

# Beyond the mental number line:

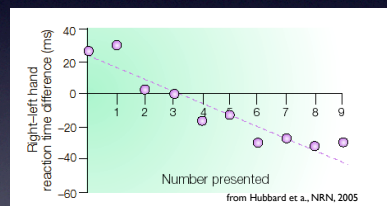
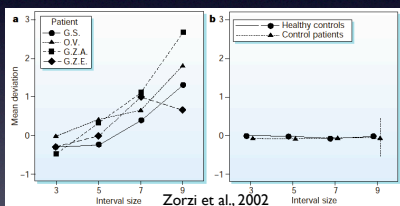
multiple links between number and space

Wim Fias  
Ghent University  
Belgium

## number-space associations reflected in

number bisection bias in neglect

SNARC effect



## the mental number line hypothesis

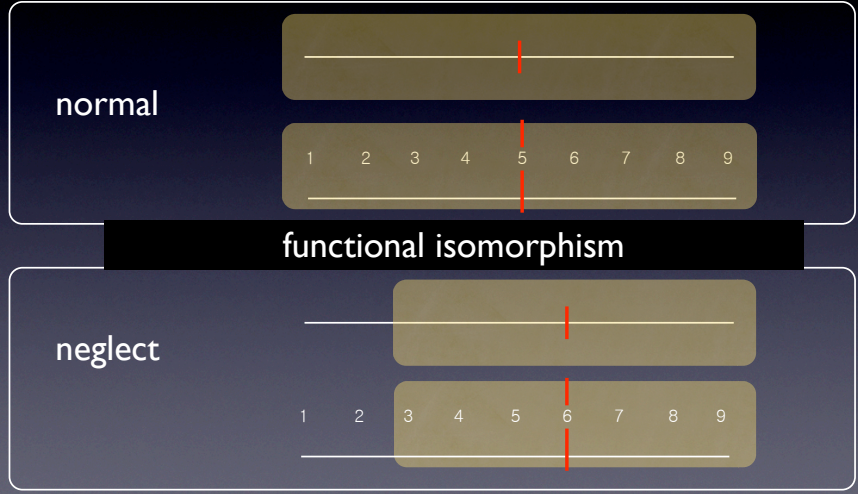
- both phenomena can be explained by a single type of spatial representation: the mental number line

Hubbard, et al., Nat Rev Neurosci (2005); Fias & Fischer (2005), de Hevia et al., NS&BBR (2008); Umiltà, et al., EBR (2009), ...

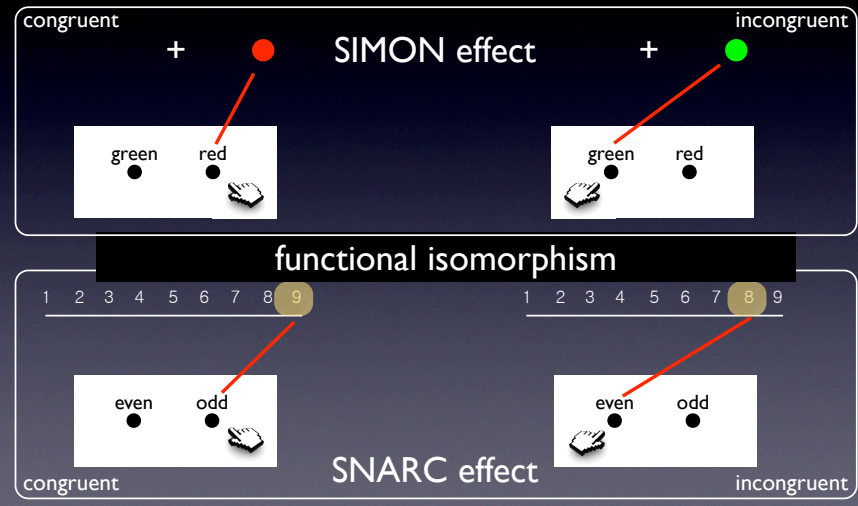
- functional isomorphism between number space and physical space

Hubbard et al., (2005); Priftis et al. (2005); Zorzi et al. (2002)

# Mental number line can explain bisection bias in neglect patients



# Mental number line can explain SNARC effect



# questioning the mental number line hypothesis

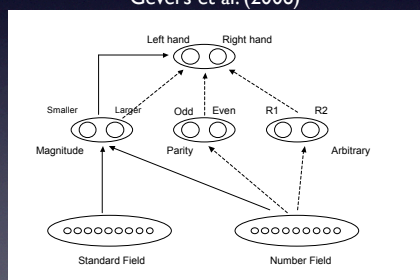
## SNARC effect: conceptual congruency

derives from congruency between conceptual verbal categories, not from congruency between a position on mental number line and left or right response

Proctor et al. (2006): polarity coding

minus	plus
left	right
small	large
young	old
cold	hot
jin	jang

Gevers et al. (2006)

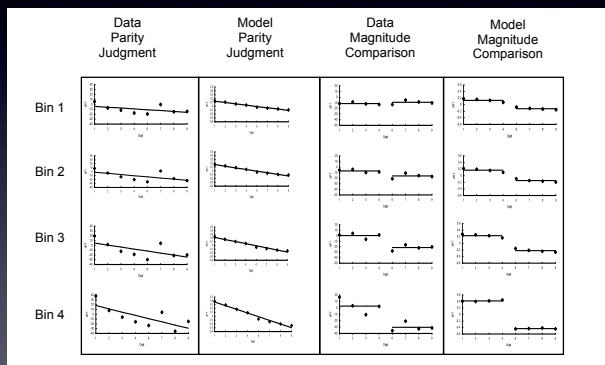


Kosslyn: categorical vs coordinate spatial processing

Paivio: verbal symbolic vs analogue to sensory experience

# evidence in favor of conceptual account

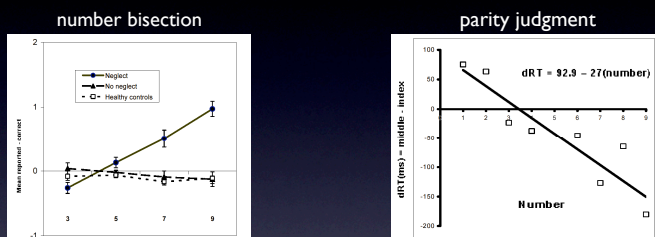
## 1. model captures the data quite well



but that's no proof of existence

# evidence in favor of conceptual account

## 2. neglect patients: number bisection bias with normal SNARC effect



conceptual nature of SNARC effect implies that it is dissociable from number bisection bias

BUT advocates of the number line hypothesis argue: not a matter of representation but of access

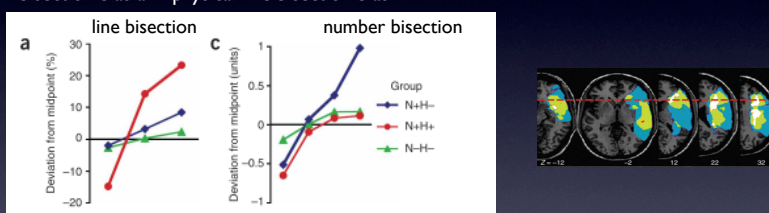
- parity judgment: access to MNL is implicit
- bisection task: access to MNL is explicit

Priftis et al., JOCN, 2005

# questioning the mental number line hypothesis

## no isomorphism between MNL and physical space

Dorrichi et al. (Nat NS, 2005): double dissociation between number line bisection bias and physical line bisection bias



only patients with r PFC lesion and reduced visuospatial working memory span show number bisection bias

but: advocates of MNL hypothesis argue:

- number bisection bias also in patients without frontal damage
- restricted role of WM in simple tasks like number comparison, yet abnormalities in performance (e.g. Veuilleumier et al., 2004)

# goal

provide additional evidence in favor of conceptual account of the SNARC effect

critically examine isomorphism

try to specify relation between SNARC effect and number bisection bias

## OVERVIEW

### PART 1:

1. behavioral exp in healthy subjs: manipulating mappings
2. fMRI study: conceptual vs physical space
3. behavioral exp in healthy subjs: loading working memory

### PART 2:

4. single case patient study
5. multiple case patient study

## study I: Manipulating mappings

### EXPERIMENT I

parity judgment

verbal responses: say left or right  
manual responses: press left or right

within subjects

Gevers et al. (in press, JEP:General)

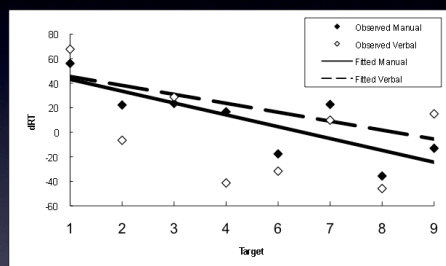
## study I: Manipulating mappings

### EXPERIMENT I

parity judgment

verbal responses: say left or right  
manual responses: press left or right

within subjects



SNARC effect is the same for verbal responses

conceptual coding of space is sufficient for the SNARC effect

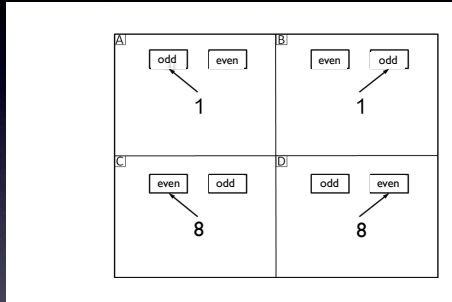
Gevers et al. (in press, JEP:General)

# study I: Manipulating mappings

## EXPERIMENT 2

reponse buttons variably labelled "odd" or "even"

no systematic conceptual coding



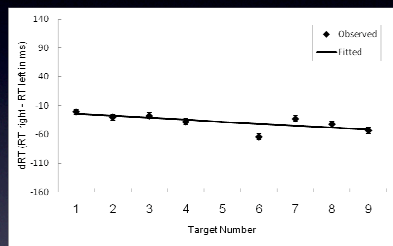
Gevers et al. (in press, JEP:General)

# study I: Manipulating mappings

## EXPERIMENT 2

reponse buttons variably labelled "odd" or "even"

no systematic conceptual coding



weak but significant SNARC effect

visuospatial coding of space is sufficient for the SNARC effect

Gevers et al. (in press, JEP:General)

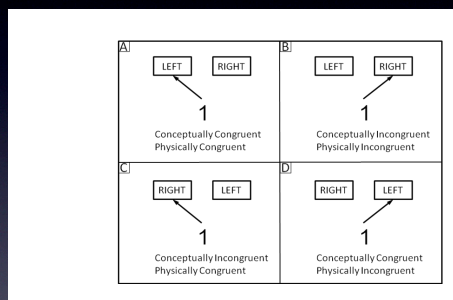
# study I: Manipulating mappings

## EXPERIMENT 3: pitting conceptual space against physical space

parity judgment

reponse buttons variably labelled "left" or "right"

task:  
if even press on button labelled "left"  
if odd press on button labelled "right"  
(or vice versa)



Does the SNARC effect follow

- position of the hand (physical congruency)

or

- position of the labels (word congruency)

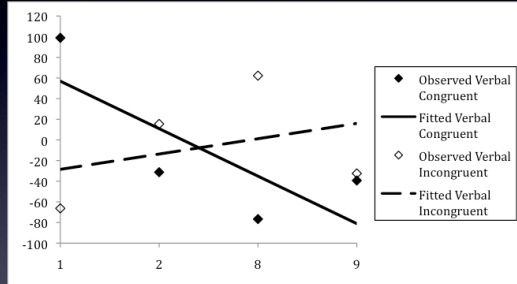
# study I: Manipulating mappings

## EXPERIMENT 3: pitting conceptual space against physical space

parity judgment

response buttons variably labelled "left" or "right"

task:  
if even press on button labelled "left"  
if odd press on button labelled "right"  
(or vice versa)



SNARC effect determined by the words, not by the position of the response button

conceptual coding dominates visuospatial coding in parity judgement

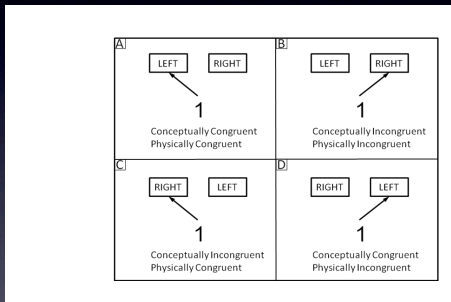
# study I: Manipulating mappings

## EXPERIMENT 4: pitting conceptual space against physical space

magnitude comparison

response buttons variably labelled "left" or "right"

task:  
if smaller than 5 press on button labelled "left"  
if larger than 5 press on button labelled "right"  
(or vice versa)



Does the SNARC effect follow  
- position of the hand (physical congruency)  
or  
- position of the labels (word congruency)

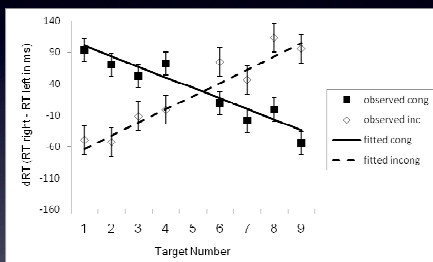
# study I: Manipulating mappings

## EXPERIMENT 4: pitting conceptual space against physical space

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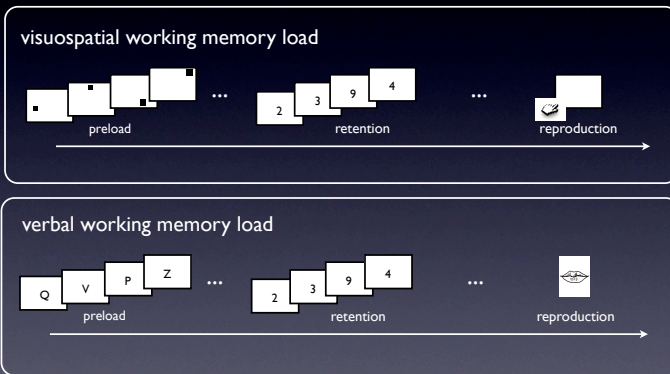
SNARC effect determined by the words, not by the position of the response button

conceptual coding dominates visuospatial coding in magnitude comparison



- processing of verbal and pictorial spatial information subserved by differently lateralized but homologous parietal areas
- future: similar lateralization for spatial aspects of number?

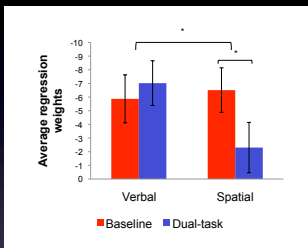
### Study 3: the role of working memory in the SNARC effect



during retention interval:  
parity judgment  
magnitude comparison

Van Dijck, Gevers, & Fias (in press, Cognition)

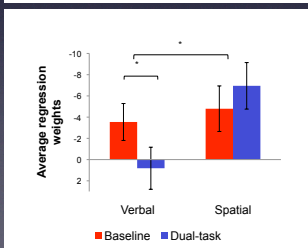
### study 1: experimental investigation of SNARC effect in parity judgment and number comparison



#### magnitude comparison:

- SNARC effect disappeared under visuospatial load
- SNARC effect preserved under verbal load

cfr. Herrera et al., Acta Psychologica, 2008



#### parity judgment:

- SNARC effect disappeared under verbal load
- SNARC effect preserved under visuospatial load



- double dissociation between task and load
- reflection of dissociation between
  - verbally mediated conceptual representation of space
    - in line with Proctor et al. (2006): SNARC effect originates from congruency between polarity of concepts (small/large; left/right)
    - in line with Gevers et al. (2006): model
    - involved in parity judgment
  - visuospatial representation of space
    - Mental number line
    - involved in magnitude comparison

## interim conclusion

the hypothesis that the mental number line is the sole link between numbers and space has been disproved

rather, there are multiple links between numbers and space:

- a link between number and spatial concepts of a verbal nature
  - dominant
- a visuospatial mental number line,
  - especially usefull in number comparison

Both are related to working memory

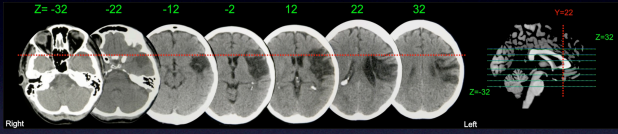
## part 2

examine the isomorphism between number space and physical space

- nature of the number bisection bias in neglect

try to specify relation between SNARC effect and number bisection bias

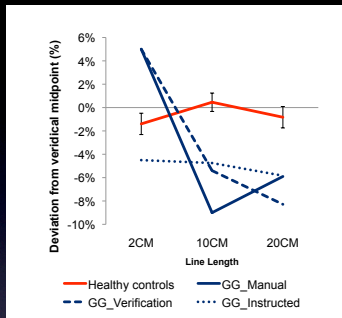
# STUDY 4: case GG



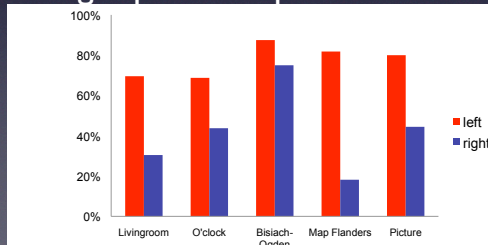
52 year old female  
 Left hemisphere damage  
 Right handed  
 Paralysed right side of the body  
 No hemianopia  
 No aphasic problems  
 No deficits in number and word processing

Van Dijck, Gevers, Lafosse, Doricchi, & Fias (in preparation)

## neglects right part of physical space

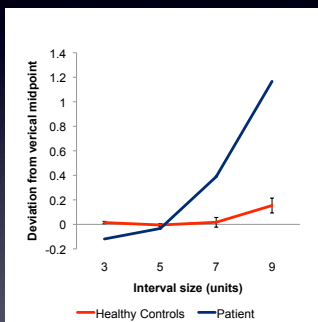


## neglects right part of representational space

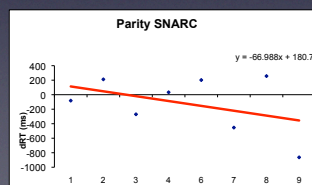


# number bisection

## neglects small numbers (left part of number line)



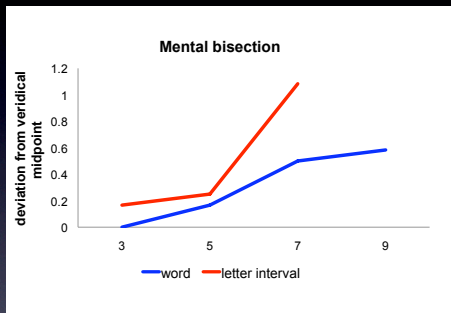
number line is not reversed:  
 normal SNARC effect



- MNL, isomorph to physical space, cannot explain this result

How to account for dissociation number bias and neglect in physical and representational space?

### bisection of non-numerical sequences: neglects left part

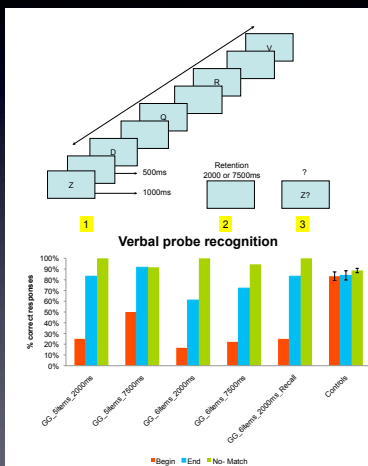


word: what is middle letter of the word?  
 letter interval bisection: which letter lies in middle between a and f?

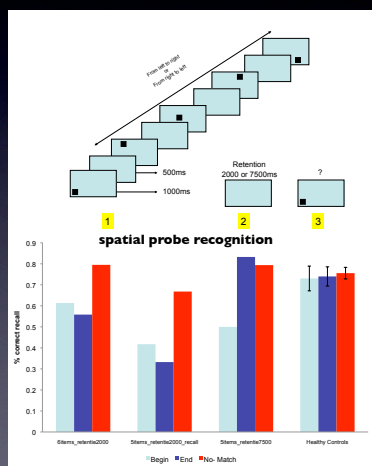
rightward bisection bias also for verbal sequences

### bias associated with positional problems in WM?

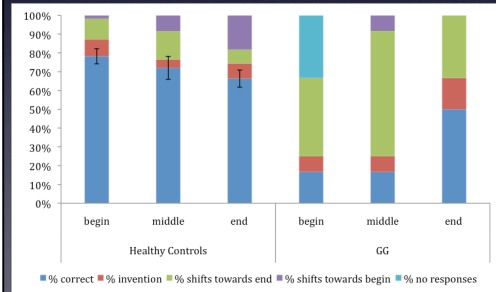
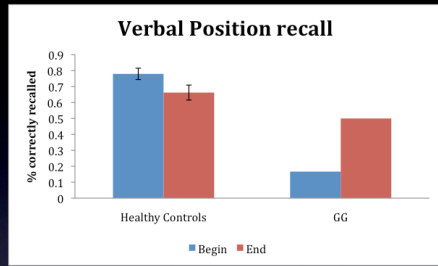
#### verbal WM



#### visuospatial WM



## verbal position recall task



nature of errors:  
shift towards the end

- number neglect dissociates from physical and representational neglect
- ➔ functional isomorphism hard to maintain
- bisection bias associated with positional deficit in verbal working memory
- further research should test positional effects in working memory
  - cfr Dorrichi: number bisection bias only in patients with reduced WM span

## study 5: patient group study

### neglect patients

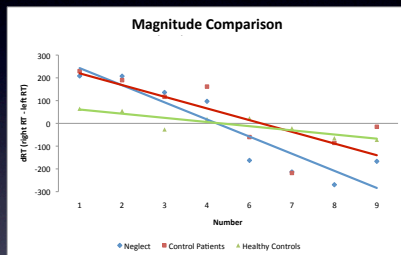
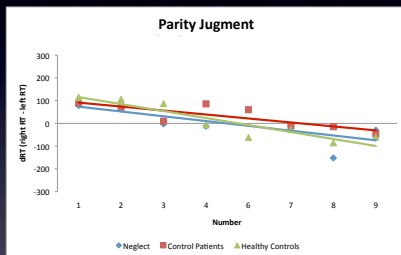
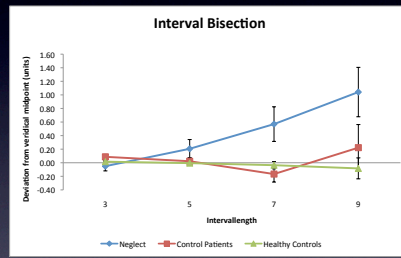
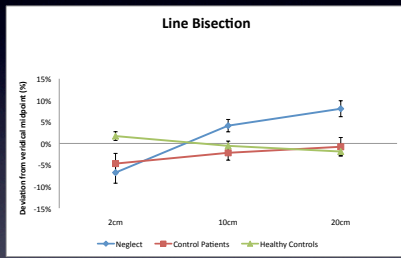
n=8  
right hemisphere damage  
right handed  
age: 70 yrs (SD = 9)

### patient control group - no neglect

n=5  
right hemisphere damage  
right handed  
age: 63 yrs (SD = 11)

### healthy control group

n=11  
neurologically intact  
age: 69 yrs (SD = 11)  
right handed



### PCA

	factor 1	factor 2	factor 3
magnitude SNARC	0.91		
parity SNARC		0.93	
line bisection bias			1
number bisection bias	0.68	-0.59	

- line and number bisection on different factors:
  - in line with single case GG and Dorrichi
- magnitude and parity snarc on different factors
  - expected from working memory load experiments
    - parity judgment: conceptual space
    - magnitude comparison: visuospatial
- number bisection loads on same on same factor as magnitude comparison (also partly on parity judgment)

# general conclusion

Number line hypothesis:

It was a good strategy to push this hypothesis to its limits and see how far we could get with it. Now its limits become clear:

The mental number line is only part of the story:

- there is a link between numbers and visuospatial processing but the isomorphism between the mental number line and physical space is questionable.

- It is constrained by visual working memory resources

- it plays primarily a role in number comparison and number bisection

Numbers are also associated to conceptual representations of space.

- it is constrained by verbal working memory resources

- These associations occur consistently in parity judgment

- can overrule the visuospatial number-space associations

# future questions

- what are the precise mechanisms? what is role of working memory?
- what is the nature of the spatial associations that underly other effects
  - prism adaptation: improvement of working memory?
  - attentional bias induced by numbers?
  - associations observed in developmental disorders (dyscalculia, non-verbal learning disorders,...)?

# Thank you!

- Jean-Philippe Van Dijck (UGent, Belgium)
- Wim Gevers (UGent, Belgium)
- Tom Verguts (UGent, Belgium)
- Fabrizio Dorricchi (la Sapienza, Rome, Italy)
- Christophe Lafosse (Hof ter Schelde, Belgium)
- Ruth Seurinck (UGent, Belgium)
- Simone Kuhn (MPI Leipzig, Germany)
- Seppe Santens (UGent, Belgium)