Memory and expectation under the same roof

Plots and analysis

Russian experiment

Empirical plots

Experiment 1

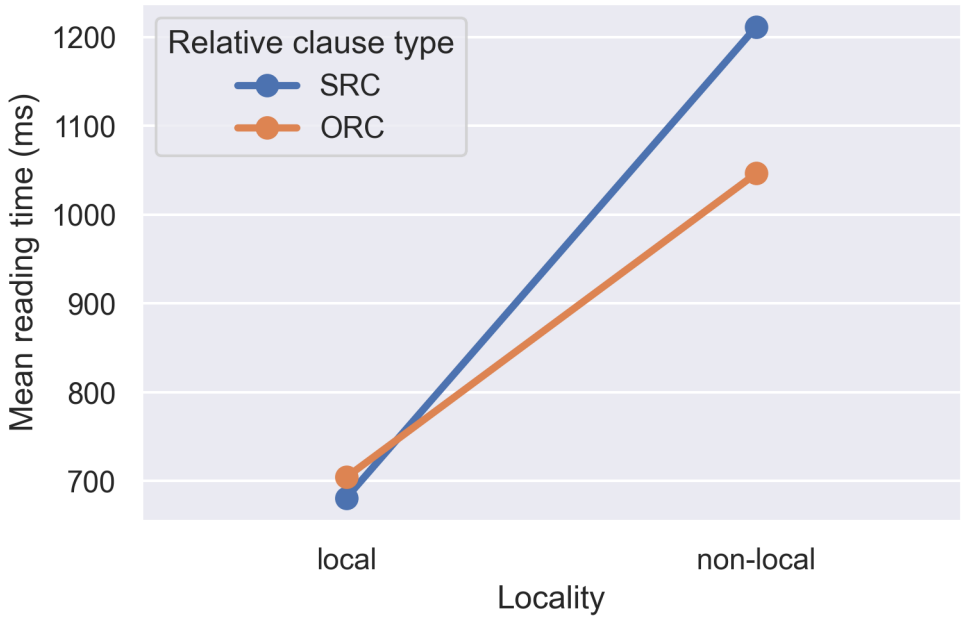


Figure 1: *Russian:* Mean reading times at the verb in Experiment 1a, @levyetal2013.[1] These were qualitatively the same as in Experiment 1b.

Experiment 2

[1]Taken from Figure 2, @levyetal2013, p. 470.
[2]Taken from Figures 6 and 7, @levyetal2013, p. 470.

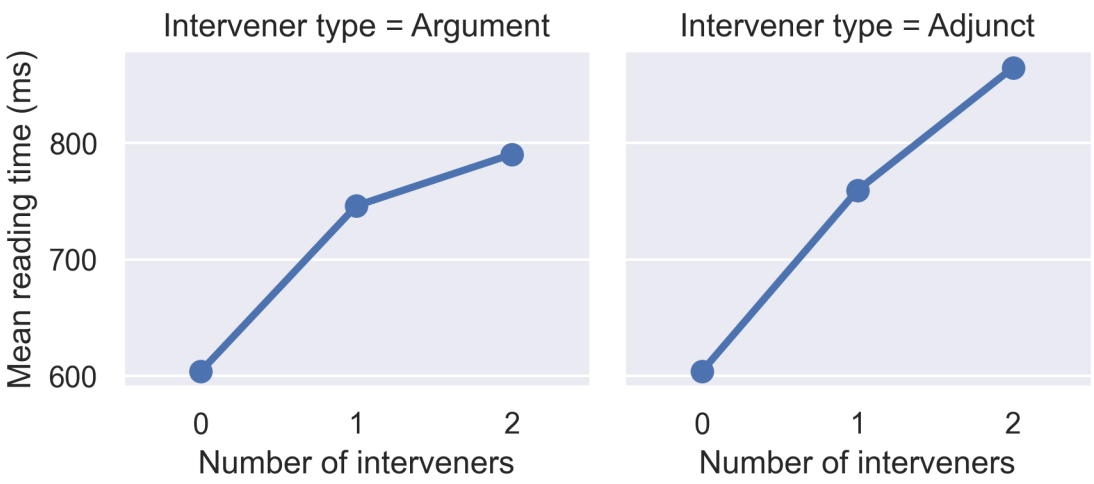


Figure 2: *Russian:* Mean reading times at the verb in Experiment 2a, @levyetal2013.[2] These were qualitatively the same as in Experiment 2b.

Grammar

Table 1: The PCFG used to model the Russian results. Terminal symbols are surrounded by single quotes.

Rule	**Probability**
RC → SRC	p(SRC)
RC → ORC	$1 - p$(SRC)
SRC → SRCRP 'V' ArgSRC	p(SRC Local)$(1 - p$(Adjunct intervener)$)$
SRC → SRCRP ArgSRC 'V'	$(1 - p$(SRC Local)$)(1 - p$(Adjunct intervener)$)$
SRC → SRCRP AdjIntv 'V' ArgSRC	p(Adjunct intervener)p(SRC Local)
SRC → SRCRP AdjIntv ArgSRC 'V'	p(Adjunct intervener)$(1 - p$(SRC Local)$)$
SRCRP → 'RPNom'	p(SRC Case marked)
SRCRP → 'chto'	$1 - p$(SRC Case marked)
ArgSRC → 'DO'	p(One argument)
ArgSRC → 'DO' 'IO'	$1 - p$(One argument)
ORC → ORCRP 'V' ArgORC	p(ORC Local)$(1 - p$(Adjunct intervener)$)$
ORC → ORCRP ArgORC 'V'	$(1 - p$(ORC Local)$)(1 - p$(Adjunct intervener)$)$
ORC → ORCRP AdjIntv 'V' ArgORC	p(Adjunct intervener)p(ORC Local)
ORC → ORCRP AdjIntv ArgORC 'V'	p(Adjunct intervener)$(1 - p$(ORC Local)$)$
ORCRP → 'RPAcc'	p(ORC Case marked)
ORCRP → 'chto'	$1 - p$(ORC Case marked)
ArgORC → 'Subj'	p (One argument)
ArgORC → 'Subj' 'IO'	$1 - p$ (One argument)
AdjIntv → 'Adj1'	p(One adjunct) $\cdot$ 0.5
AdjIntv → 'Adj2'	p(One adjunct) $\cdot$ 0.5

Rule	**Probability**
AdjIntv → 'Adj1' 'Adj2'	$0.5(1 - p(\text{One adjunct}))$
AdjIntv → 'Adj2' 'Adj1'[3]	$0.5(1 - p(\text{One adjunct}))$

[3]The use of two unique adjunct symbols is a consequence of the implementation of the progressive noise model. Using the same symbol for both adjuncts makes it impossible to discern if the first or the second adjunct has been deleted, and since the retention probability is dependent on the position of the word, the distortion probability becomes impossible to calculate correctly.

Probabilities

The probabilities were calculated as in Table 2.

Table 2: Probabilities used in the Russian PCFG. The first five were gathered from Table 1 of Levy (p. 467) and the last three using the PML Tree Query Engine (see section Counts and Queries below).

Probability	**Expression**	**Calculation**	**Value**[4]
p(SRC)	$\frac{\text{total number of SRCs}}{\text{total number of RCs}}$	$\frac{154+9+17+2}{154+9+17+2+42+74+9+14}$	0.57
p(SRC local)	$\frac{\text{total number of local SRCs}}{\text{total number of SRCs}}$	$\frac{154+17}{154+17+9+2}$	0.94
p(SRC case-marked)	$\frac{\text{total number of case-marked SRCs}}{\text{total number of SRCs}}$	$\frac{154+9}{154+9+17+2}$	0.9
p(ORC local)	$\frac{\text{total number of local ORCs}}{\text{total number of ORCs}}$	$\frac{42+9}{52+9+74+14}$	0.37
p(ORC case marked)	$\frac{\text{total number of case-marked ORCs}}{\text{total number of ORCs}}$	$\frac{42+74}{42+74+9+14}$	0.83
p(AdjIntv)	$\frac{\text{at least one adjunct intervener}}{\text{any number of interveners}}$	$\frac{925}{5851}$	0.16
p(One adjunct)	$\frac{\text{at least one adjunct intervener}-\text{at least two adjunct interveners}}{\text{at least one adjunct intervener}}$	$\frac{925-49}{925}$	0.95
p(One argument)	$\frac{\text{at least one argument}-\text{at least two arguments}}{\text{at least one argument}}$	$\frac{1621-107}{1621}$	0.93

Counts

Table 3: Corpus frequencies for Russian across the four corpora.

Description	**SynTagRus**	**GSD**	**PUD**	**Taiga**	***Total***
any number of interveners	5110	347	122	272	5851
at least one adjunct intervener	845	32	8	40	925
at least two adjunct interveners	45	3	0	1	49
at least one argument	1410	106	33	72	1621
(only noun arguments)	982	80	23	45	1130
at least two arguments	94	3	4	6	107
(only noun arguments)	38	1	1	1	41

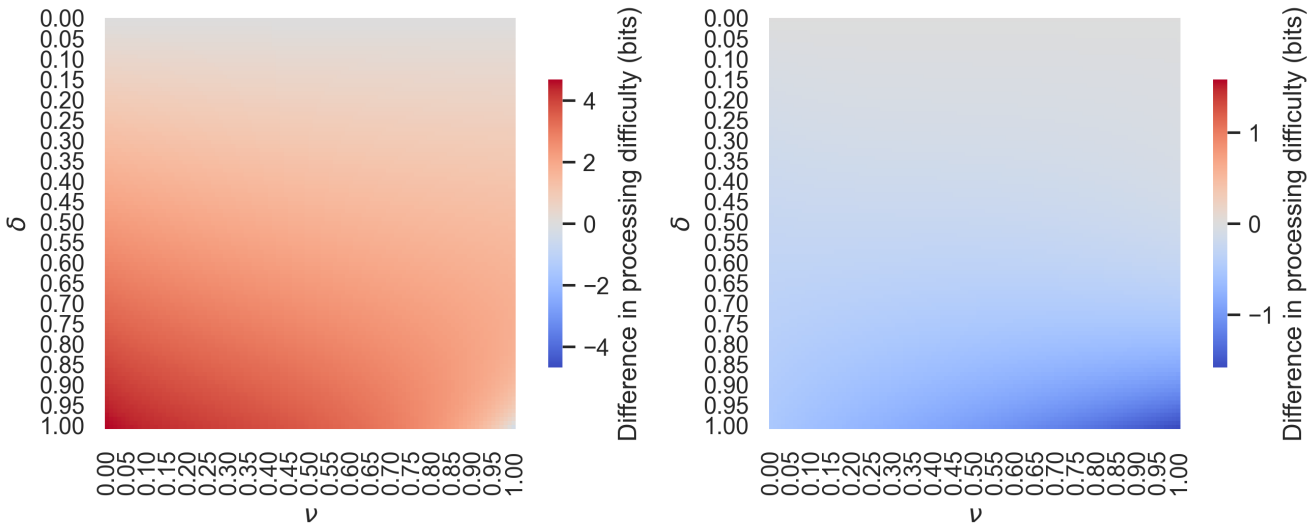
Results

Experiment 1

Experiment 1a

In Experiment 1a, subject- and object-extracted relative clauses were investigated, with the main manipulation being the placement of the verb (directly following the relative pronoun or separated from it by an argument).

[4]Rounded to two digits.



(a) Subject-extracted relative clauses.

(b) Object-extracted relative clauses.

Figure 3: Difference in processing difficulty at the verb between non-local and local SRCs (a) and ORCs (b), respectively. Red indicates locality and blue anti-locality.

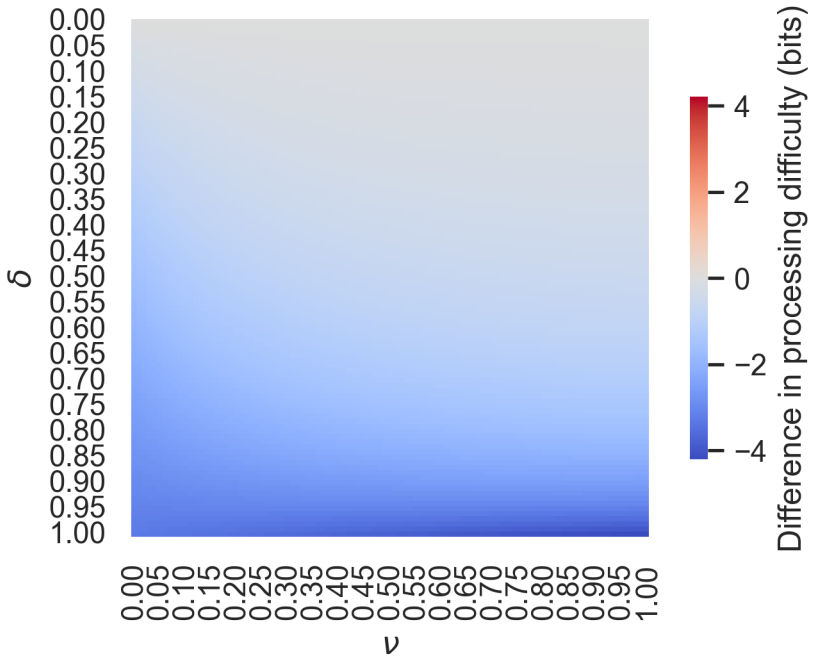
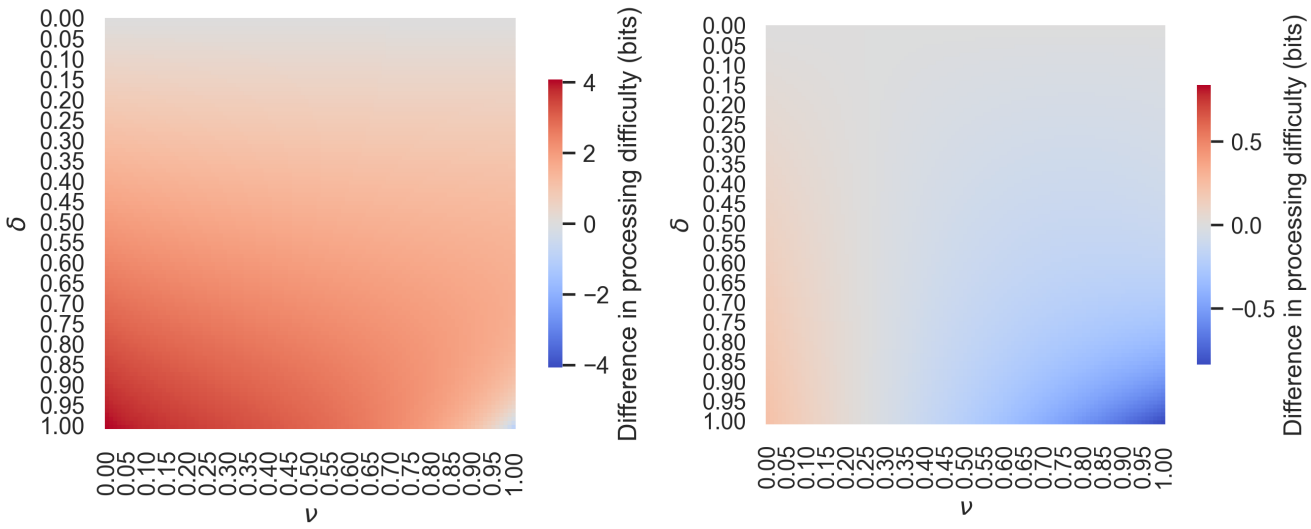


Figure 4: Difference in processing difficulty at the accusative NP placed postverbally and preverbally. Blue indicates a surprisal effect, in line with the empirical results.

Experiment 1b



(a) Case-synchretized subject-extracted relative clauses.

(b) Case-synchretized object-extracted relative clauses.

Figure 5: Difference in processing difficulty at the verb between non-local and local SRCs (a) and ORCs (b) with the case-synchretized relative pronoun 'chto', respectively. Red indicates locality and blue anti-locality.

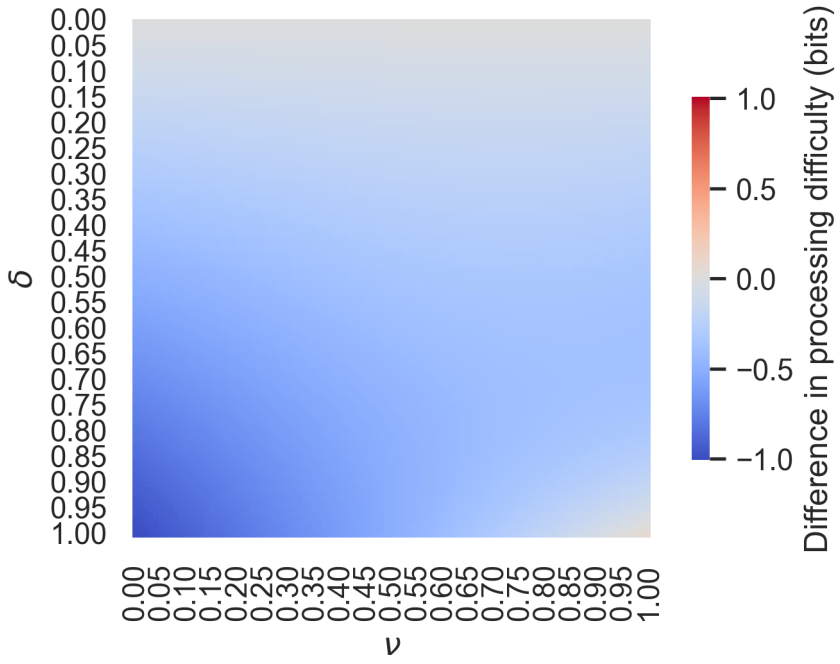
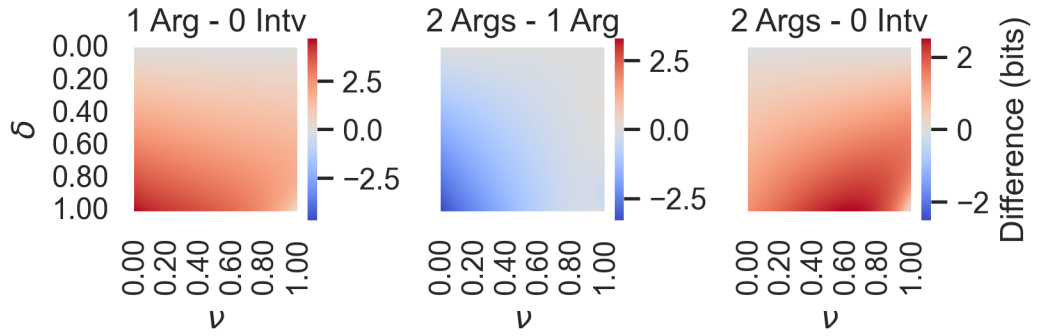
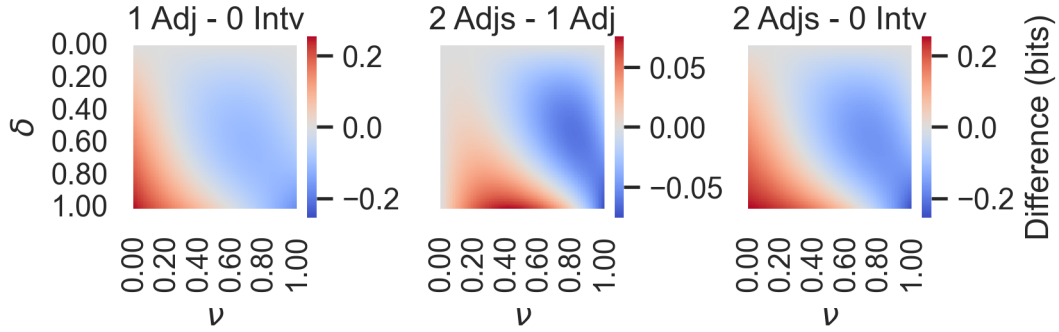


Figure 6: Difference in predicted processing difficulty between a pre- and postverbal subject NP with a case-syncretized relative pronoun. Blue indicates a processing advantage for preverbal subject NPs, in line with the empirical results.

Experiment 2



(a) Argument interveners.

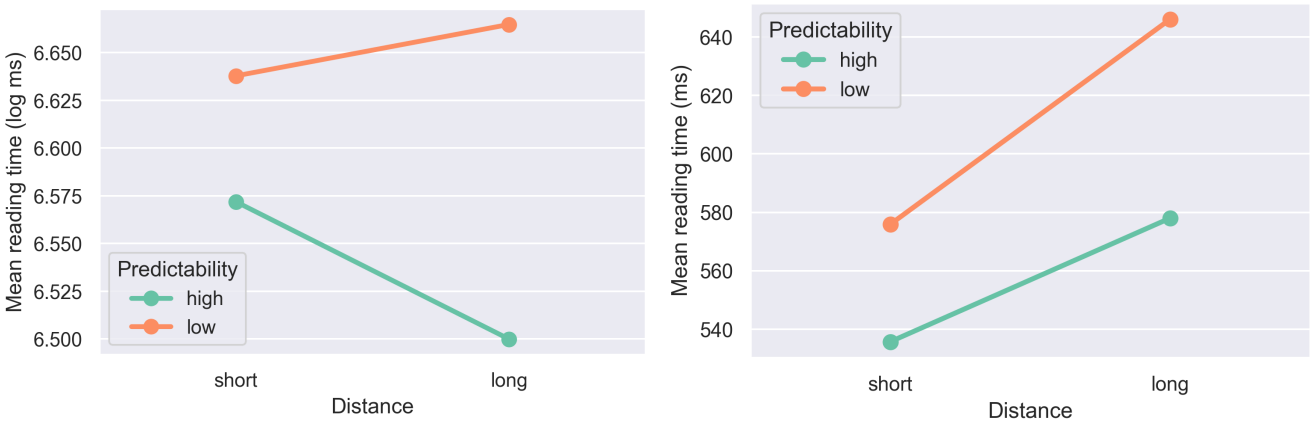


(b) Adjunct interveners.

Figure 7: Difference in predicted processing difficulty at the verb between Experiment 2 conditions. Red indicates locality and blue anti-locality. Note also the much smaller scales of the effect of adjunct interveners.

Persian and Hindi

Empirical plots



(a) Hindi.

(b) Persian.

Figure 8: *Hindi/Persian:* Reading times at the verb in Experiment 2 of @husainetal2014 (a), taken from Figure 4 (p. 11) and in Experiment 1 of @safavietal2016 (b), taken from Figure 1 (p. 7). The results were qualitatively the same in the rest of the experiments done by @safavietal2016.

Grammar

Table 4: The PCFG used to model complex and simple predicates in Persian and Hindi.

Rule	**Probability**
S → CPP	p(CP)
CPP → 'CPNoun' CPIntv CPVerb	p(CP Intervener)
CPP → 'CPNoun' CPVerb	$1 - p$(CP Intervener)
CPIntv → 'Adj1'	$0.5 \cdot p$(CP Short)
CPIntv → 'Adj2'	$0.5 \cdot p$(CP Short)
CPIntv → 'Adj1' 'Adj2'	$0.5(1 - p$(CP Short))
CPIntv → 'Adj2' 'Adj1'	$0.5(1 - p$(CP Short))
CPVerb → 'LightVerb'	p(Light verb | CP)
CPVerb → 'OtherVerb'	$1 - p$(Light verb | CP)
S → SPP	$1 - p$(CP)
SPP → 'SPNoun' SPIntv SPVerb	p(SP Intervener)
SPP → 'SPNoun' SPVerb	$1 - p$(SP Intervener)
SPIntv → 'Adj1'	$0.5 \cdot p$(SP Short)
SPIntv → 'Adj2'	$0.5 \cdot p$(SP Short)
SPIntv → 'Adj1' 'Adj2'	$0.5(1 - p$(SP Short))
SPIntv → 'Adj2' 'Adj1'	$0.5(1 - p$(SP Short))

Rule	Probability
SPVerb → 'LightVerb'	p(Light verb | SP)
SPVerb → 'OtherVerb'	$1 - p$(Light verb | SP)

Probabilities

Table 5: The probabilities used for the Hindi/Persian grammar.

	Description	Hindi	Persian
p(CP)	the probability of the sentence containing a complex predicate.	0.5	0.72
p(CP Intervener)	the probability of a complex predicate construction having intervening adjuncts.	0.05	0.0002
p(CP Short)	the probability of a complex predicate having only one intervener between the noun and the light verb.	0.99	0.999
p(Light verb | CP)	the probability of the specific light verb appearing, given that the noun in the sentence was the corresponding complex predicate noun.	0.75	0.64
p(SP Intervener)	the probability of a simple predicate construction having intervening adjuncts.	0.06	0.02
p(SP Short)	the probability of a simple predicate having only one intervener between the noun and the light verb.	0.99	0.99
p(Light verb | SP)	the probability of a the specific light verb appearing, given that the noun in the sentence was *not* the corresponding complex predicate noun.	0.18	0.33

The probabilities of light verbs in the different sentence types were taken from sentence completion studies conducted by @husainetal2014 and @safavietal2016, respectively. The rest were calculated according to Table 6.

Table 6: Expressions for calculating probabilities for the Persian/Hindi PCFGs.

Probability	Expression
p(CP)	$\frac{\text{CPs}}{\text{CPs+SPs}}$
p(SP intervener)	$\frac{\text{SPs at least one intervener}}{\text{SPs}}$
p(SP Short)	$\frac{\text{SPs at least one intervener-SPs at least two interveners}}{\text{SPs at least one intervener}}$
p(CP intervener)	$\frac{\text{CPs at least one intervener}}{\text{CPs}}$
p(CP Short)	$\frac{\text{CPs at least one intervener-CPs at least two interveners}}{\text{CPs at least one intervener}}$

Counts

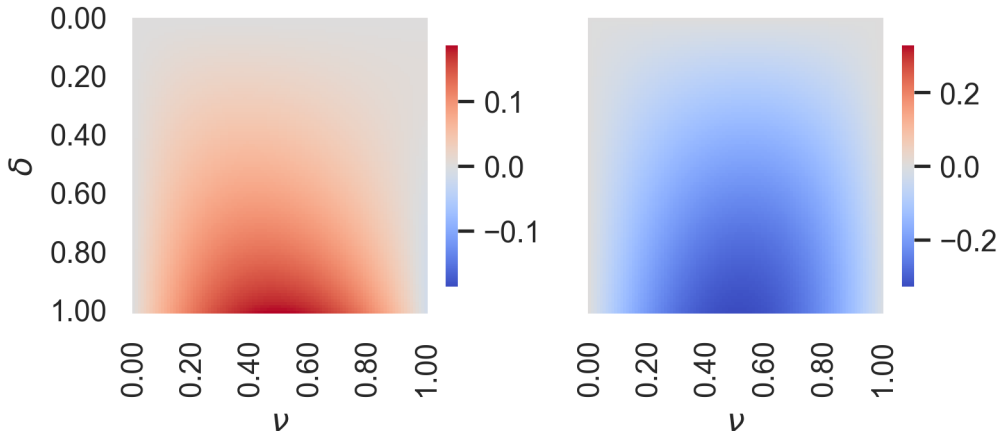
Hindi

	HDTB	PUD	Total
SP	2291	493	2784
CP	2808	2	2810
SP at least one intv	122	40	162
SP at least two intv	1	0	1
CP at least one intv	138	2	140
CP at least two intv	0	0	0

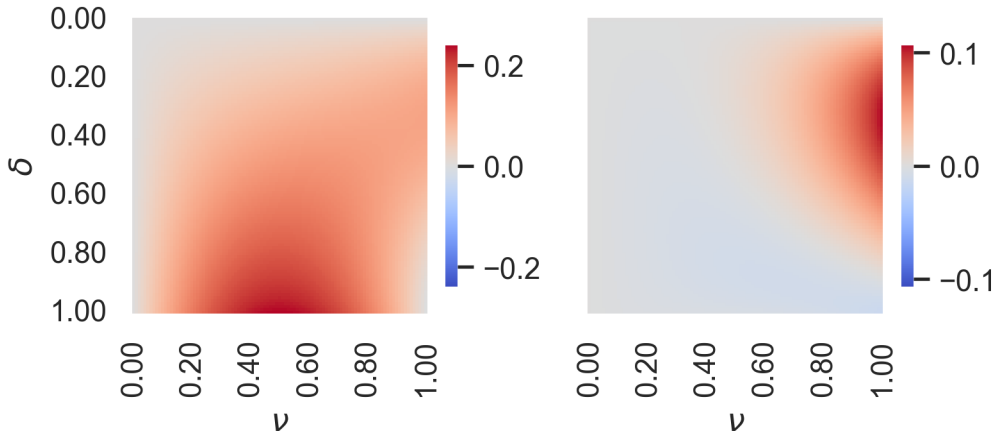
Persian

	PerDT	Seraji	Total
SP	3748	505	4253
CP	9597	1108	10705
SP at least one intv	80	17	97
SP at least two intv	1	0	1
CP at least one intv	2	0	2
CP at least two intv	0	0	0

Results



(a) Hindi.

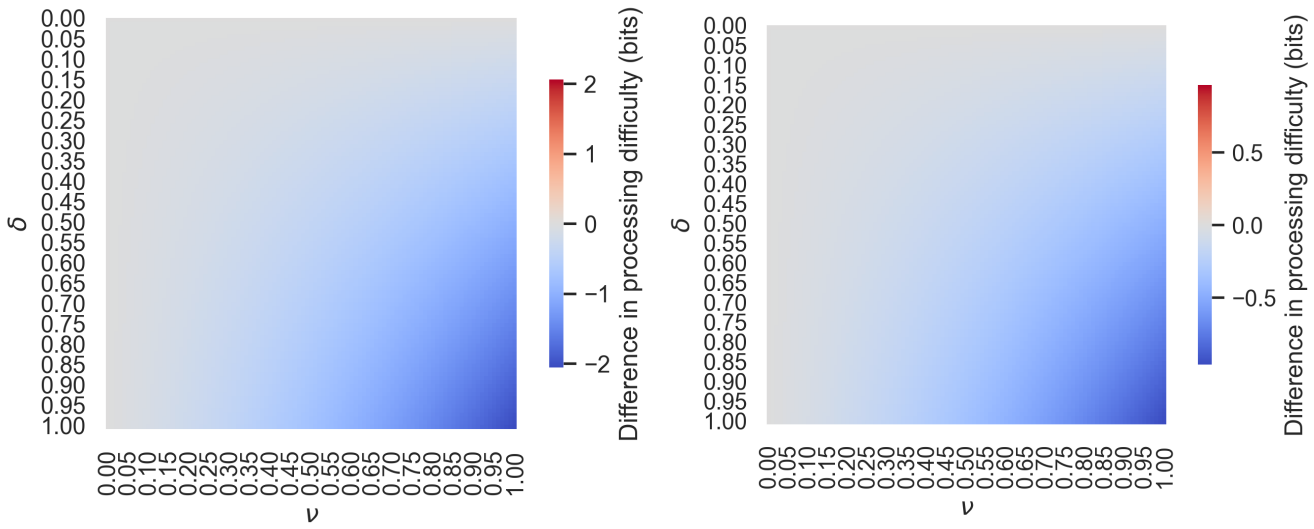


(b) Persian.

Figure 9: Difference in predicted processing difficulty at the light verb between long and short conditions for CPs (left) and SPs (right).

Parameter search for Hindi interaction

There were 0 parameter combinations from Figure 9a yielding the observed interaction in Hindi.



(a) Hindi.

(b) Persian.

Figure 10: *Hindi/Persian:* Predicted difference in average processing difficulty at the verb between complex and simple predicates. Blue indicates a processing advantage at the verb in complex predicates across both short and long conditions.

Queries

Russian

Any number of interveners:

```
a-node $v := [
  tag="VERB",
  deprel = "acl:relcl",
  child a-node $r := [
    tag = "PRON",
    lemma = "    "
  ],
] >> count()
```

At least one adjunct intervener:

```
a-node $v := [
  tag="VERB",
  deprel = "acl:relcl",
  child a-node $r := [
    tag = "PRON",
    lemma = "    ",
  ],
```

```
  child a-node [
    tag = "ADV",
    deprel = "advmod",
    order-follows $r,
    order-precedes $v
  ]
] >> count()
```

At least two adjunct interveners:

```
a-node $v := [
  tag="VERB",
  deprel = "acl:relcl",
  child a-node $r := [
    tag = "PRON",
    lemma = "    ",
  ],

  child a-node [
    tag = "ADV",
    deprel = "advmod",
    order-follows $r,
    order-precedes $v
  ],

  child a-node [
    tag = "ADV",
    deprel = "advmod",
    order-follows $r,
    order-precedes $v
  ],
] >> count()
```

At least one argument:

```
a-node $v := [
  tag="VERB",
  deprel = "acl:relcl",
  child a-node $r := [
    tag = "PRON",
    lemma = "    ",
    deprel = "nsubj" or deprel = "obj"
  ],

  child a-node [
    deprel = "obj" or deprel = "nsubj",
  ],
```

```
  child a-node [
    deprel = "iobj"
  ]
] >> count()
```

At least two arguments:

```
a-node $v := [
  tag="VERB",
  deprel = "acl:relcl",
  child a-node $r := [
    tag = "PRON",
    lemma = "    ",
    deprel = "nsubj" or deprel = "obj"
  ],

  child a-node [
    deprel = "obj" or deprel = "nsubj",
  ],

  child a-node [
    deprel = "iobj"
  ]
] >> count()
```

Persian/Hindi

The following queries work for Persian. Because of labeling differences between Hindi and Persian, `compound:lvc` has to be changed to just `compound` for the queries to work for the Hindi corpora.

Simple predicates

Any number of interveners

```
a-node $v := [
    tag = "VERB",
    deprel = "root",
    child a-node [
        deprel = "obj",
        tag = "NOUN"
    ],
    !child a-node [
      deprel = "compound:lvc",
    ]
] >> count()
```

With at least one intervener:

```
a-node $v := [
    tag = "VERB",
    deprel = "root",
    child a-node $o := [
        deprel = "obj",
        tag = "NOUN"
    ],
    !child a-node [
      deprel = "compound:lvc",
    ],
    child a-node [
        order-precedes $v,
        order-follows $o,
        deprel = "advmod"
    ]
] >> count()
```

With two interveners:

```
a-node $v := [
    tag = "VERB",
    deprel = "root",
    child a-node $o := [
        deprel = "obj",
        tag = "NOUN"
    ],
    !child a-node [
      deprel = "compound:lvc",
    ],
    child a-node [
        order-precedes $v,
        order-follows $o,
        deprel = "advmod"
    ],
    child a-node [
        order-precedes $v,
        order-follows $o,
        deprel = "advmod"
    ]
] >> count()
```

Complex predicates

Any number of interveners:

```
a-node $v := [
    tag = "VERB",
    deprel = "root",
```

```
    !child a-node [
        deprel = "obj",
    ],
    child a-node [
      deprel = "compound:lvc",
      tag = "NOUN"
    ]
] >> count()
```

With one intervener:

```
a-node $v := [
    tag = "VERB",
    deprel = "root",
    !child a-node [
        deprel = "obj",
    ],
    child a-node $o := [
      deprel = "compound:lvc",
      tag = "NOUN"
    ],
    child a-node [
        order-precedes $v,
        order-follows $o,
        deprel = "advmod"
    ]
] >> count()
```

With two interveners:

```
a-node $v := [
    tag = "VERB",
    deprel = "root",
    !child a-node [
        deprel = "obj",
    ],
    child a-node $o := [
      deprel = "compound:lvc",
      tag = "NOUN"
    ],
    child a-node [
        order-precedes $v,
        order-follows $o,
        deprel = "advmod"
    ],
    child a-node [
        order-precedes $v,
        order-follows $o,
```

```
        deprel = "advmod"
    ]
] >> count()
```