ReadMode (categorical)

0: more than 1 backward, 1: 1 backward, 2: same word,
3: next word, 4: more than 1 forward (increasing IncWord)

- Number of possible reading strategies fixed in advance (must try several numbers, here: 5)
- From one state to another, the probability of each ReadMode should change (eventually the probabilities define the states)

Model hypotheses and parameters

- State S_t at fixation t : reading strategy at t .

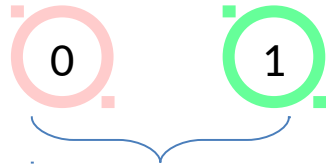
$$S_t \in \{0, \dots, 4\}$$

- Given $S_t = k$, X_t has distribution P_k .
- Zone $S_t = S_{t+1} = \dots = S_{t+L}$: within this zone, the observations are independent with same distribution.
- Changes of zones are ruled Markovian-like:
transition matrix $A_{jk} = P(S_t = k \mid S_{t-1} = j)$
- Zone length L : random variable which distribution depends on current state of zone (this is the semi-Markov aspect)
- All we know is X_1, \dots, X_n , the states must be deduced from them.

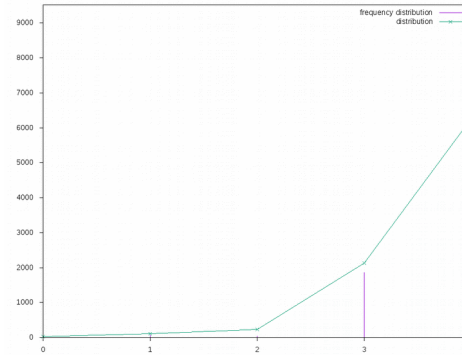
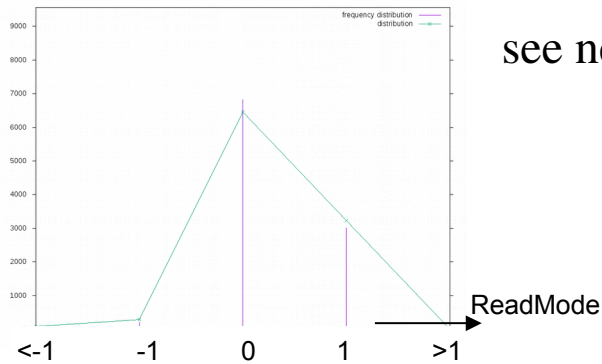
Parameter estimation

- Parameters:
 - $A_{jk} = P(S_t = k \mid S_{t-1} = j)$
 - $B_{rk} = P(X_t = r \mid S_t = k)$
 - Parameters of the zone length distributions (e.g. Binomial or Poisson with offset)
- All trials are assumed to follow the same hidden semi-Markov distribution (no individual / text effect here).
- Parameter estimation by maximum likelihood (numerical optimization by the EM algorithm)

Transitions / observations



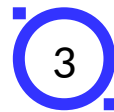
see next slides



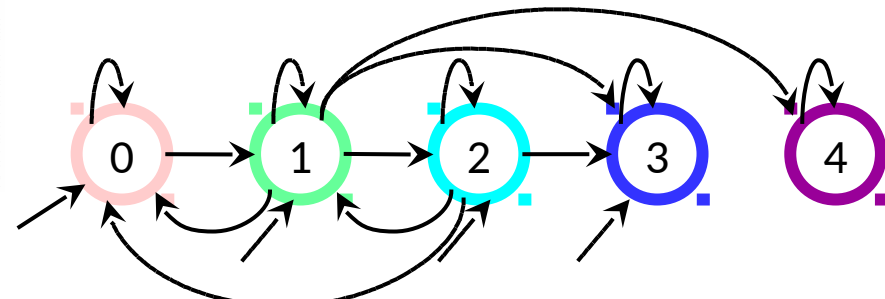
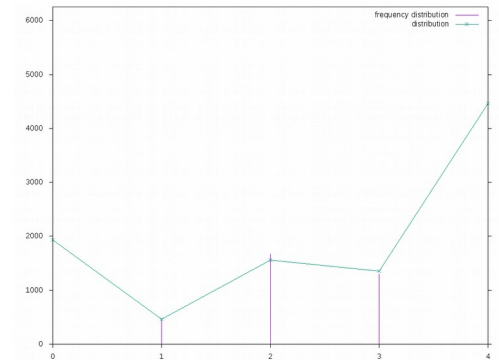
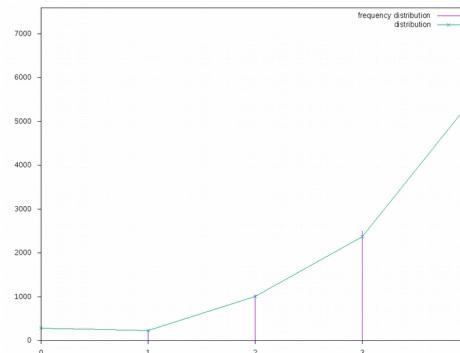
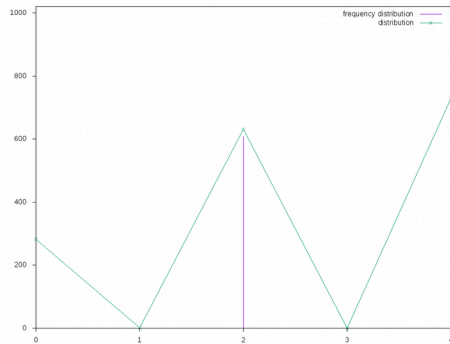
confirmation



unsure

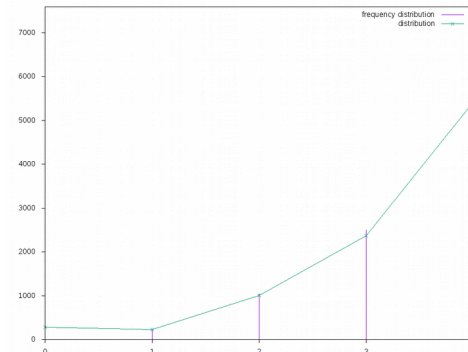
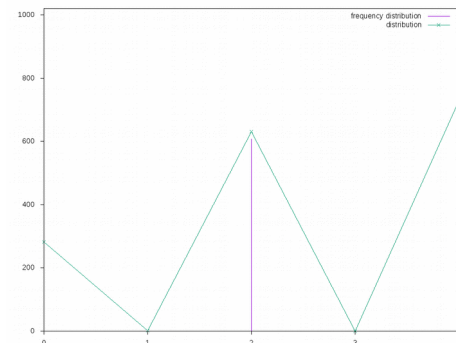
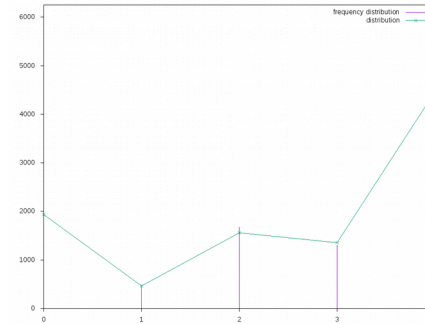
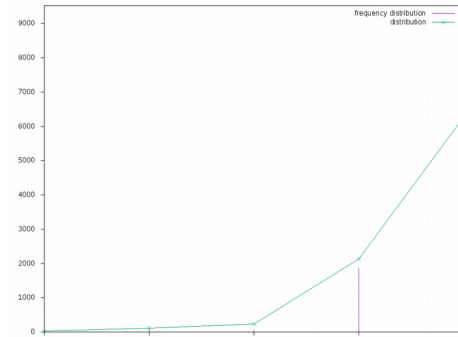
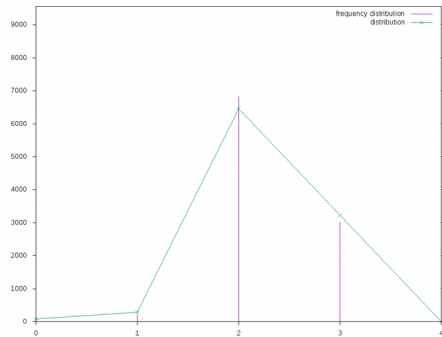


speed reading

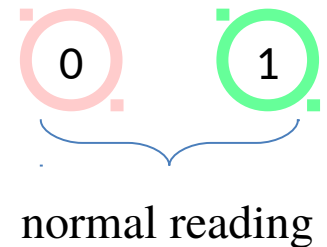
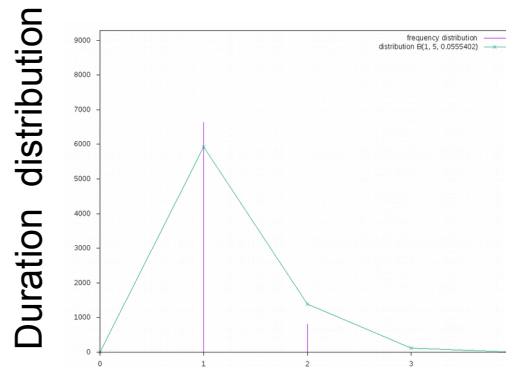
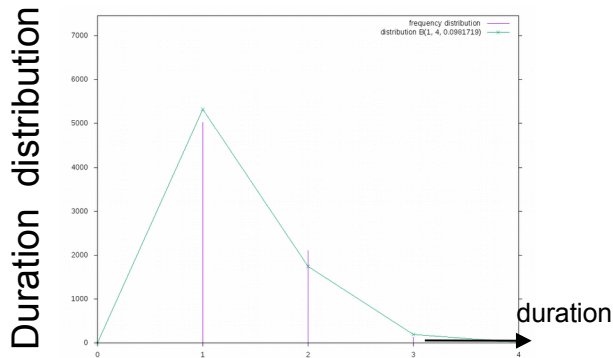
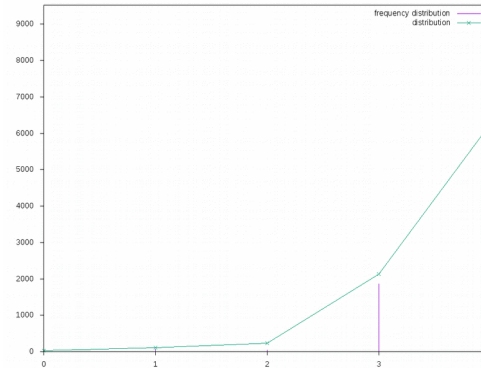
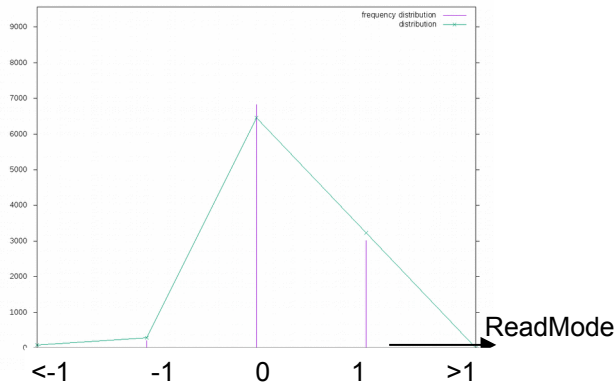
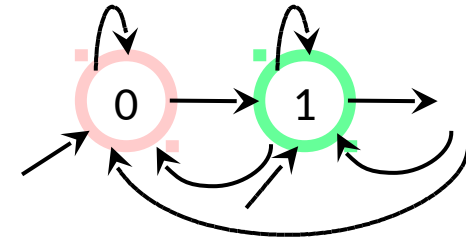


“Hidden” aspects

- Each possible value of ReadMode may be observed in several states (observation distributions overlap)
- For example ReadMode = 3 (reading next word) may be observed in states 0, 1, 2 and 4.
- Given the observed variable, we cannot be sure of current state, hence “hidden”

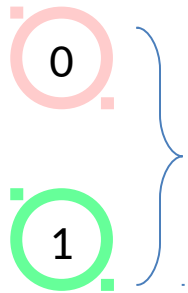


Phases



- Alternation between short stays between 0 and 1 is a very strong pattern that will remain even in a 3-state model.
- Combine 0/1 into one “phase” and call it “normal reading”

Sojourn duration distributions for other states



normal reading



unsure

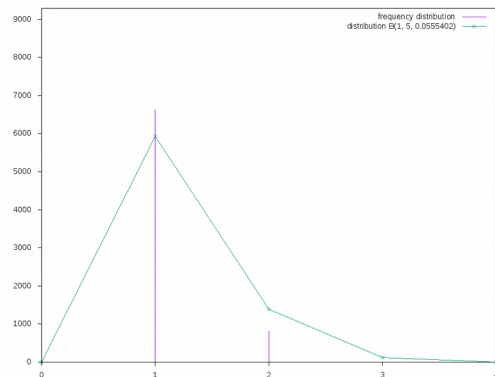
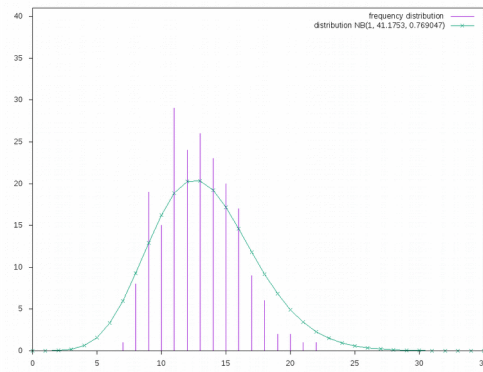
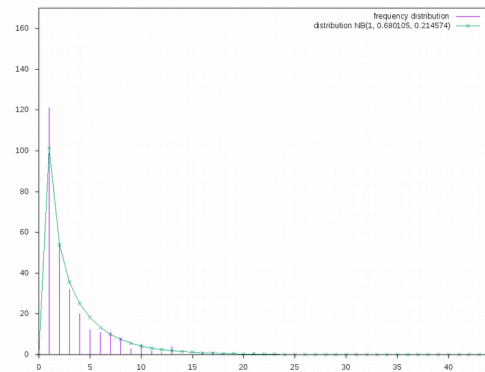
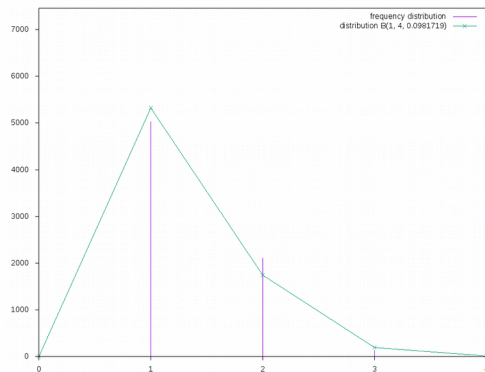


speed reading

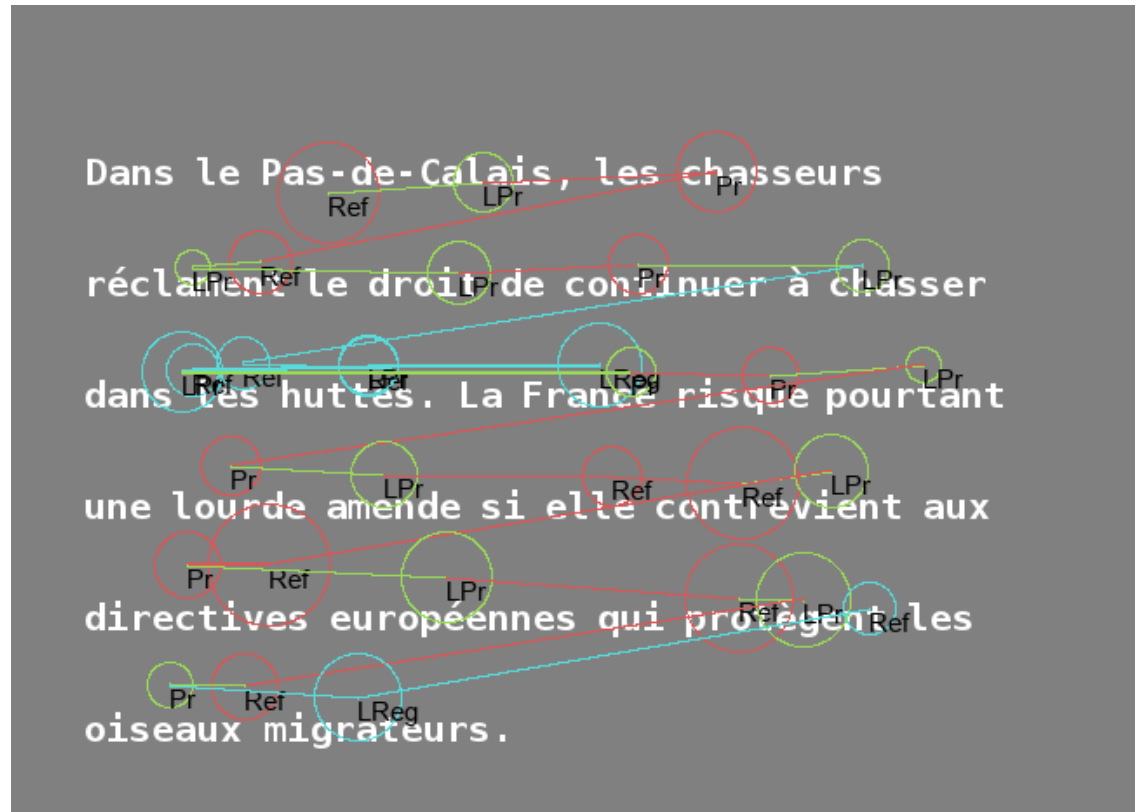
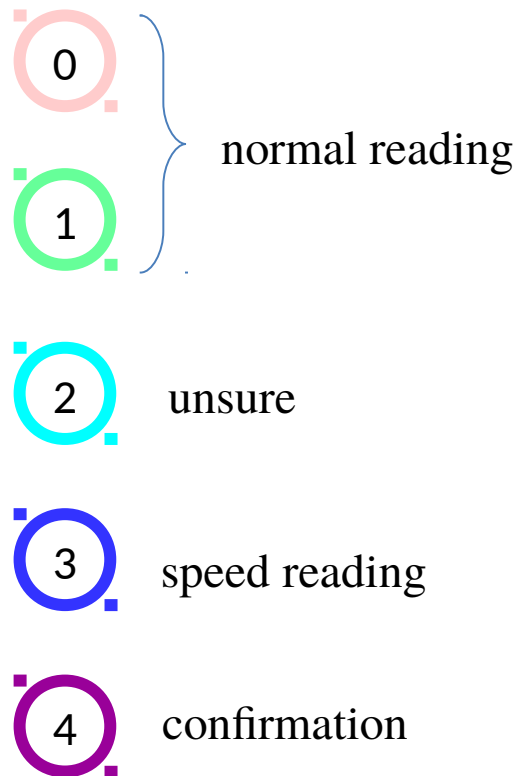


conf.

$+\infty$



Segmentation



Subject 4, text 26 (bird hunting)

$$\hat{S}_1, \dots, \hat{S}_n = \arg \max_{S_1, \dots, S_n} P(S_1, \dots, S_n | X_1, \dots, X_n)$$

Variability: text effect

Dans le Pas-de-Calais, les chasseurs
réclament le droit de continuer à chasser
dans les huttes. La France risque pourtant
une loupe si elle contrevient aux
directives européennes qui protègent les
oiseaux migrateurs.

L'état de l'unique route ne peut supporter
un afflux simultané de tous les réfugiés.
Le HCR prévoit des campagnes d'information
de masse dans les camps pour sensibiliser
au danger des mines.

Subject 1,
4 different texts

On se souvient du fameux symbole du dollar
revu par Andy Warhol. Le non-artiste
américain avait d'un signe simple amalgamé
l'art et l'argent pour la plus grande joie
de ses collectionneurs.

Ces combats, qui ne remettent pas en cause
la suprématie des talibans sur
l'Afghanistan, prouvent que l'état-major
veut et peut maintenir la pression sur ses
adversaires.

Variability: individual effect

Dans le Pas-de-Calais, les chasseurs
réclament le droit de continuer à chasser
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une lourde amende si elle contrevient aux
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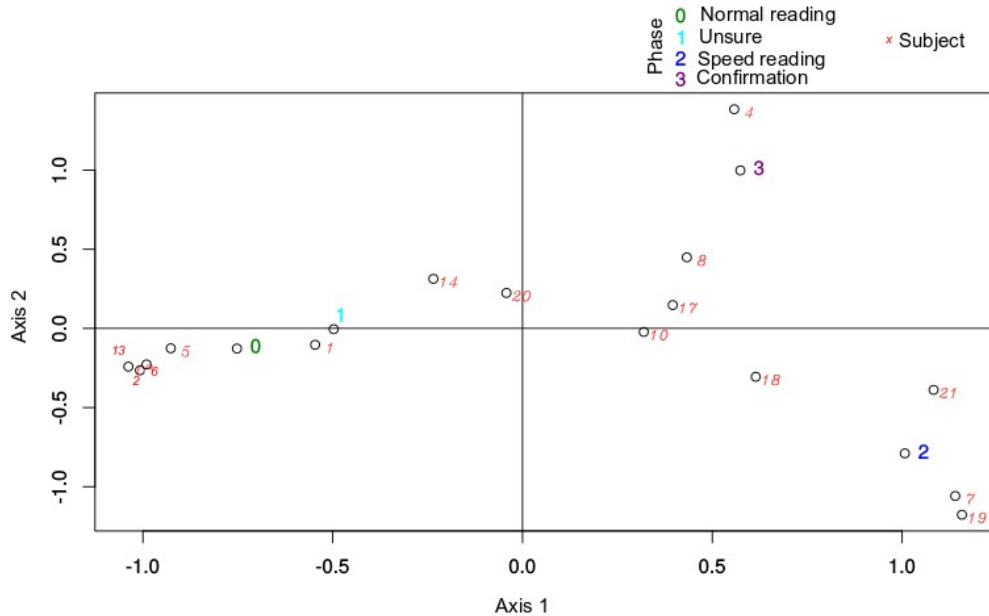
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Text 26,4 different subjects

Dans le Pas-de-Calais, les chasseurs
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Variability: individual effect



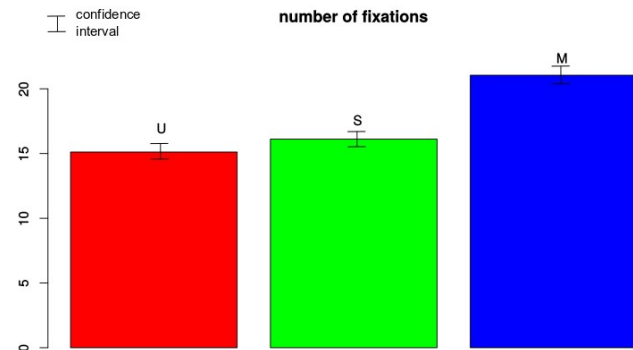
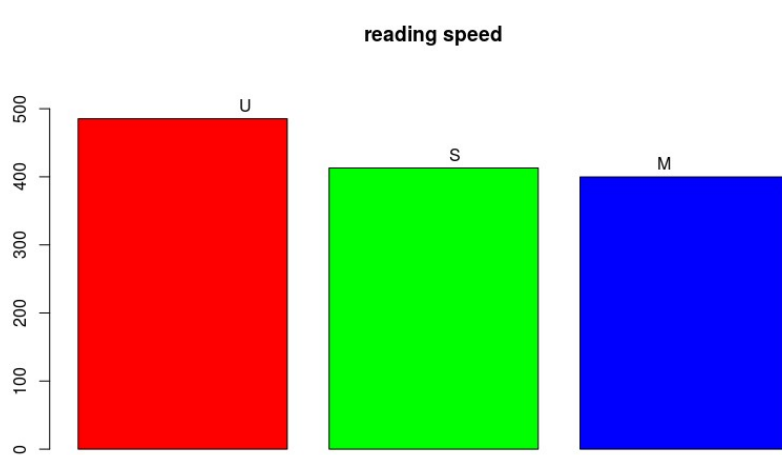
Factorial Correspondence Analysis:
phase and subject

Clusters of individuals:

- + Normal reading / unsure ; - speed reading / confirmation
- + Speed reading ; - normal reading / unsure
- + Confirmation; - normal reading / unsure

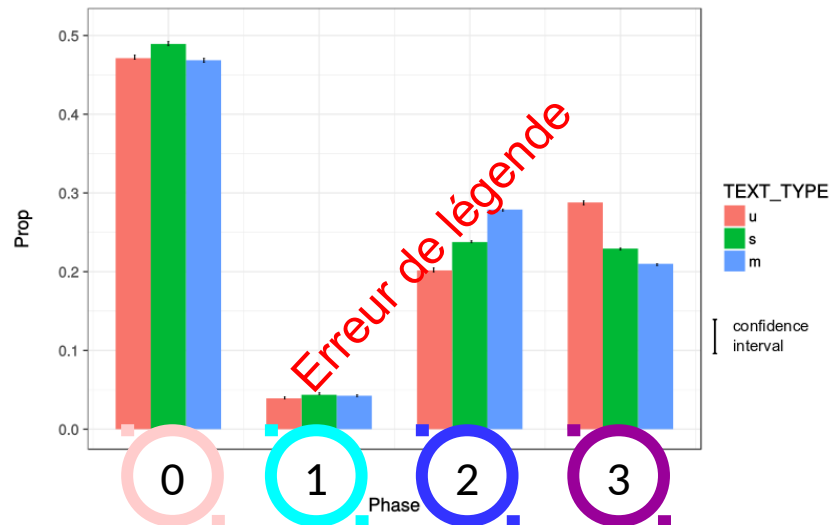
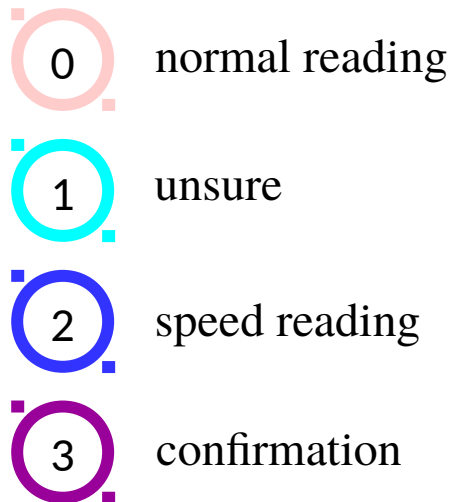
→ gradient between fast and careful readers

Type of text effect



Number of fixations per type of text

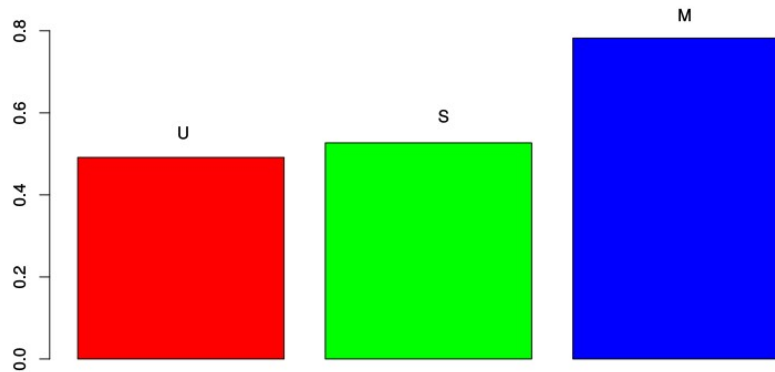
Reading speed in words per minute



Proportion of states per type of text

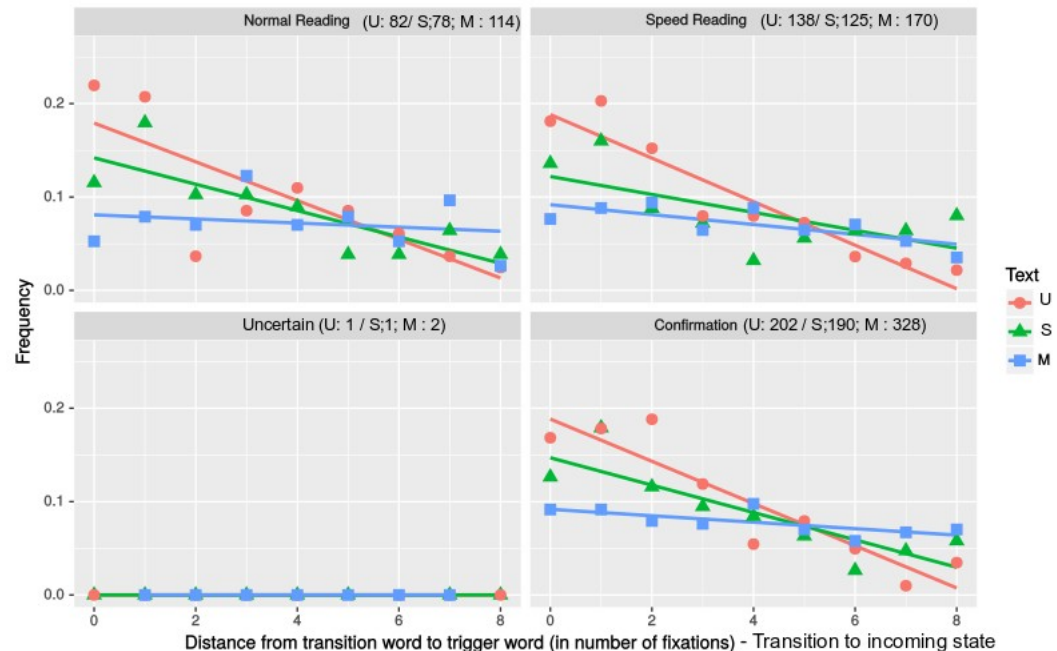
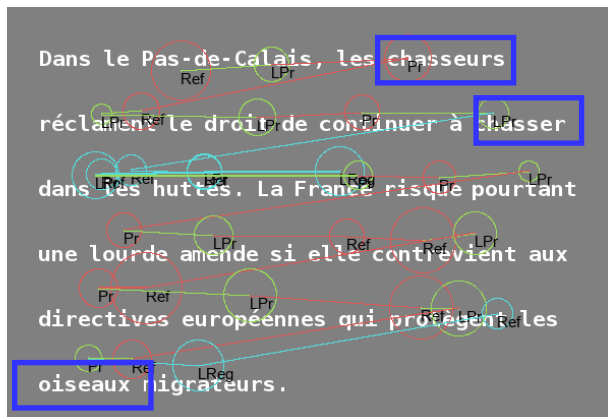
Type of text effect

Mean number of transitions

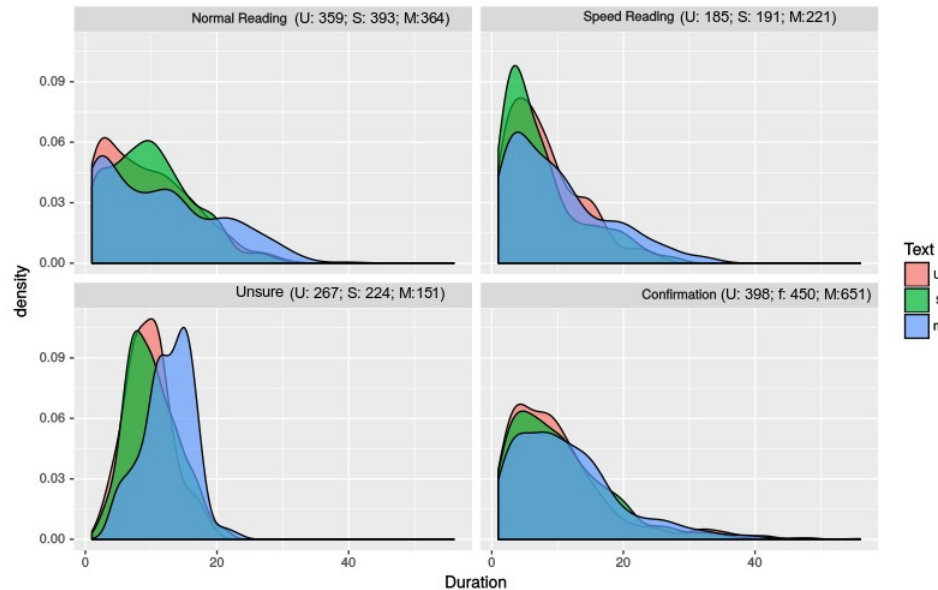


Mean number of transitions
per type of text

 trigger words



Type of text effect



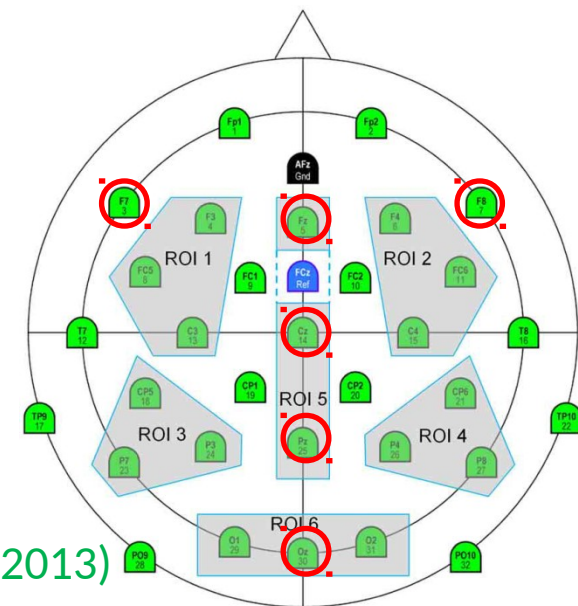
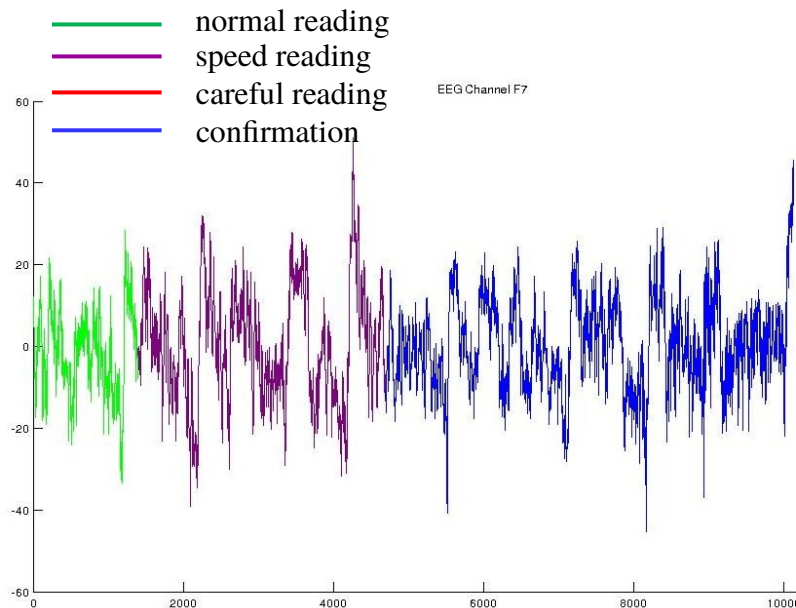
Distribution of the number of fixations
per phase and type of text

Conclusion: gradient in complexity between U, S, M characterized by

- Number of fixations
- Reading speed
- Time spent in confirmation vs. speed reading
- Number of strategy changes
- Effect of trigger words on strategy changes

EEG data

- Records: 10 s EEG on 30 channels at 1,000 Hz.
- Ideally phases should have contrasted EEG properties
- Use wavelet transform in place of Raw EEGs (too noisy for clear and contrasted patterns to emerge from phases)
- First results on “S” texts only with a different 5-states model: differences in variances / correlations between channels / band frequencies regarding phases



Frey et al. (2013)

Conclusion and possible extensions

- Hidden Markov models: useful approach to infer strategies
- Strategies seemingly related to subjects, reading speed, type of text and semantic properties
- Strong effect of type of text on taking decisions
- Modeling eye movements and EEGs jointly
- Coupling hidden Markov models
- Infer zones in brains involved in different reading strategies and their synchronisms

References

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- J. Simola, J. Salojärvi and I. Kojo. Using hidden Markov model to uncover processing states from eye movements in information search tasks. *Cognitive Systems Research* 9(4), 237-251 (October 2008)
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