Multivariate pattern of inflectional and phrasal computations revealed by combined MEG/EEG

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Introduction

The dynamic interpretation of spoken grammatical utterances requires complex combinatorial computations and activates bilateral fronto-temporal neural activity [1]. Neuroimaging and neuropsychological evidences suggest that language functions are distributed over two neurobiologically distinct sub-systems:

- a bilateral fronto-temporal network supporting lexical, semantic and pragmatic interpretation of sentences [2].
- a left lateralised fronto-temporal network supporting the core grammatical combinatorial computations including syntax and inflectional morphology [1].

While inflectionally complex words (follow+ed) trigger activity in the dorsal LH perisylvian network, the processing of simple phrases (I follow) engages temporal regions bilaterally [Bozic *et al.*, under review] as well as ventral inferior frontal gyrus (IFG) in some studies [3].

Here we use combined MEG and EEG to track the spatiotemporal dynamics of these different combinatorial processes, examined in spoken words and phrases. Our goal is to define how and whether grammatical computations are distributed over these two systems.

We use multivariate pattern analysis (MVPA) techniques based on Representational Similarity Analysis (RSA) [4]. These methods access the fine grained patterns of brain activity underpinning complex language processes.

Methods

Participants

18 adult, right-handed, native English speakers.

Task

Passive listening of single words or phrases with 10 % one back memory task.

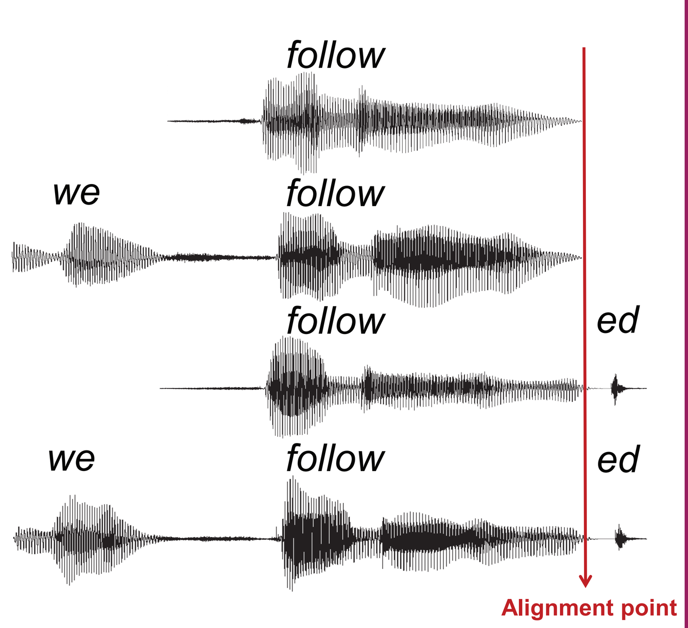
Stimuli

120 verbs divided into 3 groups (N=40) based on their verb category dominance [5], matched on length, lemma and word form frequency. Each verb is heard in 4 different contexts.

	Non-inflected	inflected
isolation	Bare stem *follow*	Inflection *followed*
Phrase	Context *we follow*	Combined *we followed*

Acquisition & multimodal source reconstruction

- EEG-MEG (306-channel MEG, 70-channel EEG Vectorview system)
- Three-layer boundary element model (Freesurfer) using participants' MRI scans
- L2 Minimum Norm Estimate [6]
- Region of interest (ROI) defined anatomically in FreeSurfer, one functional ROI - frontal operculum defined using Talairach coordinates (-36, 20, -3) [7] with radius of vertices joining to BA44 & BA45.

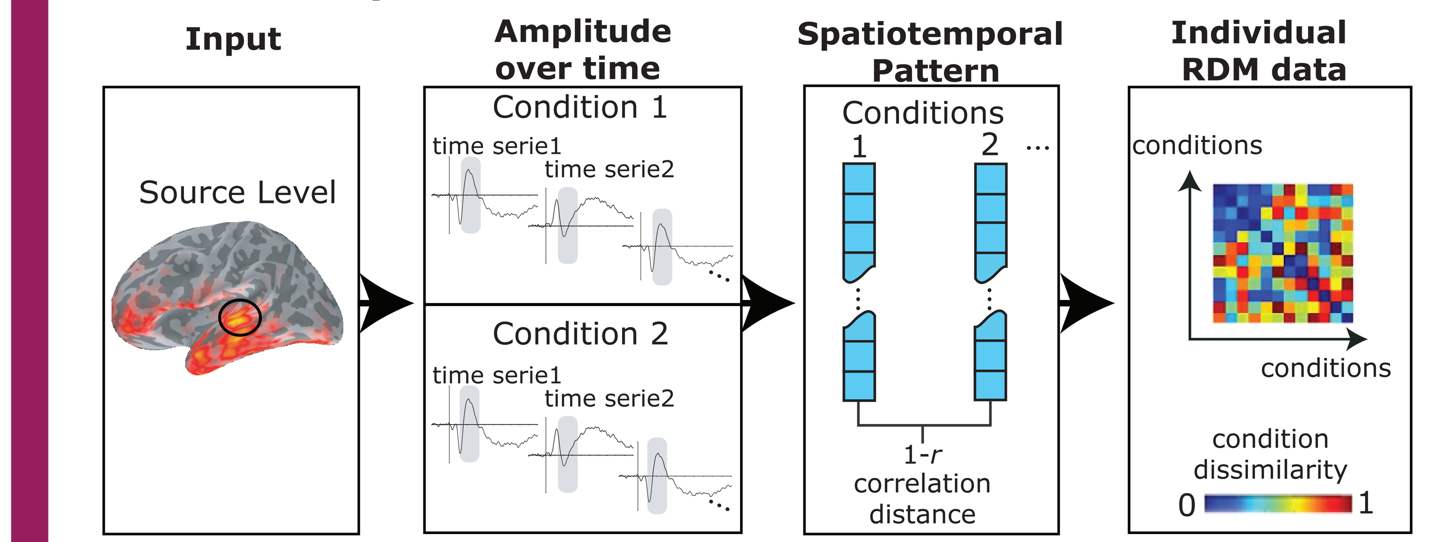


Alignment point

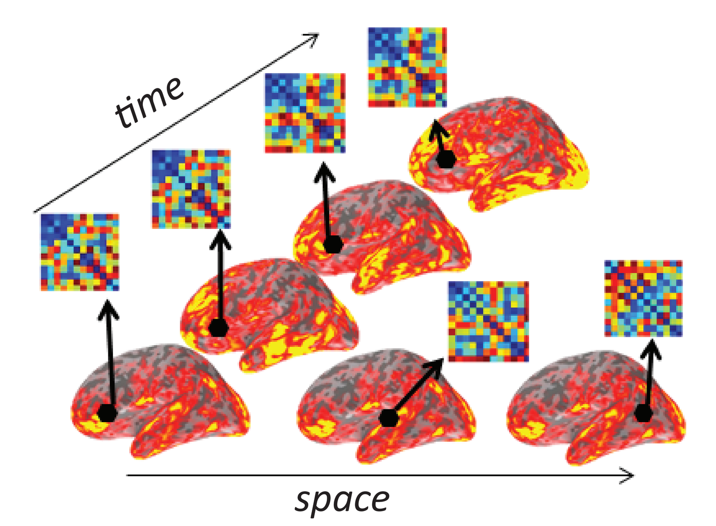
MEG/EEG time-series are aligned to the point reflecting the occurence of the suffix (onset closure), or to the end of the acoustic signal for the non-inflected items. Epochs were analysed between -200 and +200ms.

Representational Similarity Analysis

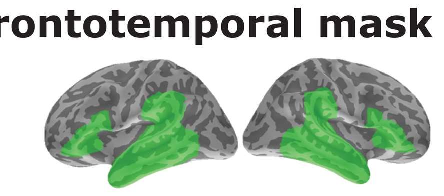
First Level Analysis: Construct the Representational Dissimilarity Matrix (RDM data)



Searchlight RSA: Space and time Representational Dissimilarity Matrix (RDM data) [8]

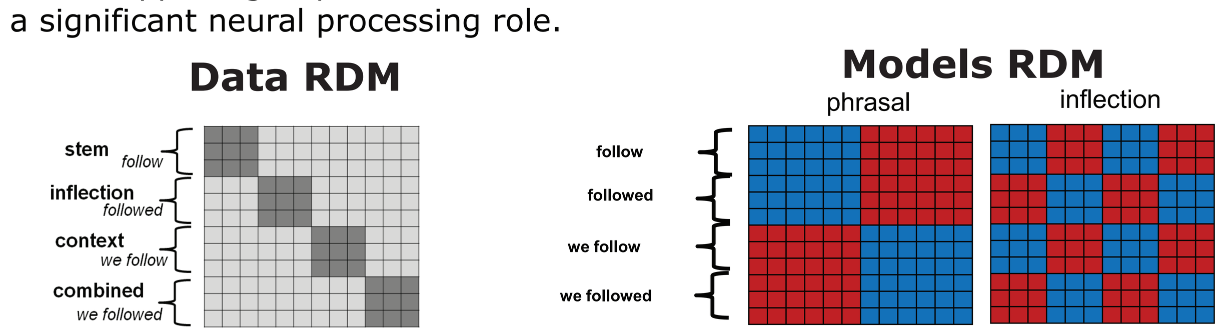


Frontotemporal mask



Options searchlight: radius - 20 mm; window width - 50ms; time step - 10 ms Source data of items of each word type for each participant averaged and treated as one condition: 3 verb types x 4 conditions = 12 cells in total

Second Level Analysis: Compares the brain-based RDM to contrasting functional models and applies group statistics. Each model tests whether the relevant dimension plays a significant neural processing role.

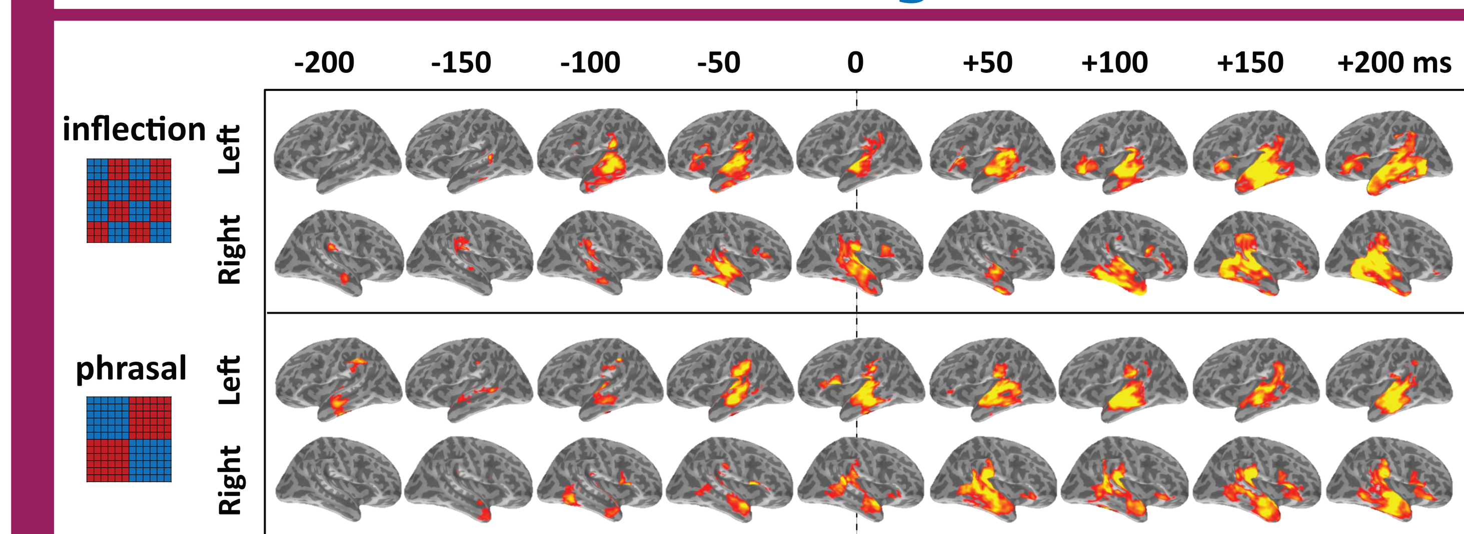


Inflection model: tests for effects of the inflectional morpheme.
Phrasal model: tests for effects of the phrasal marker.
Blue squares indicate that activation patterns correlate due to a shared property.

Group Statistics: Random effect based on nonparametric methods with permutation and cluster level statistics. This controls for multiple comparisons.

From the searchlight we extracted t-values averaged over specific regions of interest for comparing the 2 models, and r values to run more specific comparisons.

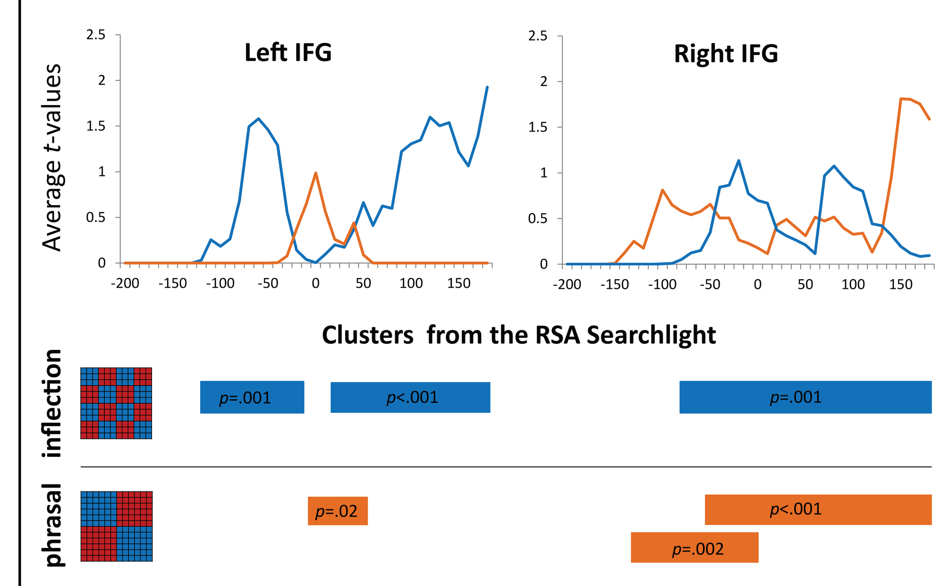
Results: RSA Searchlight - model fit



The results show that inflectional and phrasal computations engage overlapping, yet distinct processing mechanisms. Both combinations activate bilateral and anterior temporal areas with a similar time course, but differ within the Inferior Frontal Gyrus area (IFG). We focus on differences within the IFG (defined as BA44, BA45, BA47 and frontal operculum).

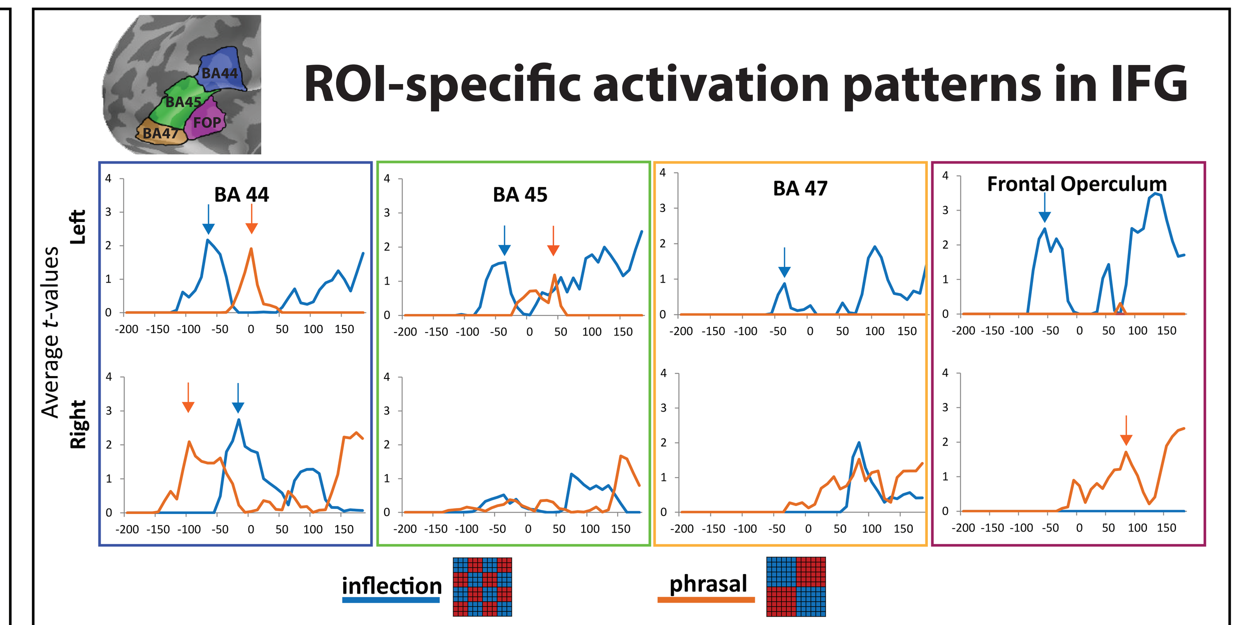
Results: Model fit in IFG

Hemispheric differences within the IFG



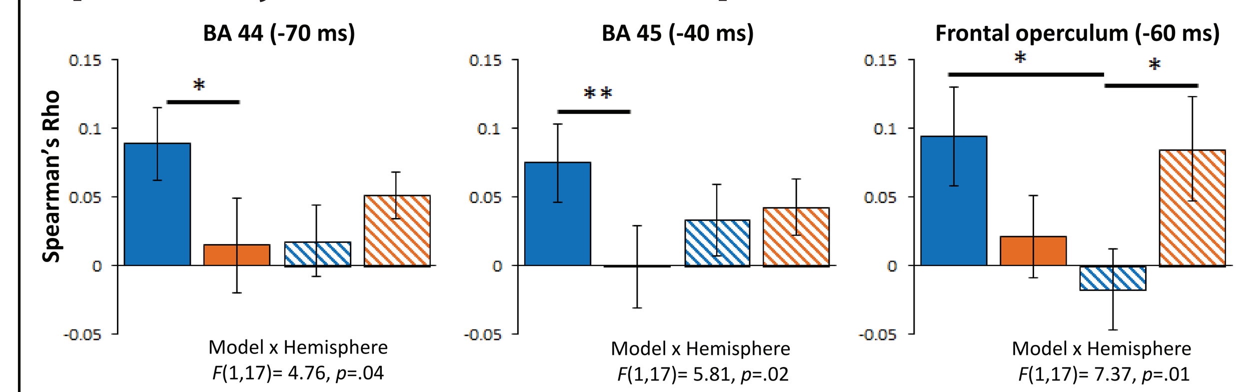
The presence of an inflection marker engages left and right IFG before onset closure, with the strongest and earliest effects in LIFG. The phrasal marker shows early effects in RIFG and much weaker and later effects in LIFG.

ROI-specific activation patterns in IFG



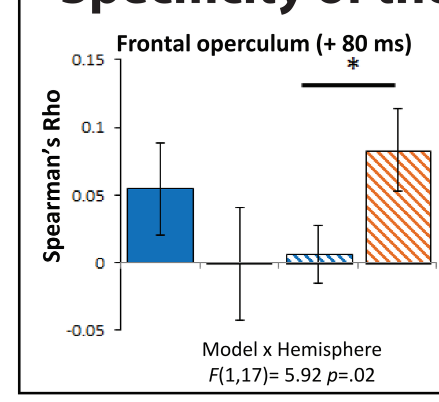
Inflectionally specific processing is seen before and after onset closure in all left IFG sites and before onset closure only in right BA44. Before onset closure, inflectionally specific processing peaks at -70 ms in left BA44; -60 ms in left Frontal Operculum and -40 ms in left BA45.
Phrasal model fit is seen late in left BA44 and BA45 and early in right BA44, with late effects in all right IFG sites. Before onset closure, activity is seen in right BA44 at -100 ms.

Specificity of the inflectional pattern within the LIFG

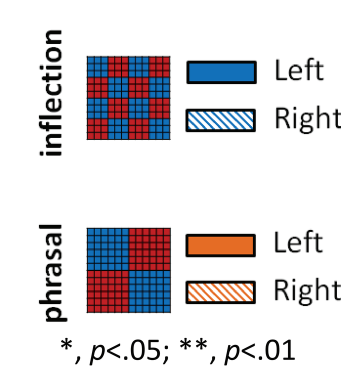


RSA results show inflectionally specific effects at early time points in left BA44, frontal operculum and BA45. All these sites are related to morpho-phonological processing. No significant differences between models were seen in BA47.

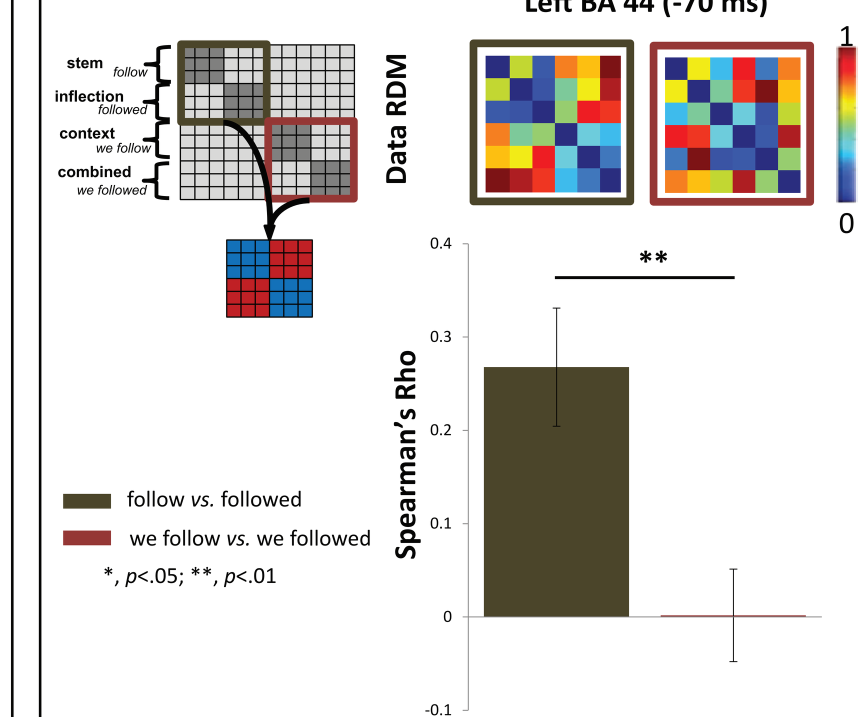
Specificity of the phrasal pattern within the RIFG



The phrasal model shows specific early and late effects in right frontal operculum. No significant differences between models in right BA44.



Interaction of inflection with phrasal markers



Early activity in left BA44 is mainly due to the presence of an inflection in words in isolation (follow/followed), while the activity in BA45 and frontal operculum is driven by the presence of an inflection in both contexts.

Discussion

Both type of grammatical computations engage distributed activation in bilateral temporal areas with evidence of earlier activation in the left compared to the right hemisphere.

Within the IFG, both types of computation activate specific patterns:

- Inflectionally complex words elicit early activation pattern in left BA44, suggesting sensitivity to phonological cues indicating an upcoming suffix. Later this activation pattern is also seen in left BA45 and frontal operculum, as well as in right BA44.
- Minimal phrases engage frontal operculum on the right at early and late time points, suggesting the engagement of ventral IFG in the computation of local grammatical structure.
- Early left BA44 activity for inflectionally complex words is mainly due to words in isolation whereas the activation pattern in BA45 and frontal operculum is elicited by both types of sequence (single words and minimal phrases).

In conclusion, our results reveal the dynamic interaction of temporal and frontal activity during spoken language comprehension and confirm the role of the left-lateralised frontal temporal system in supporting inflectional grammatical computations.

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References

[1] Marslen-Wilson & Tyler (2007) *Philos Trans R Soc Lond B Biol Sci.* 362(1481):823-836.
[2] Hickock & Poeppel (2007) *Nat Rev Neurosci.* 8(5):393-402
[3] Friederici (2011) *Physiological Review.* 91(4):1357-1392
[4] Kriegeskorte, *et al.* (2008) *Front. Syst. Neurosci.* (4). doi:10.3389/neuro.3306.3004.2008.
[5] Tyler, *et al.* (2008) *Journal of Cog. Neurosci.* 20(8):1381-1389.
[6] Hämäläinen & Ilmoniemi (1994) *Med. and Bio. Eng. and Comp.* 32(1):35-42.
[7] Friederici, *et al.* (2006) *PNAS.* 103(7):2458-2463.
[8] Su, *et al.* (2012) *PRNI 2012.* http://dx.doi.org/10.1109/PRNI.2012.26