



C. Zanini – R. Rugani - G. Arcara - F. Franzon

University of Zurich - University of Padova
IRCCS Ospedale San Camillo, Venezia - SISSA

chiara.zanini@uzh.ch - ffranzon@sissa.it

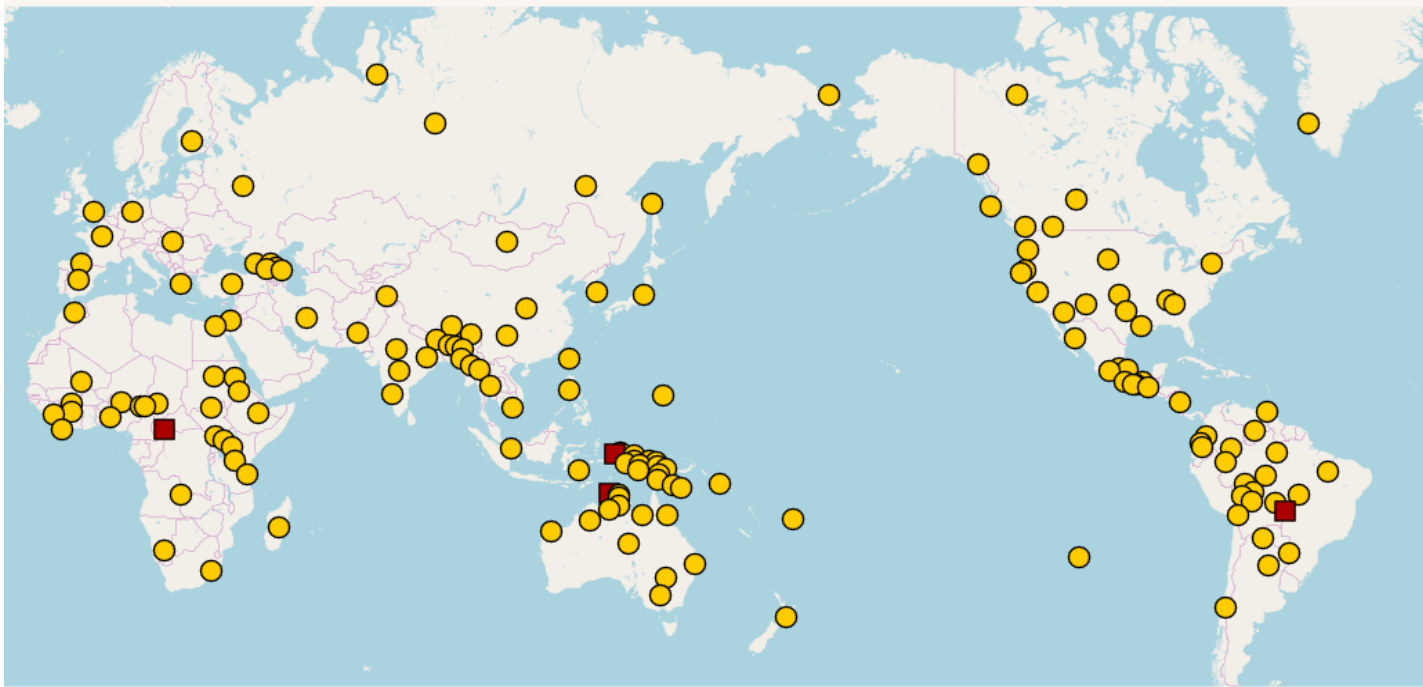
Does cognition shape Number paradigms?

Insight from typology and an ERP study

Morphology encodes only some of all the possible information in the referential world.

Some meanings tend to occur more than others in natural languages and to be functionally encoded in morphology or syntax.

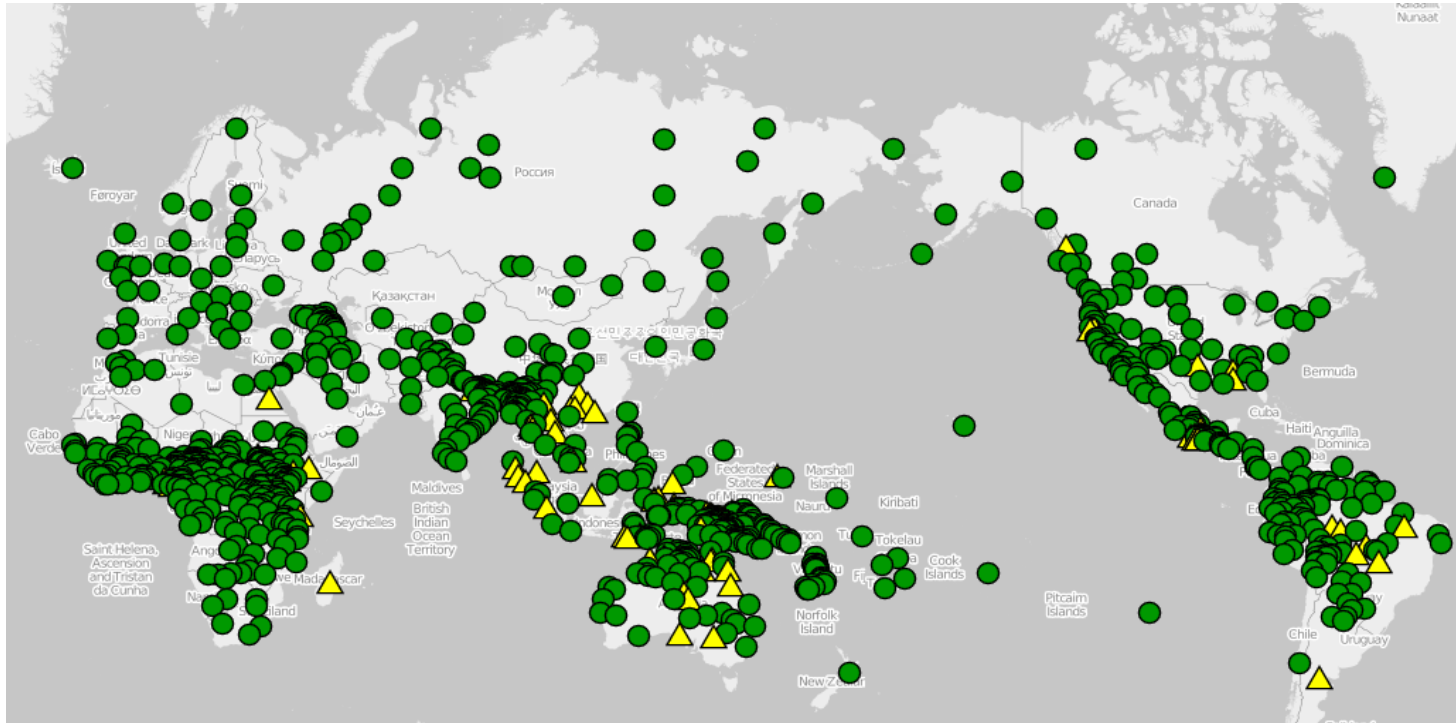
Tense, mood, aspect



WALS, map 21:

■ 4 languages out of 160 do not mark tense and aspect on the verb.

Bickel & Nichols (2013). In: Dryer, Matthew & Haspelmath, (eds.) The WALS Online.



WALS, map 33A:

- Plural marking
- ▲ No plural marking

90.8% (968/1066) of reported languages have a grammatical device to encode **nominal plurality**.

Number morphology is widespread throughout natural languages and encodes the **numerosity** of the referents.

(Corbett, 2000; Dryer, 2013)

- Why is Number so widespread across languages?
- Why are other features (e.g. color) not encoded into morphology?

- **Core knowledge hypothesis:** animals, including humans, would be endowed with a set of cognitive systems to represent the most relevant aspects of the environment.

(Spelke, 2000; Carey, 2009)

- Core knowledge systems can be considered as cognitive tools that favourite animal interactions within their natural environment.

(Vallortigara et al., 2010)

- Some of these systems can be so relevant to shape the grammatical structure of languages.
- Links have been outlined between the salience of conceiving of naïve physics, animacy, countability and the fact that they are encoded in the grammar of natural languages.

(e.g. Bickel et al., 2015; Franzon, Zanini & Rugani, 2018; Strickland, 2017; Zanini et al., 2017)

- It has been proposed that the core structure of human language stems from processing mechanisms rather than the other way round.

(Christiansen & Chater, 2008)

Non-verbal numerical cognition is supposed to be based on two systems:

1) Object File System (OFS)

- founded on the capability of individuating each new object entering into a scene, to which a new file ('object file') is assigned and stored in the working memory;
- its signature is a limit to the number (usually 3 or 4) of object-files that can be simultaneously tracked and stored.

(Trick & Pylyshyn, 1994)

2) Analog Magnitude System (AMS)

- estimation involving larger numerosness;
- the AMS functioning would be ratio-dependent according to Weber's law;
- as the ratio between the numbers to be discriminated becomes larger, response times decrease and accuracy increases.

(Gallistel & Gelman, 1992)

Extra-linguistic numerical abilities are phylogenetically ancient; they can be observed in:

- educated adult humans when, under specific experimental conditions, language use is prevented;

(Cordes et al., 2001)

- adult speakers having no number words;

(Butterworth et al., 2008; Pica et al., 2004)

- preverbal infants;

(deHevia, 2011; McCrink & Wynn, 2007)

- non-human animals.

(Agrillo et al., 2014; Rugani et al., 2010, 2015; Vallortigara, 2012; Cantlon & Brannon 2006)

Core cognition, core grammar

Language encodes into morphology **only some** of all the possible **information** present in the referential world.

The diffusion of certain features in morphological systems could mirror their **biological salience** and **phylogenetic ancestry** at the extra-linguistic cognitive level.

Core cognition, core grammar

Morphology, as compared to other linguistic domains appears particularly suitable to efficiently convey this type of information:

- systematical encoding of meaning in paradigms;
- morphological values are mostly phonologically short and are mostly mandatorily expressed.

Core cognition, core grammar

- The Number values that can be encoded in noun morphology in natural languages seem to resemble the values that non-human animals and pre-verbal infants can distinguish by non-verbal number systems.

(Franzon, Zanini & Rugani, 2018)

| Non-verbal numerical cognition | Morphological Value |
|--|--|
| Analogue Magnitude System (AMS) Quantity estimation | Paucal - Greater Paucal – Plural – Greater Plural |
| Object File System (OFS) Exact Numerosity up to 3/4 | Dual – Trial – (Quadral) |

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- The singular marks the precise numerosity of “one” only in opposition to other values.
- Thus, it is not always possible to trace whether the singular is used to denote a reference explicitly encoding a numerosity, a quantity or not.

Numerosity = 1
General Number
Uncountability

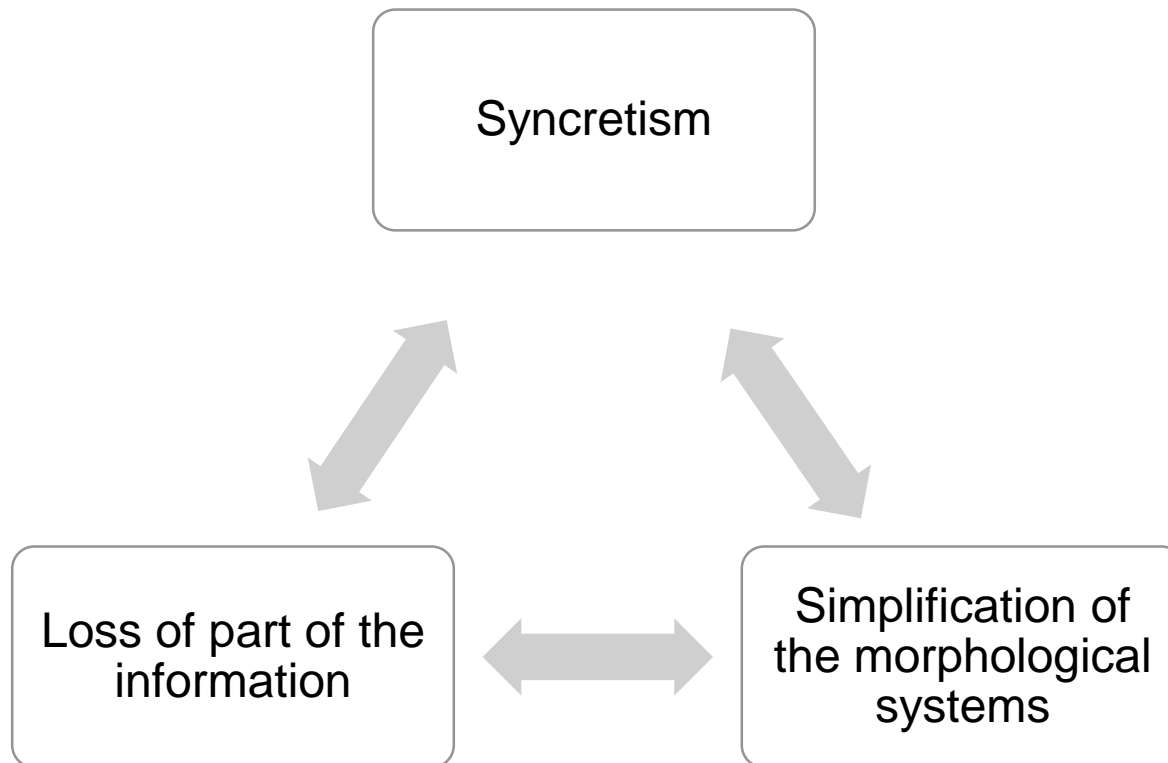
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Numerosity = 1
General Number
Uncountability

**Syncretism of values
(Singular)**

No language encodes all the information processed by the non verbal numerical cognition: most Number systems have a singular vs. plural paradigm.

(Corbett 2000)



Numerical cognition, Number morphology

Is the representation of numerosities and magnitudes accessed whenever these are communicated within language?

Number morphology *per se* and its link with numerosity have been scantily considered in experimental studies.

Numerical cognition, Number morphology

Most works have tackled this issue in relation to the lexicon.

(i.e., Butterworth et al., 1999; Carey, 2004; Clark & Grossman, 2007; Gelman & Gallistel, 2004; Gordon, 2004; Lipton & Spelke, 2003; Ochtrup et al., 2013; Pica et al., 2004; Rath et al., 2015; Salillas, Barraza & Carreiras, 2015; Semenza, 2008; Troiani, Peelle, Clark & Grossman, 2009).

Fewer works have focussed on morphology.

- neural signature: Carreiras, Carr, Barber & Hernández, 2010;
- number line [SNARC] studies: Roettger & Domahs, 2015;
- developmental studies: Almoammer et al., 2013; Barner et al., 2007; Marušić et al., 2016; Sarnecka et al., 2007.

Numerical cognition, Number morphology

- In a fMRI study, Carreiras et al. (2010) found increased activation of the right superior parietal gyrus and of the right intraparietal sulcus only in conditions tackling the morphological Number, but not in conditions dealing with other morphological features such as gender.
- The activation of these areas was found to be associated with non-verbal numerosity processing.

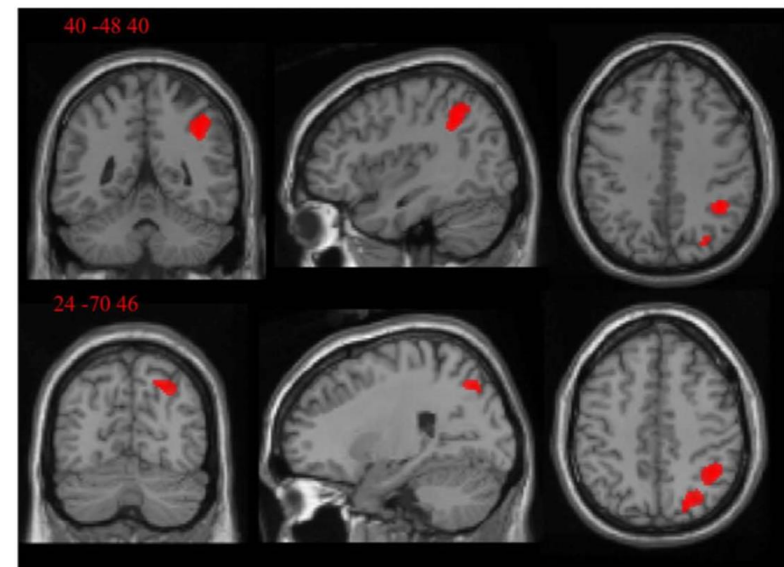
(Dehaene et al. 2003; Piazza et al. 2002; 2006; 2007; Pinel et al. 2004)

Determiner–noun word pairs:

- (a) Agreement, e.g., *El piano* ($the_{m-s} piano_{m-s}$).
- (b) Gender disagreement, e.g., *La piano* ($the_{f-s} piano_{m-s}$).
- (c) Number disagreement, e.g., *Los piano* ($the_{m-p} piano_{m-s}$).

Noun–adjective word pairs:

- (d) Agreement, e.g., *Faro alto* ($lighthouse_{m-s} high_{m-s}$).
- (e) Gender disagreement, e.g., *faro alta* ($lighthouse_{m-s} high_{f-s}$).
- (f) Number disagreement, e.g., *faro altos* ($lighthouse_{m-s} high_{m-p}$).



from Carreiras et al. (2010)

ERP studies:

long-standing tradition of works investigating the functional facet of Number as a feature to perform agreement (e.g. Friederici, 1995; Hagoort, Brown, & Groothusen, 1993; Kutas & Hillyard, 1983; Osterhout & Mobley, 1995).

*the cat meows vs . *the cat meow*

An ERP study: state of the art

- Kutas and Hillyard (1983) found that subject-verb Number agreement violations elicited a negative peak (Left Anterior Negativity, LAN) in electrical brain activity between 200 and 500 ms in anterior zones after stimulus presentation.
- Hagoort et al. (1993) reported a P600 effect, i.e. a posterior positive peak occurring 600 ms after stimulus presentation, in response to the same type of agreement violations.
- The LAN effect alone, the P600 effect alone or the LAN-P600 pattern have been reported in most of the later studies (e.g. Barber & Carreiras, 2003, 2005; Barber, Salillas, & Carreiras, 2004; De Vincenzi et al., 2003; Kaan, 2002; Silva-Pereyra & Carreiras, 2007), even in studies involving other morphological features such as Gender (e.g. Caffarra, Janssen, & Barber, 2014).

An ERP study: state of the art

“Although a large number of papers have been devoted to Number agreement, no study until now has focused on the qualitative distinction between the values that express Number.”

(Molinaro et al., 2011: 926)

An ERP study: methods

We conducted an ERP study to measure the time course of the processing of singular and plural, which are the two typologically more widespread Number values (Corbett 2000).

The study was conducted in Italian:

- a. una mela
‘one’ + noun.SG
- b. *alcune mele*
‘some’ + *noun.PL*

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'some' + *noun.PL*
- c. *qualche mela*
'some^o' + *nouns.SG*

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‘some^o’ + *nouns.SG(general)*

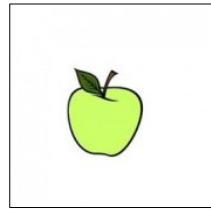
At the **phrase level**:
plural numerosity with a
meaning of paucal.
(Zamparelli 2008)

An ERP study: methods

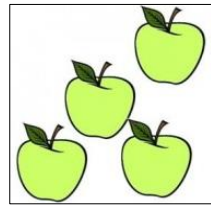
180 EXPERIMENTAL STIMULI:

30 nouns referring to countable, concrete objects (e.g. mela 'apple').

Two pictures for each noun: in one, the object was represented once, in the other four times.















uno 'one' +*noun.SG*
qualche 'some^o' +*noun.SG*
alcuni 'some' +*noun.PL*



uno 'one' +*noun.SG*
qualche 'some^o' +*noun.SG*
alcuni 'some' +*noun.PL*

Filler stimuli were added to counterbalance each experimental condition; 120 of them presented a semantic violation.

An ERP study: methods

| Condition | Picture numerosity | Presented phrase | Phrase example | Numerosity at phrase level /congruence | Numerosity at morphological level/congruence | N° of Stimuli |
|---------------------|---|----------------------|----------------------------------|--|--|---------------|
| Depicted Numerosity |  | <i>one+noun.SG</i> | “one apple” (una mela) | SG / True | SG / True | 30 |
| |  | <i>one+noun.SG</i> | “one apple” (una mela) | SG / False | SG / False | 30 |
| |  | <i>some+noun.PL</i> | “Some apples” (alcune mele) | PL / False | PL / False | 30 |
| |  | <i>some+noun.PL</i> | “Some apples” (alcune mele) | PL / True | PL / True | 30 |
| |  | <i>Some°+noun.SG</i> | “Some° apple” (qualche mela) | PL / False | SG / True | 30 |
| |  | <i>Some°+noun.SG</i> | “Some° apple” (qualche mela) | PL / True | SG / False | 30 |
| Depicted Object |  | <i>one+noun.SG</i> | “one orange” (una arancia) | SG / True | SG / True | 30 |
| |  | <i>one+noun.SG</i> | “one sponge” (una spugna) | SG / True | SG / True | 30 |
| |  | <i>some+noun.PL</i> | “some oranges” (alcune arance) | PL / True | PL / True | 30 |
| |  | <i>some+noun.PL</i> | “some sponges” (alcune spugne) | PL / True | PL / True | 30 |
| |  | <i>Some°+noun.SG</i> | “some° orange” (qualche arancia) | PL / True | PL / False | 30 |
| |  | <i>Some°+noun.SG</i> | “some° sponge” (qualche spugna) | PL / True | PL / False | 30 |

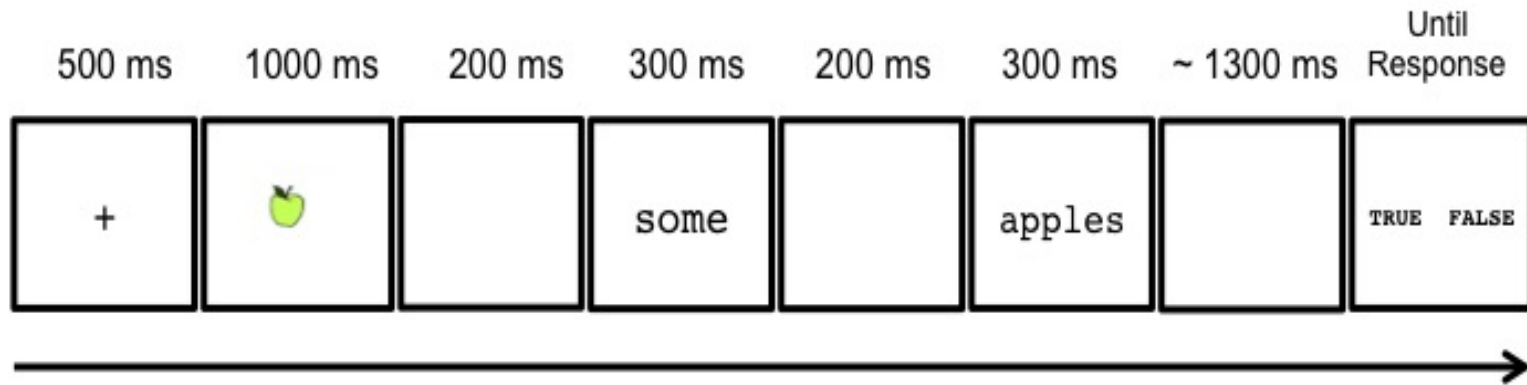
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An ERP study: methods

TASK

Participants were asked to press one key if the phrase matched with the picture, another key in the opposite case.



PARTICIPANTS

26 young adult native speakers of Italian took part to the study as volunteers (females = 17; mean age = 24.5; min age = 20; max age = 32; SD = 2.98).

All participants were right-handed, had normal or correct-to-normal vision, and had no reported history of reading or learning disorders.

All participants signed a written informed consent before taking part to the study. The experiment was approved by the Local Ethics Committee.

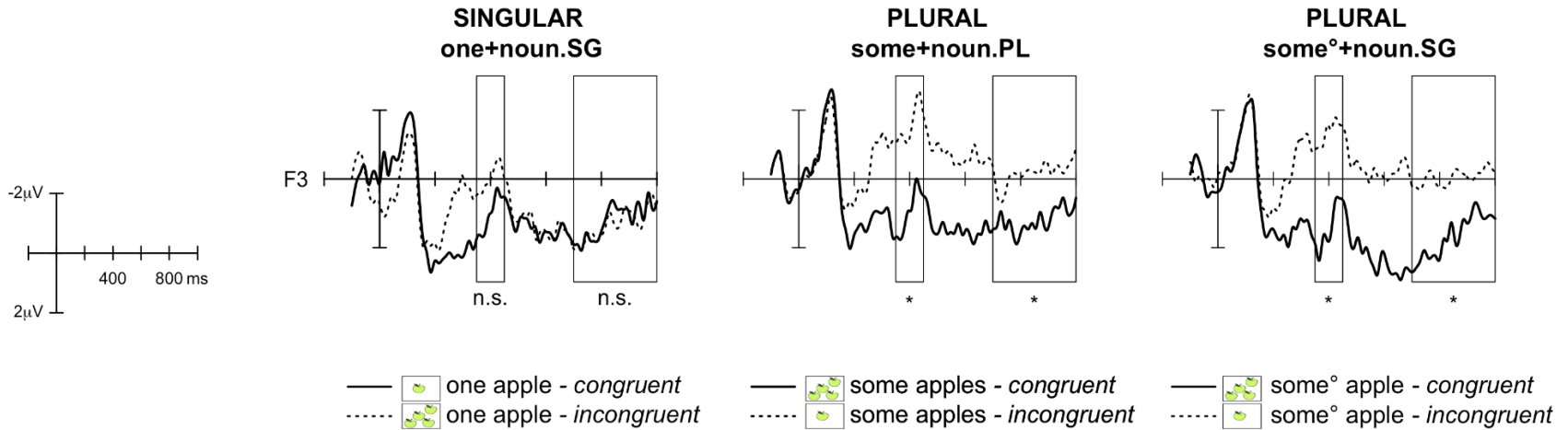
An ERP study: hypothesis

- Given previous evidence on partial incremental processing of language (Urbach & Kutas, 2010), more negative LAN-like components are elicited in the **incongruent** condition as compared to the congruent one.
- No specific expectations on the difference between singular and plural.

We analysed ERPs time-locked to the presentation of the **noun**.

An ERP study: results

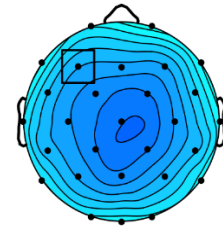
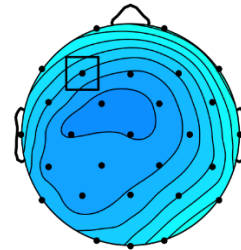
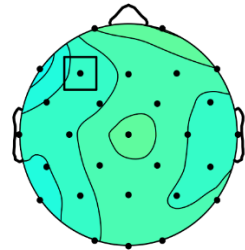
Contrast on Depicted Numerosity



Topoplots

*incongruent
minus
congruent*

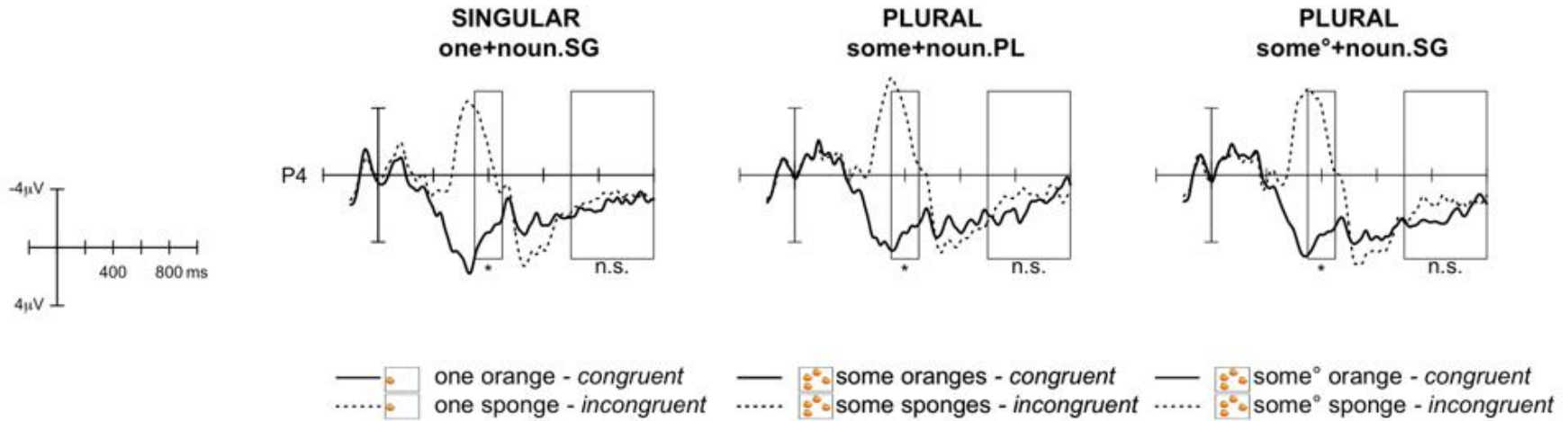
(350 - 450 ms)



-7 µV +7 µV

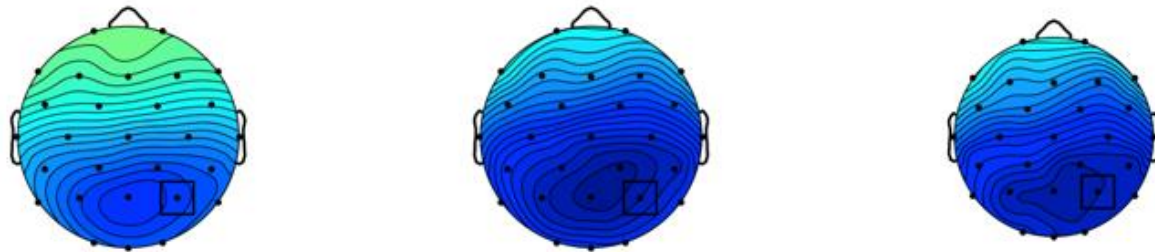
An ERP study: results

Contrast on Depicted Object



Topoplots

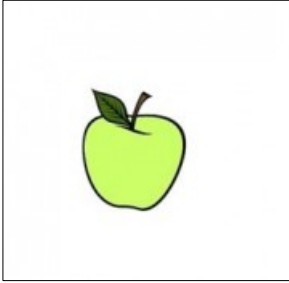
*incongruent
minus
congruent*
(350 - 450 ms)



-8 µV +8 µV

An ERP study: results

Incongruent condition:



qualche 'some°' + noun.SG(general)

alcuni 'some' + noun.PL

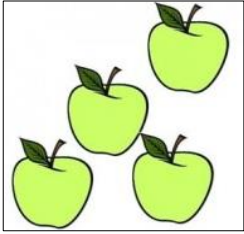
→ LAN

After a picture representing one object, nouns following both *qualche* and *alcuni* elicited a larger Left Anterior Negativity (LAN), as compared to the conditions involving a picture displaying four objects.

The LAN component is traditionally linked with difficulties in early processing of morphological cues.

(e.g. Molinaro et al. 2011)

Incongruent condition:



uno 'one' + noun.SG → no effects

We did not find LAN effects in the condition involving pictures displaying four objects followed by *uno* 'one'+noun.SG.

An ERP study: discussion

We find incongruence effects when

- the nouns were inflected in the plural bearing a numerosity of plurality (*alcuni* ‘some+noun.PL’);
- the plural numerosity was not specified at the morpheme level, but -unambiguously- at the phrase level (*qualche* ‘some^o+noun.SG’).

Considering the LAN as an index of morphosyntactic incongruency, this result suggests that numerical information can be accessed during the processing of morphological Number in phrase context.

This data are in line with the literature claiming a link between core cognition and core grammar.

An ERP study: discussion

We did not find any LAN effects in the condition involving *uno* 'one' +*noun.SG*. This pattern

- has been never reported in the literature before;
- may point to the fact that plurality -when encoded into Number morphology in the phrase context- has a narrower interpretability than the singular;
- may be taken as psychological evidence of the fact that singular, more than plural, is prone to be the default unmarked Number value that can convey other meanings.

- Numerical representation is to some extent accessed during Number morphological processing at the phrase level.
- If Number morphology and its processing can reflect cognitive salient information about numerosity, they do so in a non-strictly-associative fashion. In fact, we failed to observe significant incongruence effects when the morpheme was interpretable as singular at the phrase level.

- Can this pattern of results be replicated in languages with the same Number system of Italian, i.e. singular vs. plural?
- Can this pattern be differently modulated in languages with other Number systems such as singular-plural-dual or general-singular-plural?
- If Number morphology reflects salient core knowledge information, what about other morphological features such as Gender?

These questions will benefit from further investigation on typologically different languages.

THANKS FOR YOUR ATTENTION!