Certain ungrammaticality or uncertain grammaticality:

Deciding between frequent errors and infrequent grammatical structures

Maayan Keshev & Aya Meltzer-Asscher, Tel-Aviv University

Introduction

How do humans recover the intended meaning from noisy utterances?

Sentence processing models typically assume error-free input, but production/perception errors are common in language use.

Recent studies suggest that comprehends engage in (Bayesian) **rational noisy-channel processing** - interpretation is pulled towards more probable "near-neighbors", depending on:

- The likelihood of the alternative utterance given perceived utterance
- The prior probability of the different utterances

$$P(\text{utterance}/\ \text{perceived input}) \propto P(\text{perceived input}\ /\ \text{utterance}) \cdot P(\text{utterance})$$

Levy 2008; Levy et al., 2009; Gibson et al., 2013

Introduction

How do humans recover the intended meaning from noisy utterances?

Readers reevaluate spelling of an early word when it has a near neighbor that allows a structure with higher prior probability.

Levy and his colleagues (2009) exhibited that local coherence effects (slowdown at the ambiguous verb in A vs. B) disappear for prepositions of a sparse orthographic neighborhood (no difference in C vs, D).

A.	The coach smiled at the player **tossed** the frisbee	[replace 'at' with: 'as'/'and'?]
B.	The coach smiled at the player **thrown** the frisbee	[no locally coherent string]
C.	The coach smiled toward the player **tossed** the frisbee	[no near neighbor]
D.	The coach smiled toward the player **thrown** the frisbee	[no coherent string/ neighbor]

The current study

How improbable should a structure be for readers to consider it noisy?

We test the effect of uncertainty and prior probability using Hebrew **relative clauses with temporary ambiguity** [object relative vs. subject with an agreement mismatch].

We show that **the interpretation of agreement mismatch is modulated by the prior probabilities of the analyses.**

The current study

The temporary SR/OR ambiguity in Hebrew

pagasnu et *ha-studentim* *se-hikir*

We-met acc. the-students.PL that-knew.SG

The current study

The temporary SR/OR ambiguity in Hebrew

pagasnu et *ha-studentim* *se-hikir* *ha-dikan*

We-met acc. the-students.PL that-knew.SG (nom.) the-Dean

OR + post-verbal subject (very rare)

The current study

The temporary SR/OR ambiguity in Hebrew

pagasnu et *ha-studentim* *se-hikir* *et* *ha-mazkira*

We-met acc. the-students.PL that-knew.SG acc. the-secretary

OR + post-verbal subject (very rare)

Ungrammatical SR (verb-filler number mismatch)

The current study

The temporary SR/OR ambiguity in Hebrew

pagasnu et *ha-studentim* *se-hikir*

We-met acc. the-students.PL that-knew.SG

OR + post-verbal subject (very rare)

Ungrammatical SR (verb-filler number mismatch)

In this case of mismatch (FILLER.PL + VERB.SG), rational noisy-channel predicts that a SR will be formed. But – **plural verbs** allow another outlet…

The current study

The temporary SR/OR ambiguity in Hebrew (VERB.PL)

pagasnu et *ha-student* *se-hikiru*

We-met acc. the-student.SG that-knew.PL

OR + post-verbal subject (very rare)

Ungrammatical SR (verb-filler number mismatch)

The current study

The temporary SR/OR ambiguity in Hebrew (VERB.PL)

pagasnu et *ha-student* *se-hikiru* *oto be-kol ha-xugim*

We-met acc. the-student.SG that-knew.PL him in-all departments

OR + post-verbal subject (very rare)

Ungrammatical SR (verb-filler number mismatch)

OR + impersonal null subject (common)

The current study

The temporary SR/OR ambiguity in Hebrew (VERB.PL)

pagasnu et *ha-student* *se-hikiru* *oto be-kol ha-xugim*

We-met acc. the-student.SG that-knew.PL him in-all departments

OR + post-verbal subject (very rare)

Ungrammatical SR (verb-filler number mismatch)

OR + impersonal null subject (common)

Is an OR preferred in this mismatch (FILLER.SG + VERB.PL)?

Corrupted input, very probable structure	Pristine input, somewhat probable?	Pristine input, very improbable structure

The current study

Outline & Predictions

FILLER.PL+VERB.SG	FILLER.SG+VERB.PL
[e.g. We met the students that knows]	[e.g. We met the student that know]
OR + post-verbal subject (rare)	OR + post-verbal subject (rare)
Ungrammatical SR	Ungrammatical SR
→ Form a SR	OR + impersonal null subject
	→ Form an OR?

The current study

Outline & Predictions

FILLER.PL+VERB.SG

[e.g. We met the students that knows]

OR + post-verbal subject (rare)

Ungrammatical SR

→ **Form a SR**

Experiments 1A&B: Does a post-verbal subject cause processing difficulty?

FILLER.SG+VERB.PL

[e.g. We met the student that know]

OR + post-verbal subject (rare)

Ungrammatical SR

OR + impersonal null subject

→ **Form an OR?**

Experiments 2A&B: Does a (post-verbal) object cause processing difficulty (filled-gap effect)?

The current study

Outline & Predictions

FILLER.PL+VERB.SG	FILLER.SG+VERB.PL
[e.g. We met the students that knows]	[e.g. We met the student that know]
OR + post-verbal subject (rare)	OR + post-verbal subject (rare)
Ungrammatical SR	Ungrammatical SR
→ Form a SR	OR + impersonal null subject
	→ Form an OR?

Experiment 3: Sentence completion study

Experiment 1A

FILLER.PL + VERB.SG → Form a SR

Processing disruption at the subject?

SPR, 36 participants, 30 sets + 45 fillers (grammatical)

Experiment 1A
Materials

FILLER.PL + VERB.SG → Form a SR
Processing disruption at the subject?
SPR, 36 participants, 30 sets + 45 fillers (grammatical)

MATCH MISMATCH

We met the { student.SG / students.PL } that by the end of term decided.SG eventually **the principal** to expel due to poor grades.

'We met the students that, by the end of term, the principal decided to expel due to poor grades'.

BASELINE: We met because, by the end of term, decided.SG eventually **the principal** to expel the student due to poor grades.

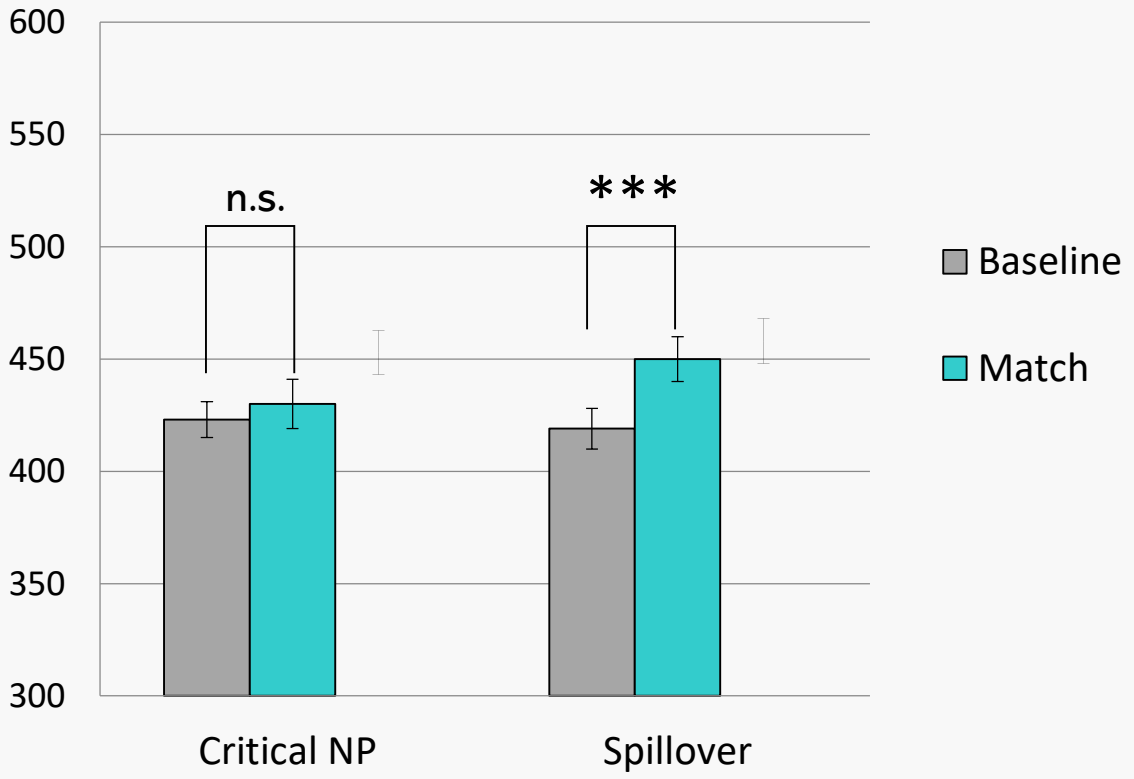
Experiment 1A
Results

FILLER.PL + VERB.SG → Form a SR
Processing disruption at the subject?

SPR, 36 participants, 30 sets + 45 fillers (grammatical)

Increased RTs at the post-verbal subject, in the **match** condition relative to the unambiguous baseline.

→ Readers constructed a **SR**



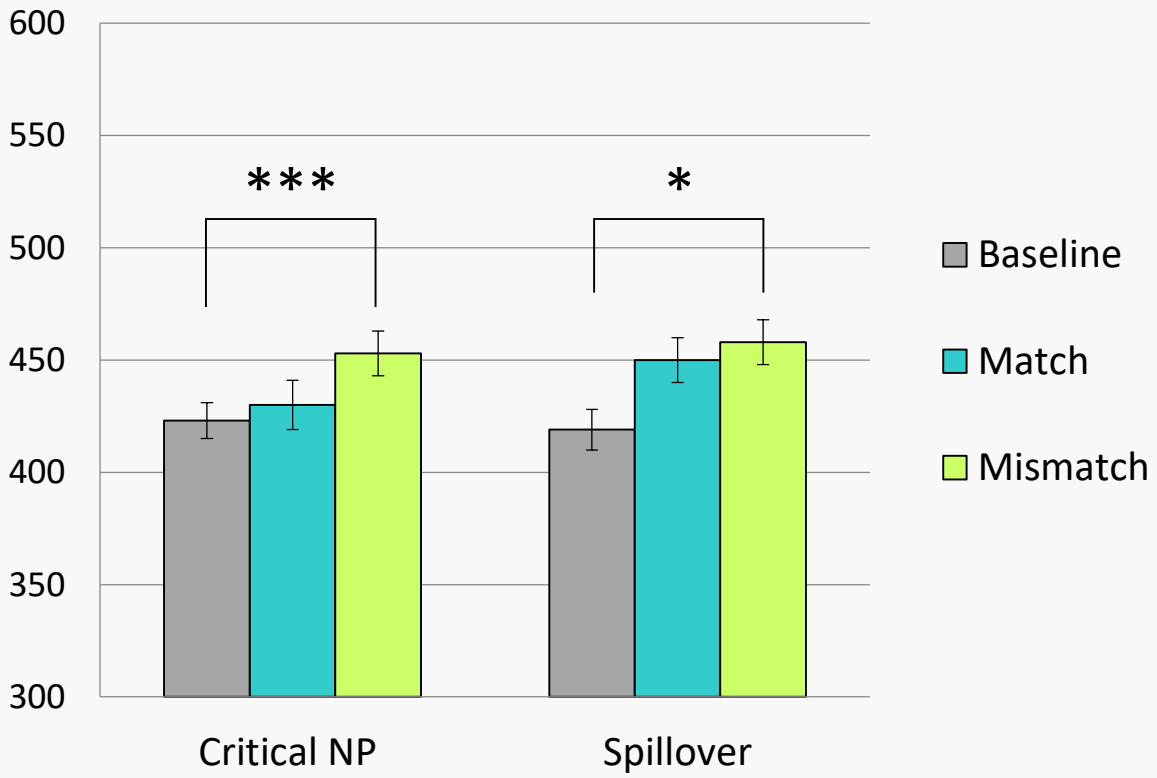
Experiment 1A
Results

FILLER.PL + VERB.SG → Form a SR
Processing disruption at the subject?

SPR, 36 participants, 30 sets + 45 fillers (grammatical)

The post-verbal subject reveals increased RTs also in the **mismatch** condition (relative to baseline).

→ Readers form a **SR** even when the verb mismatches the filler



Experiment 1B

Materials

FILLER.PL + VERB.SG → Form a SR

Processing disruption at the subject?

SPR, 48 participants, 28 sets + 45 fillers (grammatical)

MATCH 1-MISMATCH 2-MISMATCH

We met the { student.SG-M / students.PL-M / students.PL-F } that by the end of term decided.SG-M eventually **the principal** to expel due to poor grades.

'We met the students that, by the end of term, the principal decided to expel due to poor grades'.

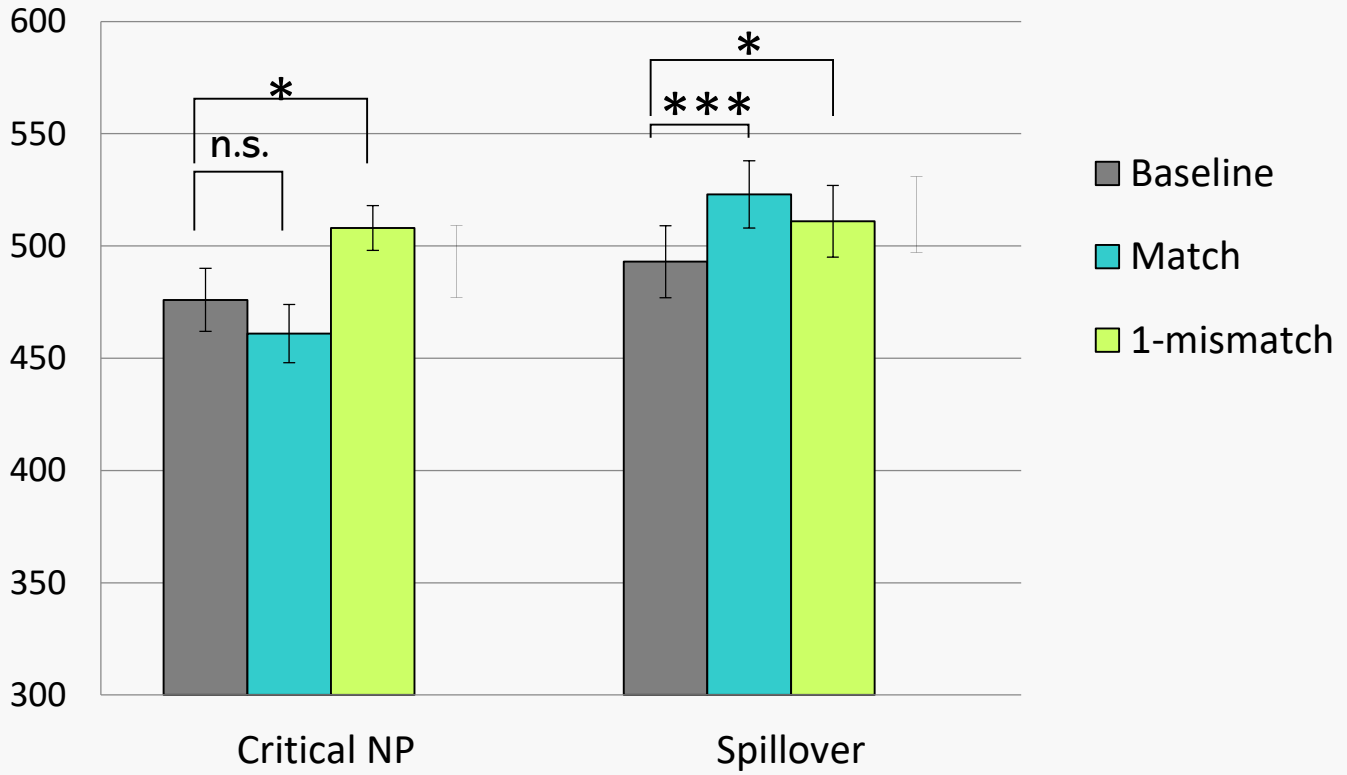
BASELINE: We met because, by the end of term, decided.SG eventually **the principal** to expel the student due to poor grades.

Experiment 1B
Results

FILLER.PL + VERB.SG → Form a SR
Processing disruption at the subject?

SPR, 48 participants, 28 sets + 45 fillers (grammatical)

Replication of the findings of Experiment 1a.

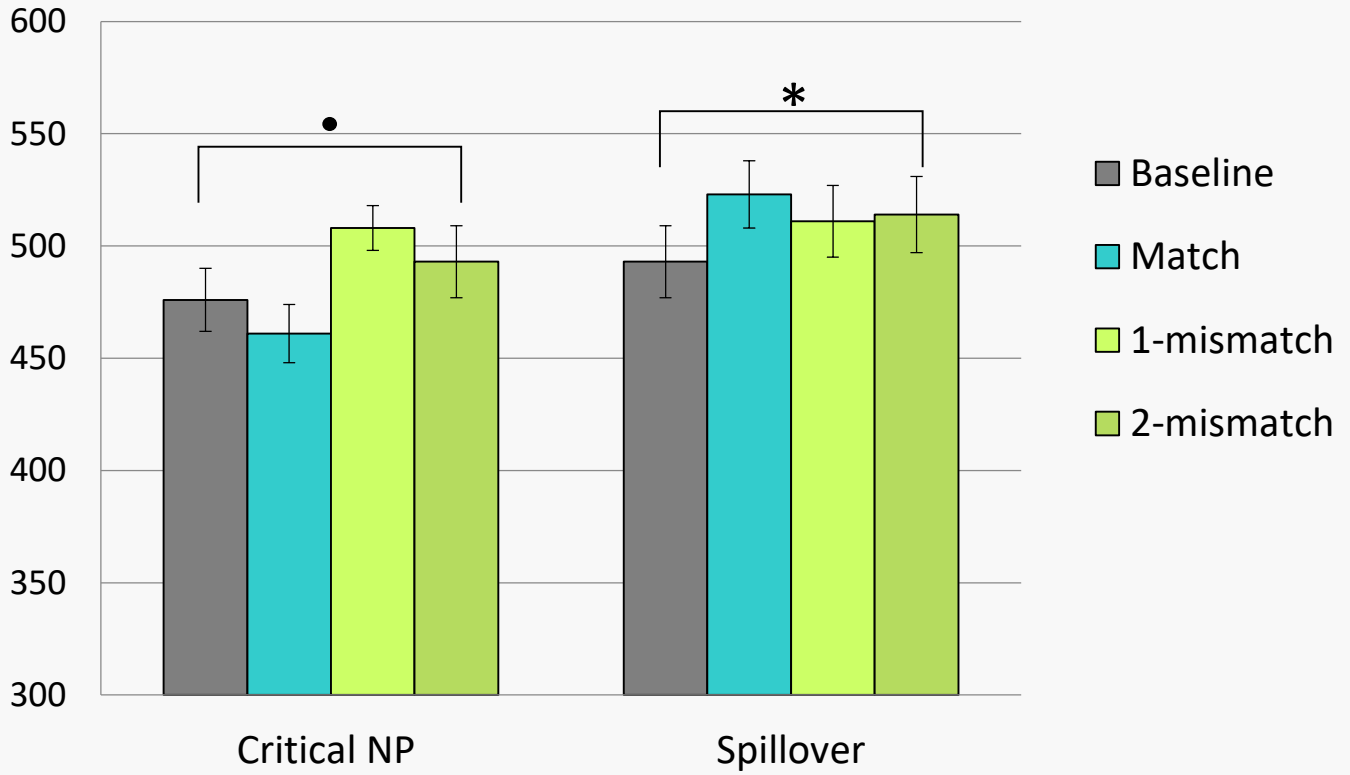


Experiment 1B
Results

FILLER.PL + VERB.SG → Form a SR
Processing disruption at the subject?
SPR, 48 participants, 28 sets + 45 fillers (grammatical)

Replication of the findings of Experiment 1a.

Extension to 2-feature mismatch.



Outline & Predictions

FILLER.PL+VERB.SG

[e.g. We met the students that knows]

OR + post-verbal subject (rare)

Ungrammatical SR

→ **Form a SR**

Experiments 1A&B: Does a post-verbal subject cause a processing difficulty?

FILLER.SG+VERB.PL

[e.g. We met the student that know]

OR + post-verbal subject (rare)

Ungrammatical SR

OR + impersonal null subject

→ **Form an OR?**

Experiments 2A&B: Does a (post-verbal) object cause a processing difficulty (filled-gap effect)?

Outline & Predictions

FILLER.PL+VERB.SG

[e.g. We met the students that knows]

OR + post-verbal subject (rare)

Ungrammatical SR

→ **Form a SR**

Experiments 1A&B: Does a post-verbal subject cause a processing difficulty? Yes!

FILLER.SG+VERB.PL

[e.g. We met the student that know]

OR + post-verbal subject (rare)

Ungrammatical SR

OR + impersonal null subject

→ **Form an OR?**

Experiments 2A&B: Does a (post-verbal) object cause a processing difficulty (filled-gap effect)?

Experiment 2A
Materials

FILLER.SG + VERB.PL → Form an OR
Processing disruption at the object?

SPR, 48 participants, 24 sets + 51 fillers (grammatical)

CLASSIC FGE: The teacher looked for the student that we found .PL eventually acc. the bag of him at the school's playground.

BASELINE: The teacher looked for the student after we found .PL eventually **acc. the bag** of him at the school's playground.

Experiment 2A

Materials

FILLER.SG + VERB.PL → Form an OR

Processing disruption at the object?

SPR, 48 participants, 24 sets + 51 fillers (grammatical)

MATCH MISMATCH

The teacher looked for the { students.PL / student.SG } that found.PL eventually **acc. the bag** of them / him at the school's playground.

'The teacher looked for the student whose bag was eventually found at the playground'.

CLASSIC FGE: The teacher looked for the student that we found .PL eventually **acc. the bag** of him at the school's playground.

BASELINE: The teacher looked for the student after we found .PL eventually **acc. the bag** of him at the school's playground.

Experiment 2A
Results

FILLER.SG + VERB.PL → Form an OR
Processing disruption at the object?

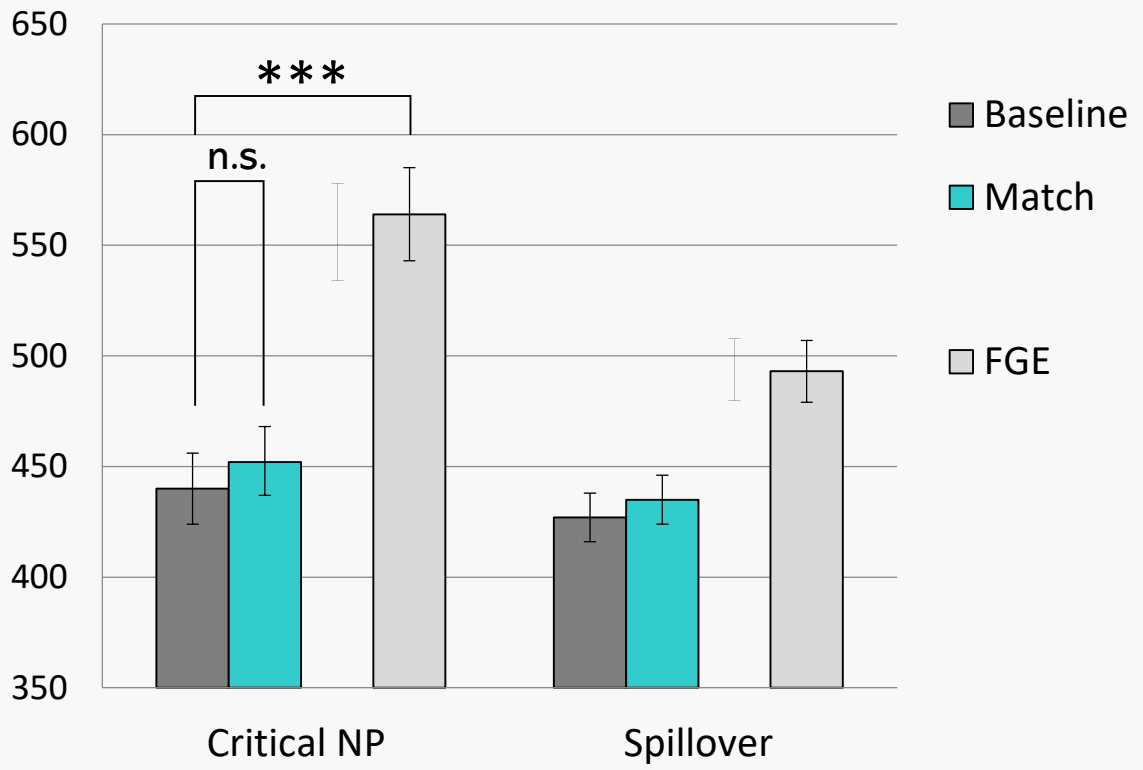
SPR, 48 participants, 24 sets + 51 fillers (grammatical)

In the **classic FGE** condition, increased RTs at the direct object, relative to baseline.

→ Readers constructed an **OR**

In the **match** condition, no slowdown at the object.

→ Readers constructed a **SR**



Experiment 2A
Results

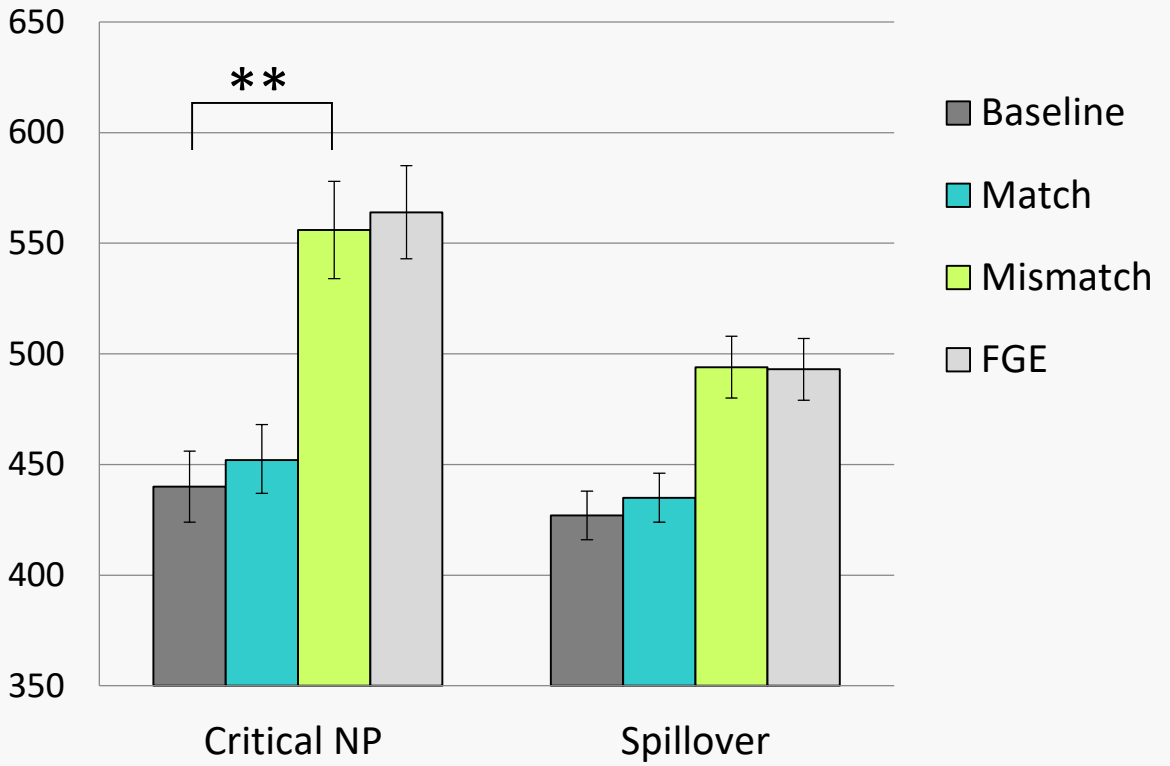
FILLER.SG + VERB.PL → Form an OR
Processing disruption at the object?

SPR, 48 participants, 24 sets + 51 fillers (grammatical)

In the **mismatch** condition, increased RTs at the direct object, relative to baseline.

(In alignment with that observed in the classic FGE condition).

→ Readers constructed an **OR**, when the impersonal subject reading is available.



Experiment 2B
Materials

FILLER.SG + VERB.PL → Form an OR
Processing disruption at the object?

SPR, 36 participants, 24 sets + 51 fillers (grammatical)

MATCH MISMATCH

The teacher looked for the { students.PL / student.SG } that **by the end of the break** found.PL eventually **acc. the bag** of them / him at the school's playground.

'The teacher looked for the student whose bag was eventually found at the playground by the end of the break'.

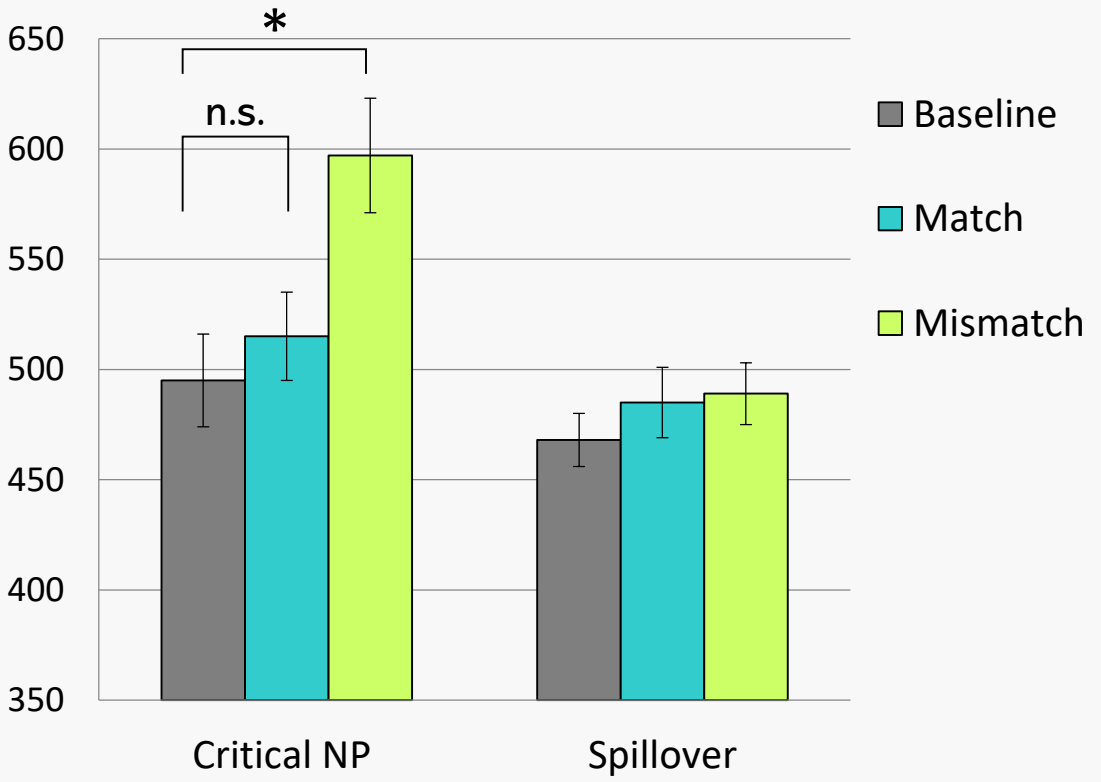
BASELINE: The teacher looked for the student after **by the end of the break** we found .PL eventually **acc. the bag** of him at the school's playground.

Experiment 2B
Results

FILLER.SG + VERB.PL → Form an OR
Processing disruption at the object?

SPR, 36 participants, 24 sets + 51 fillers (grammatical)

Replication with extended filler-verb distance.



Intermediate summary

FILLER.PL+VERB.SG (Experiments 1A&B, SPR): Readers prefer constructing an ungrammatical SR, over an OR with a post-verbal subject.

FILLER.SG+VERB.PL (Experiments 2A&B, SPR): When an impersonal subject can be licensed, the OR analysis (with a null subject) is adopted.

Experiment 3 aims to replicate both findings within one experiment, and to tap readers' preferences more directly (in a sentence completion task).

Intermediate summary

FILLER.PL+VERB.SG (Experiments 1A&B, SPR): Readers prefer constructing an ungrammatical SR, over an OR with a post-verbal subject.

FILLER.SG+VERB.PL (Experiments 2A&B, SPR): When an impersonal subject can be licensed, the OR analysis (with a null subject) is adopted.

Experiment 3 aims to replicate both findings within one experiment, and to tap readers' preferences more directly (in a sentence completion task).

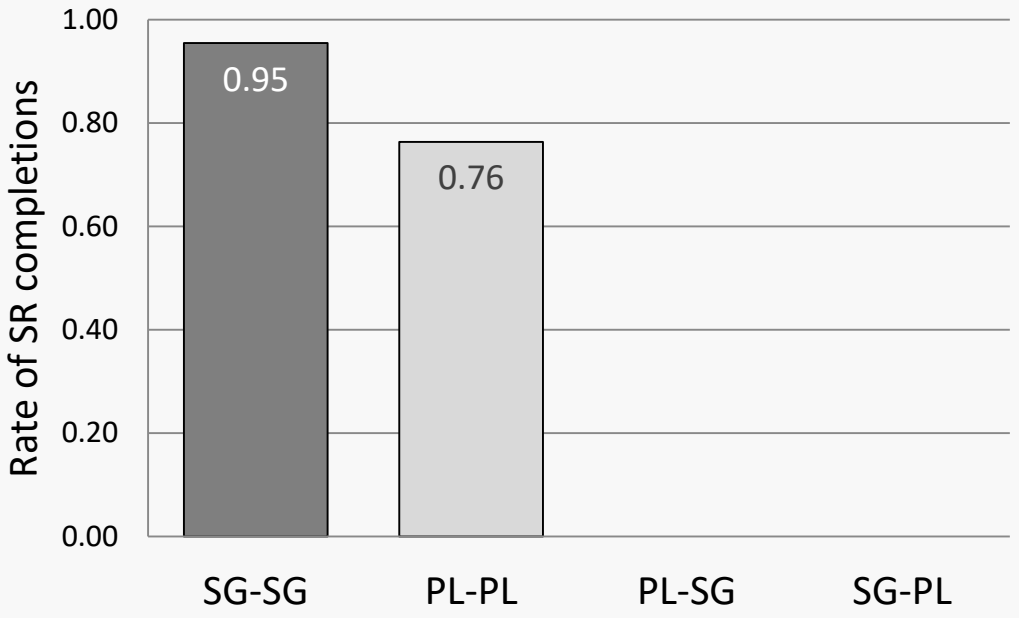
- Sentences truncated after the verb (RSVP of the preamble)
- Crossing number agreement on the verb & the filler (four conditions)
- Testing for SR/OR completions

Experiment 3
Results

FILLER.PL + VERB.SG → Form a SR
FILLER.SG + VERB.PL → Form an OR
Production, 100 participants, 24 sets + 12 OR fillers

In filler-verb match conditions -

- Strictly SR completions, when an impersonal subject isn't licensed.
- Mostly SR completions, when an impersonal null subject can be licensed.

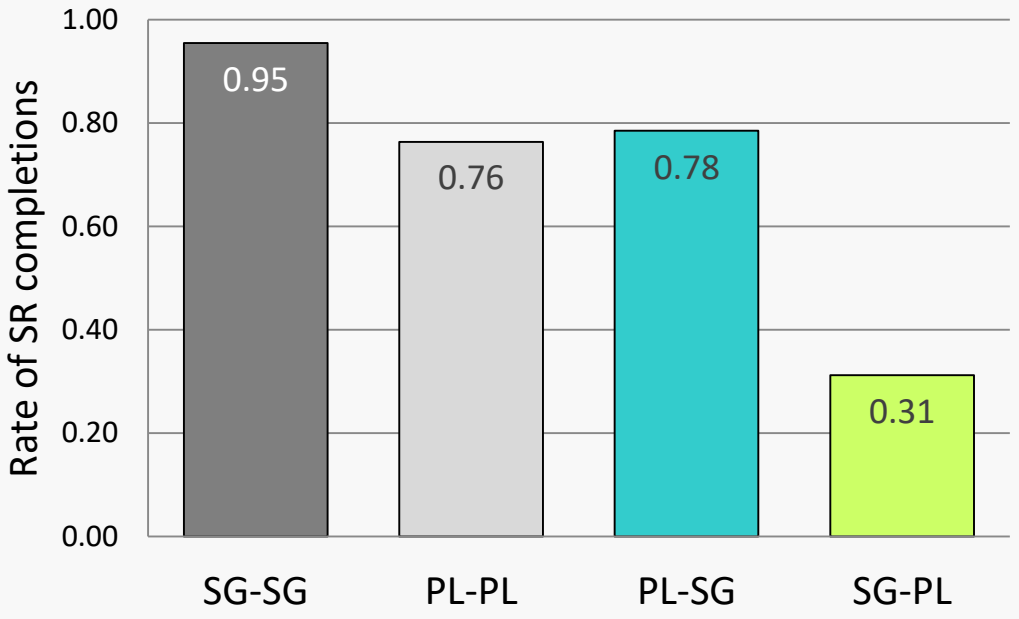


Experiment 3
Results

FILLER.PL + VERB.SG → Form a SR
FILLER.SG + VERB.PL → Form an OR
Production, 100 participants, 24 sets + 12 OR fillers

In mismatch conditions -

- Mostly SR completions (ignoring subject-verb agreement), when only a post-verbal can restore grammaticality.
- Mostly OR completions, when an impersonal subject can be licensed.



Discussion

Our study demonstrates rational noisy channel comprehension in Hebrew, showing that:

- Readers **apply elaborate probabilistic knowledge** regarding the distribution of structures in the language.
- They are willing to **compromise subject-verb agreement** to allow for a more probable structure.

Namely, the interpretation of an agreement mismatch is modulated by the prior probability of the alternative analyses.

Discussion

Self-organized sentence processing challenges the assumption that a grammar supervises parsing by defining all possible structures.

In this framework, noisy-channel effects are attributed to **bottom-up activation** of competing constructions. This can pull the interpretation towards a locally coherent (but globally ungrammatical) parse.

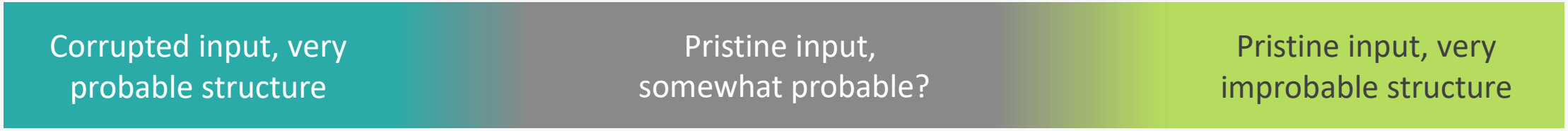
However, in our case, the adopted ungrammatical analysis is **not locally coherent.**

Tabor & Hutchins, 2004; Tabor, Galantucci, & Richardson, 2004

Directions for future research

When is it “rational” to assume a corrupted input?

- Quantitating the (im)probability of the structures.
- Testing whether readers assume post verbal subjects in other cases of filler mismatch (e.g. with short prepositions/case marking).
- Investigating the interaction between semantic plausibility and the structure’s frequency.



Thank you

Jesse Harris
Radan Nasrallah
CUNY reviewers

Contact: maayankeshev@mail.tau.ac.il

The likelihood of the different errors in the current study

Deletions are more likely (Gibson et al, 2013). Does it affect our finding?

EXP1-2:

Impersonal subject – Post-verbal subject

[VERB.sg]חיפש – [VERB.pl]חיפשו

[NOUN.sg]המלצר – [NOUN.pl]המלצרים

We cannot determine if the deletion/addition contrast is a confound since we don't know for certain weather readers amend the representation of the verb or a that of the filler.

The likelihood of the different errors in the current study

Deletions are more likely (Gibson et al, 2013). Does it affect our finding?

EXP3:

Impersonal subject – Post-verbal subject

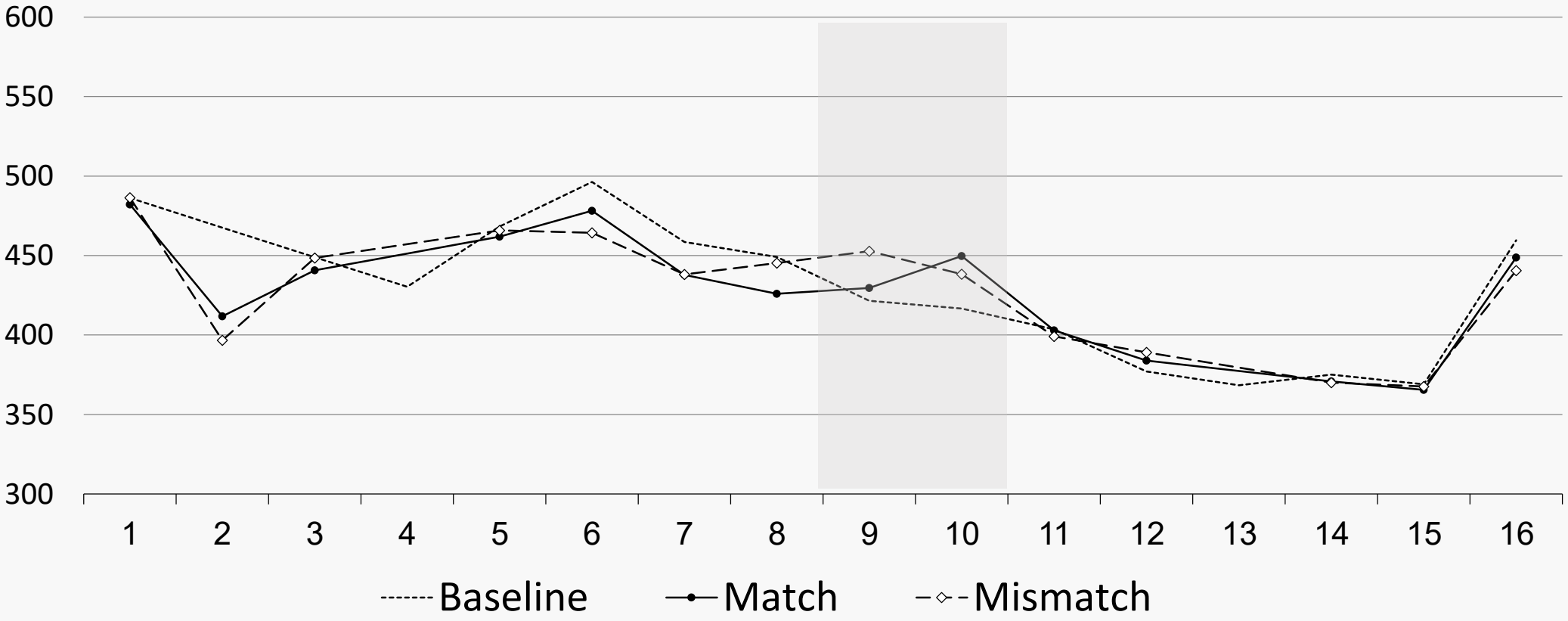
[VERB.sg]חיפשה – חיפשו[VERB.pl]

[NOUN.sg]המלצרית – המלצריות[NOUN.pl]

In experiment 3 this problem was removed by using the verbs and fillers in their feminine form. In this case, amending the verb requires **substitution** in both conditions. Amending the filler is more likely in the impersonal subject condition (in contrast to our prediction, and thus does not confound our findings).

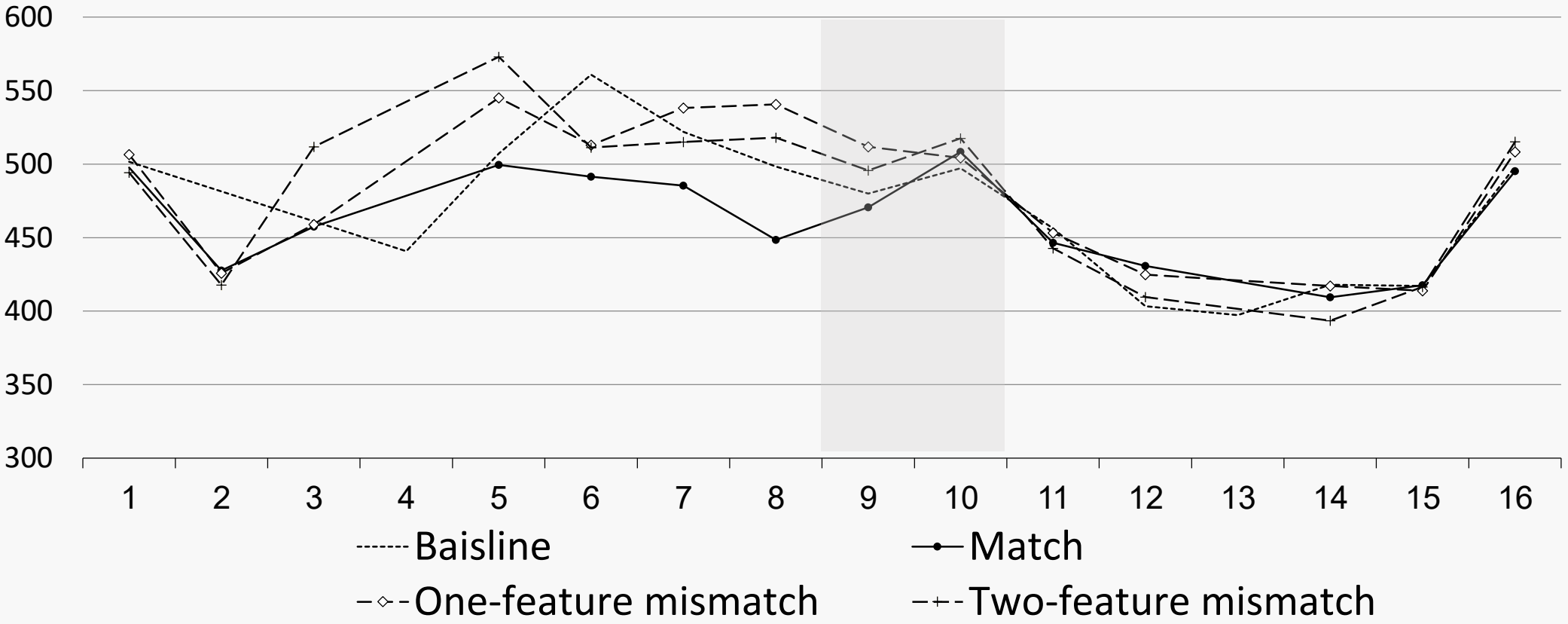
Additional figures and data

Experiment 1A



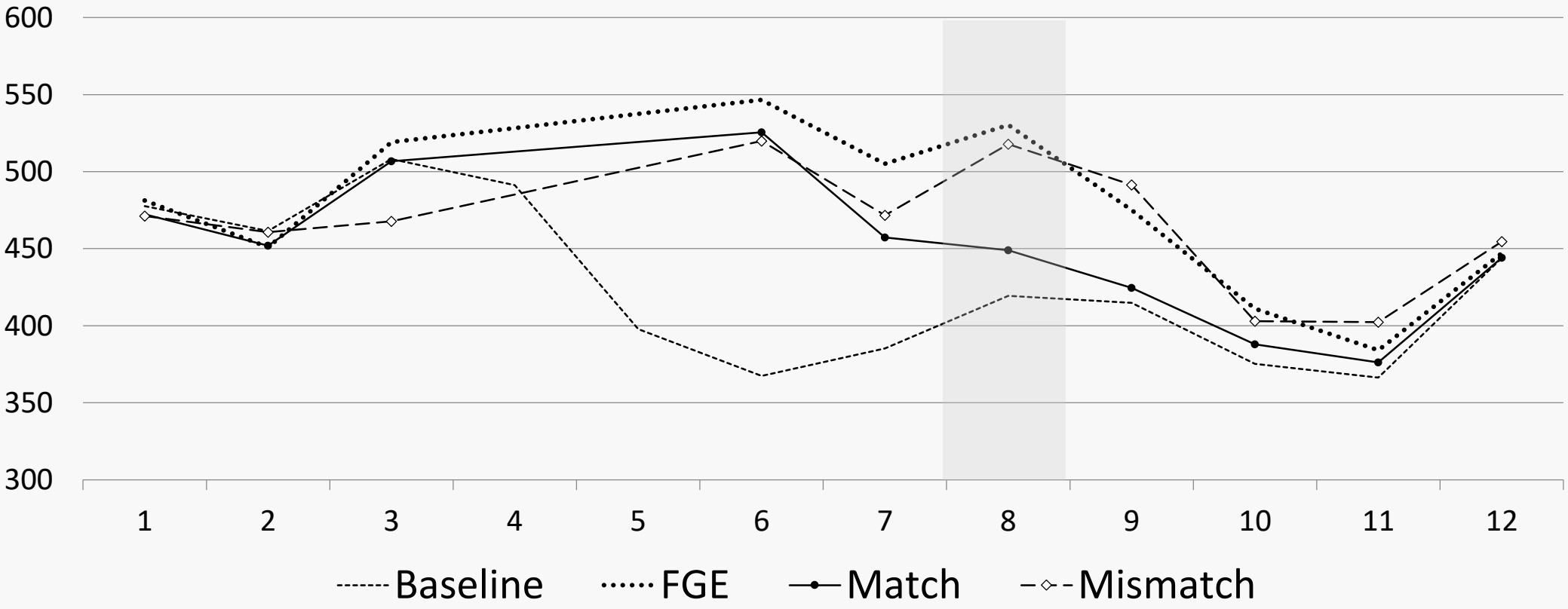
|We passed|$_1$ |near|$_2$ |the inspector|$_3$ |while|$_4$ |that during|$_5$ |the traffic jam|$_6$ |continued|$_7$ |allegedly|$_8$
|the driver|$_9$ |the violent|$_{10}$ |to attack|$_{11}$ |acc.|$_{12}$ |the inspector|$_{13}$ |without|$_{14}$ |any|$_{15}$ |shame|$_{16}$

Experiment 1B



|We passed|$_1$ |near|$_2$ |the inspector|$_3$ |while|$_4$ |that during|$_5$ |the traffic jam|$_6$ |continued|$_7$ |allegedly|$_8$
|the driver|$_9$ |the violent|$_{10}$ |to attack|$_{11}$ |acc.|$_{12}$ |the inspector|$_{13}$ |without|$_{14}$ |any|$_{15}$ |shame|$_{16}$

Experiment 2A



|The hairdresser|$_1$ |talked|$_2$ |with the designers|$_3$ |because|$_4$ |that they|$_5$ |chose|$_6$ |mostly|$_7$ |acc. the models|$_8$ |the-main|$_9$ |of them|$_{10}$ |in the moment|$_{11}$ |the last|$_{12}$

Experiment 2B

Experiment 3

The experiment also included manipulation of presentation duration [Regular: 300ms+100ms of blank; Speeded: 100ms + 300ms of blank].