Inferring the structure of underlying neurocognitive systems: MEG, morphology, and visual word recognition.

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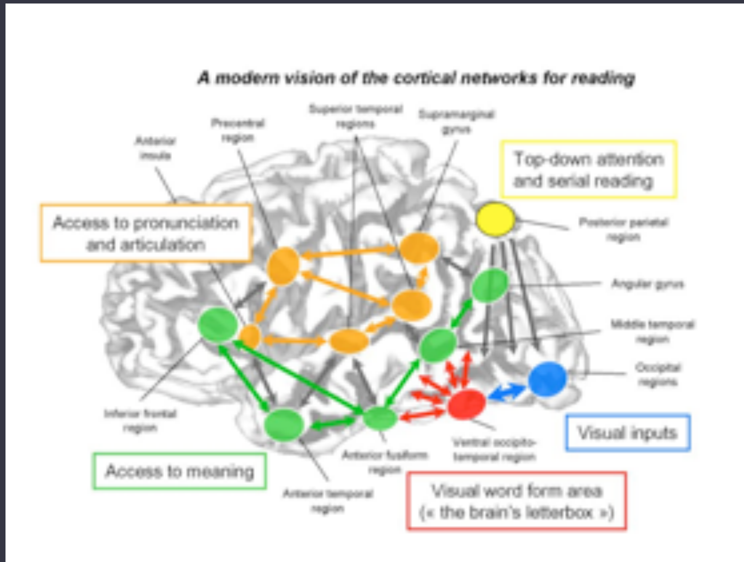
‘Nothing in biology makes sense except in the light of evolution’

Theodore Dobzhansky, 1973

- Goal of research in the cognitive neurosciences

- To infer the properties of the underlying neurocognitive systems that support key cognitive functions

- Focus here on visual word recognition.



Visual word-recognition

- The processes that map from orthographic inputs onto stored representations of lexical form and meaning
- The core neuro-biological engine driving the reading process
- In the adult, highly skilled reader of an alphabetic script (English)

- For these dynamic real-time processes need to know:
  - ***what*** neurocognitive processes are active
  - ***where*** in the brain
  - and ***when*** they are active
- MEG (+ MRI-constrained source localisation) comes closest to providing this

- Relatively simple MEG experiment*

- To answer the unresolved Q of what is the ***functional architecture*** of the visual word recognition system

    - Under what description are the outputs of orthographic analysis mapped onto lexical-level representations?

    - What is the balance between feedforward and feedback processes in the processing relationship between orthographic and lexical analysis?

- Strong clues from the behavioural domain (masked priming)

* Whiting, Shtyrov & Marslen-Wilson*, under review*

Masked priming

- Behavioural evidence for a ‘morpho-orthographic’ answer to these questions

- *corner/corn* and *hunter/hunt* but not *scandal/scan*

  - Early analysis of orthographic input into sub-lexical ‘morphemic’ units

  - Projection onto lexical level is primarily feedforward, blind to lexical constraints

- Remains in dispute behaviourally and neurally

Goal of experiment:

To define the dynamic roles of morphological, lexical, and semantic variables in the neurocognitive mapping between orthographic processing and lexical representation and interpretation

A. Define spatiotemporal coordinates of these two end points

1. Locate processes sensitive to ***orthographic structure*** but not lexical properties

- Contrast simple words (*corn*) and pseudowords (*frum*) with consonant strings (*wvkp*)

2. Locate emergence of ***lexicality*** effects - dependent on lexical access

- Contrast simple words (*corn*) and pseudowords (*frum*)

B. Properties and timing of mapping processes linking orthographic analysis to lexical representation

1. Locate processes sensitive to *morphological structure*

2. Determine role of *lexical constraints* in orthographic analysis and analysis of morphological structure

- Co-vary presence/absence of a *stem* and a *suffix* with the *lexical status* of the whole form

- Cover both *derivational* and *inflectional* morphology (representationally and decompositionally quite different)

	Condition	Full form	Stem/Affix	Sem Rel	Stem form
Derived	Transparent	*farmer*	+S +A	+ Sem	*farm*
	Pseudo-affix	*blemish*	-S +A	n/a	*blem*
Non-affixed	Pseudo-stem	*scandal*	+S -A	- Sem	*scan*
	No stem no affix	*biscuit*	-S -A	n/a	*bisc*

	Condition	Full form	Stem/Affix	Sem Rel	Stem form
Derived	Transparent	*farmer*	+S +A	+ Sem	*farm*
	Pseudo-affix	*blemish*	-S +A	n/a	*blem*
Inflected	Transparent	*blinked*	+S +A	+ Sem	*blink*
Non-affixed	Pseudo-stem	*scandal*	+S -A	- Sem	*scan*
	No stem no affix	*biscuit*	-S -A	n/a	*bisc*
Pseudoword	Derived	*frumish*	-S +A	n/a	*frum*
	Inflected	*bected*	-S +A	n/a	*bect*

	Condition	Full form	Stem/Affix	Sem Rel	Stem form
Derived	Transparent	*farmer*	+S +A	+ Sem	*farm*
	Pseudo-derived	*corner*	+S +A	- Sem	*corn*
	Pseudo-affix	*blemish*	-S +A	n/a	*blem*
Inflected	Transparent	*blinked*	+S +A	+ Sem	*blink*
	Pseudo-inflected	*ashed*	+S +A	(- Sem)	*ash*
Non-affixed	Pseudo-stem	*scandal*	+S -A	- Sem	*scan*
	No stem no affix	*biscuit*	-S -A	n/a	*bisc*
Pseudoword	Derived	*frumish*	-S +A	n/a	*frum*
	Inflected	*bected*	-S +A	n/a	*bect*

50 items in each condition; fully psycholinguistically matched

Separate masked priming study on same stimulus sets

(40 words per condition, 40 ms SOA, 29 participants)

- Significant priming only for the +S +A conditions (*farmer, corner, blinked, ashed*); none for *scandal*

- Behaviorally, presence of both a potential real stem and a potential grammatical affix is required to trigger decompositional analysis of potential complex forms

- Confirms that these stimuli elicit morphologically driven decomposition that is not blocked by lexical-level criteria

- How do these play out in neural space and time?

MEG study

- 1060 test stimuli (all full forms and stems; 160 consonant strings: total including dummy items 1120

- Pseudo-randomly assigned to 10 test-blocks (each 106 items); order of blocks alternated for participants (n = 16)

- Full-form and stem average of 559 trials apart

- Trial sequence: 500 ms fixation cross, 100 ms stimulus, 1400-1600 ms jittered blank screen

- ‘Attentive’ viewing during each block; recognition memory task at end of each block - Yes/No response to set of old/new items.

- Instructed to read attentively and not to attempt to memorise items

Joint sensor/source space analysis stream

Relates basic stages in visual word recognition to the processes that map between them

1. Sensor-space

- Conducted on gradiometers and magnetometers separately using SensorSPM implemented in SPM5

- F-tests by subject and condition over full spatiotemporal distribution of data

- Correction on whole-brain basis for multiple comparisons using RFT

2. Source space

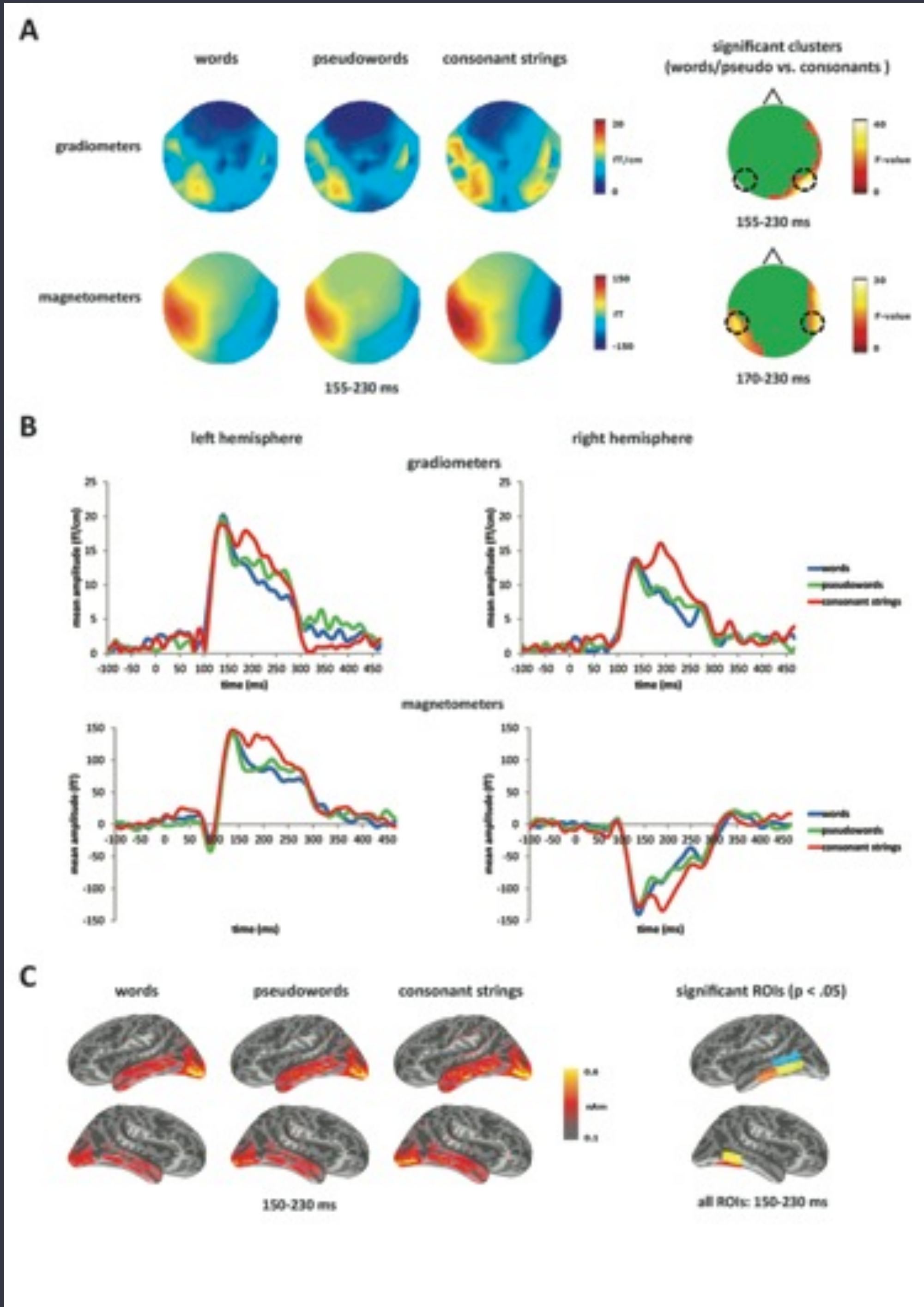
- T1-weighted structural (MRI) images used to reconstruct cortical surface for each participant

- L2 minimum norm estimation applied for source reonstruction using MNE Suite (Martinos Center)

- Data for individual subjects morphed to averaged cortical solution (10,242 dipoles per hemisphere), binned in 10 ms time steps

- Modified FreeSurfer ROIs used for repeated measures ANOVAs on subject means averaged within ROIs

- Analyses generally restricted to time windows where (corrected) significant effects found in sensor analyses

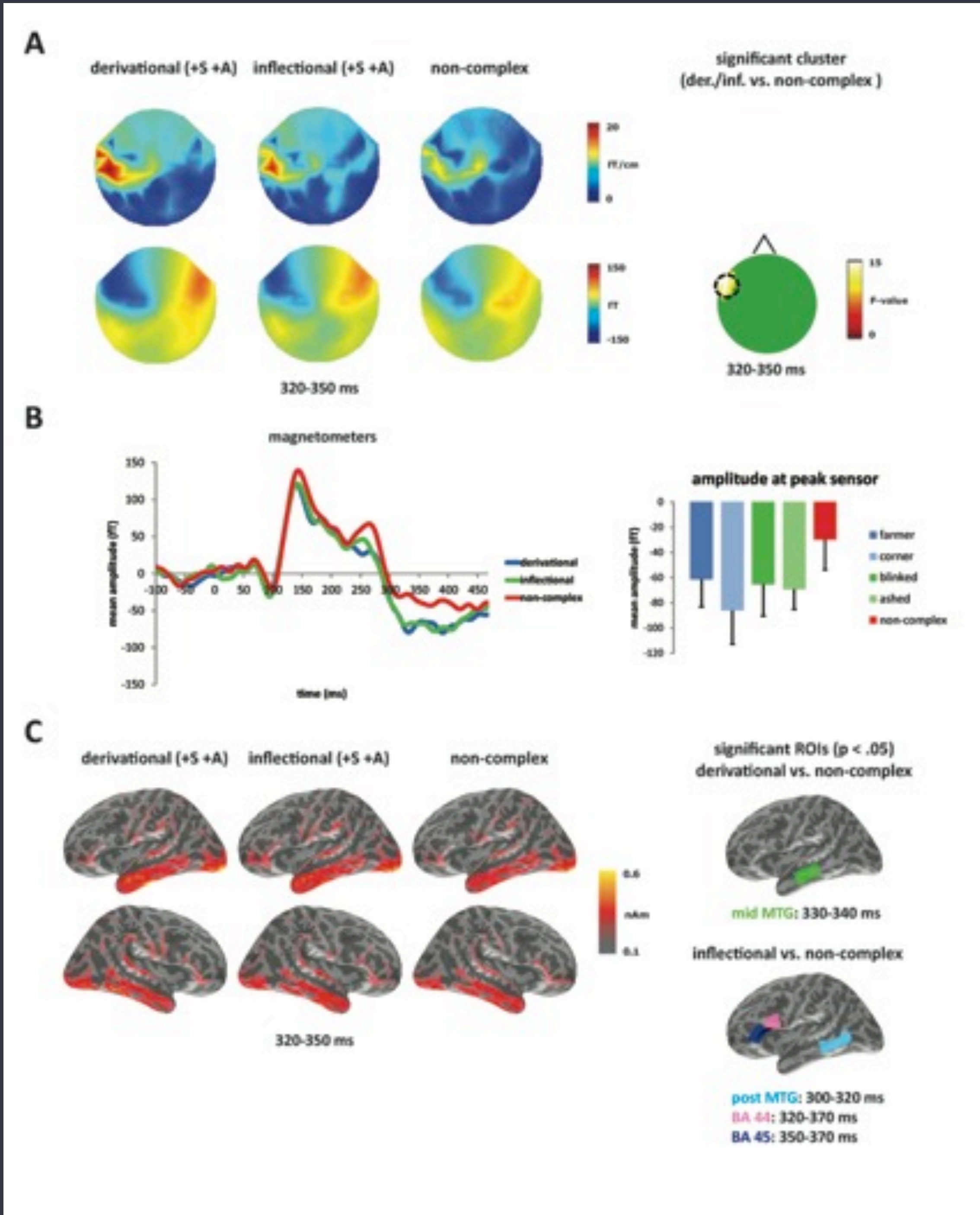


Detecting orthographic structure

100 word and pseudoword stems and matched consonant strings

Effects emerge at posterior and inferior temporal sites bilaterally in 150-230 ms time window

Increased processing for consonant strings with no differences between words and pseudowords

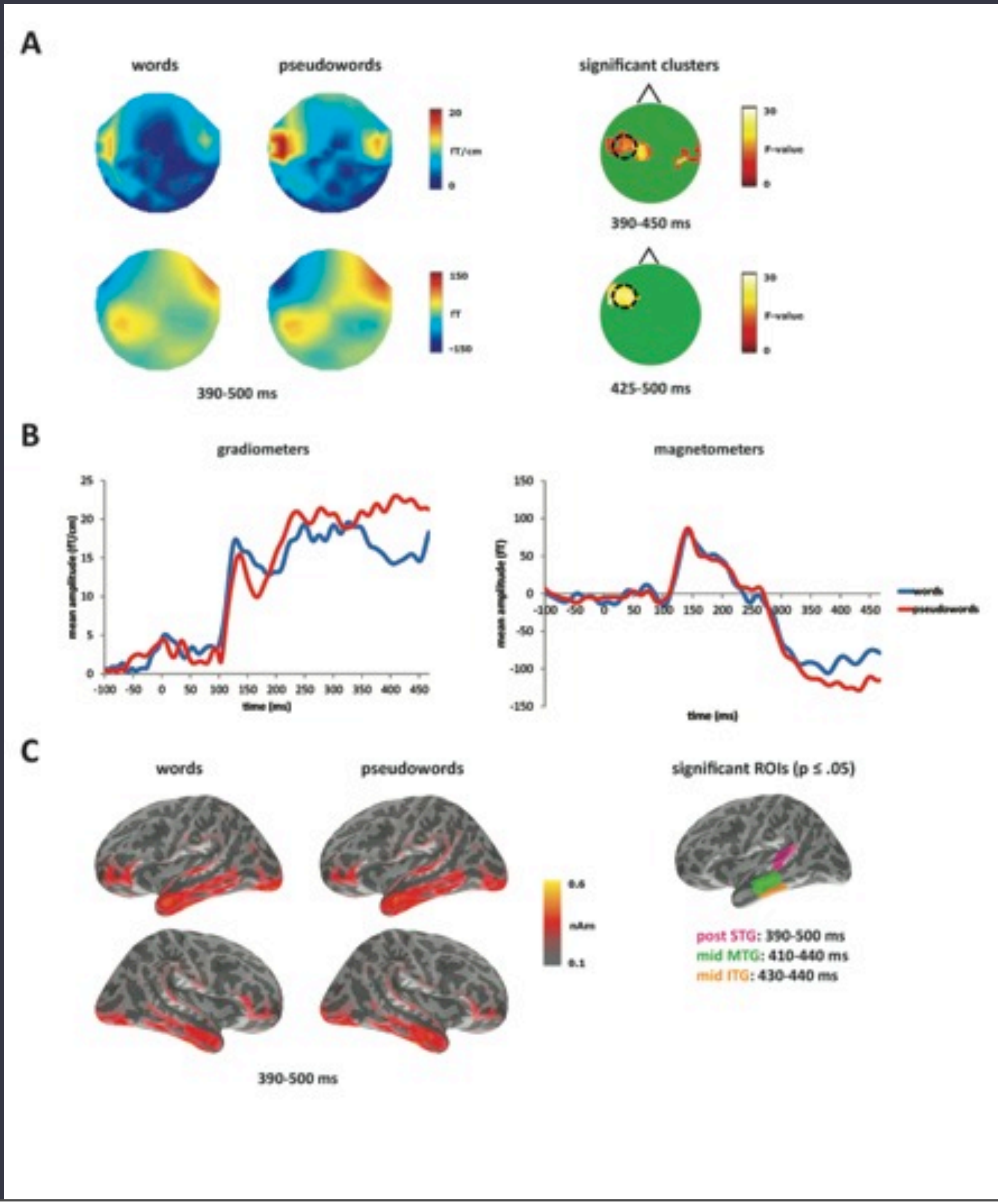


Emergence of sensitivity to *morphological structure*

Four +S +A conditions (all showing masked priming) diverge from non-complex (*scandal*, *biscuit*) sets at 320 ms in anterior LH sites

Distinctive decompositional pattern for inflected items (*blinked/ashed*)

No significant ‘lexical’ effects

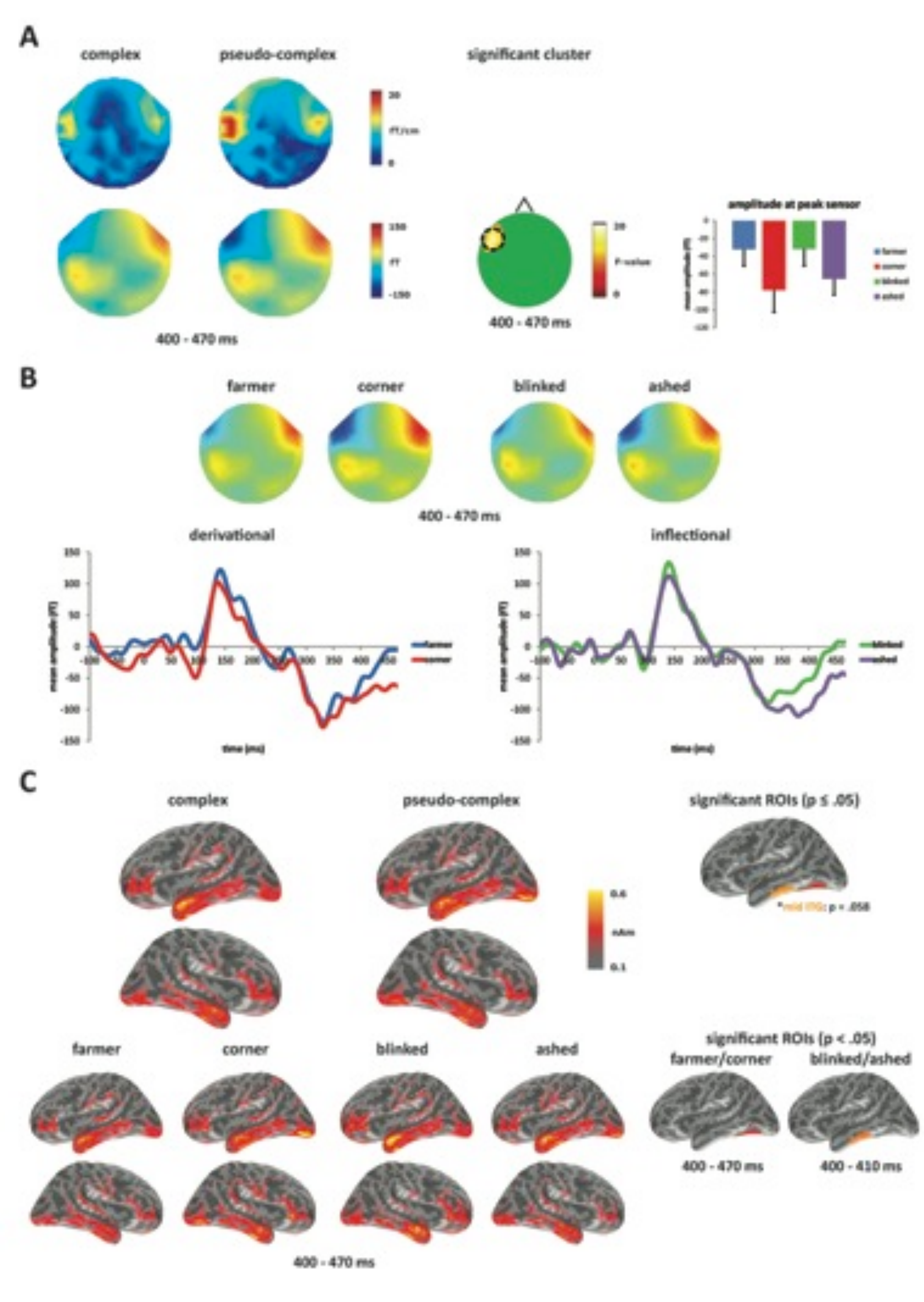


Processing lexical identity

100 word & pseudoword stems

Significant effects of lexicality emerge from 390 msec at left temporal sites

(comparable effects for complex words and pseudowords [*frumish* vs *farmer*]: 425-465 ms in L temporal sensors)



Lexical effects for morphologically complex words

Breaking down +S +A sets according to lexical status (*farmer* vs. *corner*, *blinked* vs *ashed*)

Significant effects from 400 ms; peak sensor at 450 ms

Possible posterior LH recurrent effects (L post fusiform increase for *corner* condition)

- Results unify functional characteristics of *real-time neural analysis* with functional properties of visual word recognition as reflected in *behavioural* data

- Reveals the functional architecture of the underlying neurobiological system that generates these properties

- Special role of spatio-temporal constraints provided (uniquely) by MEG

    - *When* different processes begin and end

    - *Where* they take place

Functional architecture

- Morphemically driven lexical access
- A two-phase process
- Primarily feed-forward

(Highly tuned subsystem of ventral object-processing stream)

1. Morphemically driven lexical access

- Neural patterning (320-370 ms) for +S+A sets is morpho-orthographic in nature

- Complex and pseudo-complex sets pattern together

- Process is both blind to lexical constraints and morphologically compositional

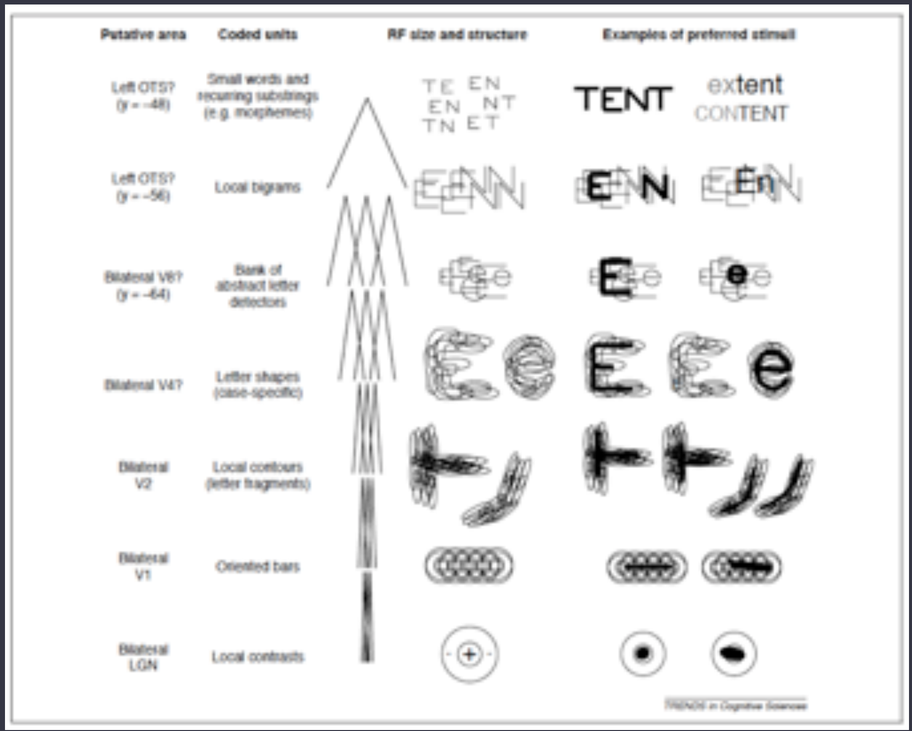
  - *ashed* cannot be stored: must be compositionally constructed
  - *corner* is lexically a simple form: must be compositionally reconstructed as *corn* + *er*

- These phenomena require the output of orthographical analysis to be morphemically decomposed

- Sensitivity of process to morphemic status of both elements of potential complex form

  - Only +S+A pseudocomplex forms behave like real complex forms

- Broadly consistent with (e.g.) Dehaene et al proposals (TICS 2005)



2. Visual word-recognition as a two-phase process

- Does the evidence for a morphemically driven morpho-orthographic process point to a separate specifically morphological processing stage?

- Spatio-temporal distribution of effects points instead to two intersecting phases

- Clear separation in neural space and time between:

  - Orthographically centered analyses

  - Analyses sensitive to morphological structure and lexical variables (largely common with regions activated in ***lexical access from speech***)

- No evidence that processes involving morphological structure and lexical variables are spatially distinct
  - Considerable overlap in core middle temporal locations
- Morphological structure effects emerging as an interaction between orthographic outputs and properties of lexical representation and analysis
  - Processes with a time-course
- Will reflect differences between and within languages in the specific properties of morpho-lexical representations
  - Inflectional/derivational contrasts in English

3. Feedforward processing and recurrence

- Processing relationship between orthographic analyses and broader lexical and contextual context

- ***No evidence*** that lexical constraints are *directly encoded* into the orthographic analysis process

    - Otherwise {*corn*} + {-*er*} would be disprefered and *ashed* would be blocked

- No evidence for early lexically-driven *recurrent* effects

    - Potential L fusiform recurrent effect only seen at 400 ms (contrast with fMRI)

- Potential broader predictive effects of context - not evaluated here
    - Letter-strings presented in isolation
    - Task-based effects minimized
- Substantial evidence that predictive contexts/attentional tuning can affect early stages of analysis of sensory inputs
- Likely that these are present for skilled reading
- Will serve to modulate the basic feedforward process, not to replace it

Implications for the analysis of behaviour

▸ Overt response is 'final common path' - confluence of many complex activities (including ***task*** and its effects)

▸ Distributional properties of language outputs similarly reflect the confluence of multiple variables (not just synchronic cognitive factors)

▸ Problematic to recover - just on this basis - the internal organisation of the neurobiological systems that (causally) generate these behavioural outputs

- ***Timing*** of RT relative to component processes of interest

  - Analysis is leaving orthographic system within 2-300 ms post onset

  - Lexical analysis may be effectively complete within 500 ms.

  - Slower RTs will increasingly reflect contributions of lexical mapping process - generating variability in many popular tasks (including masked priming) intended to tap into early analysis stages

Neurolex

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