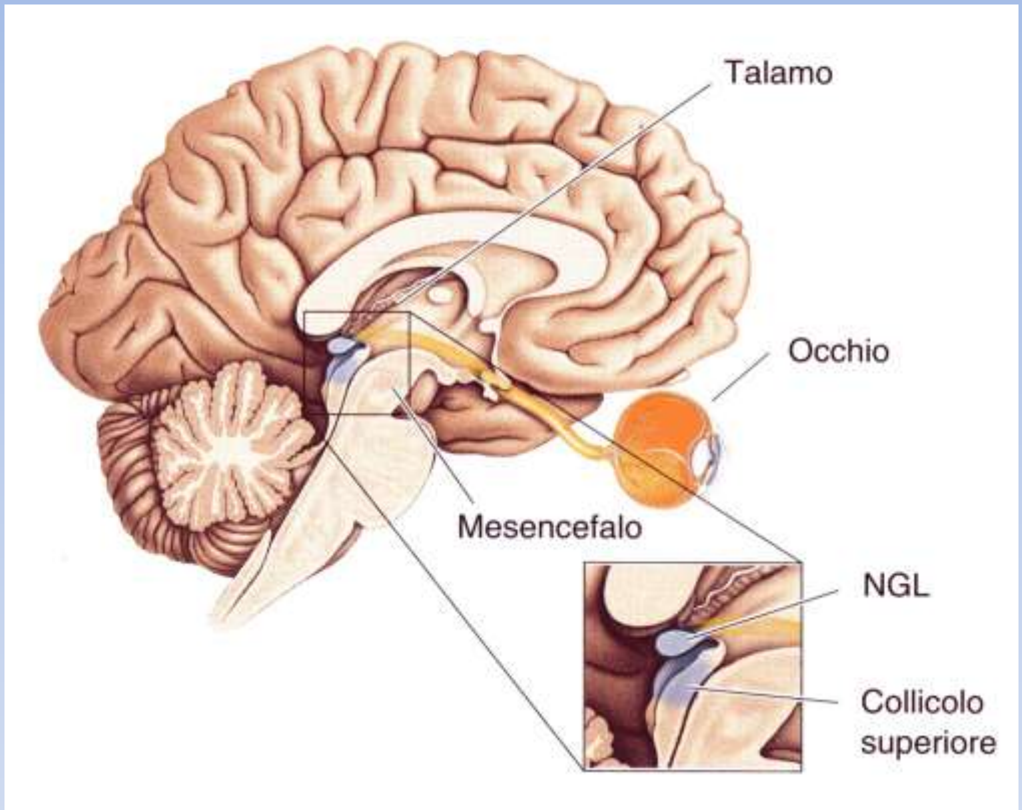
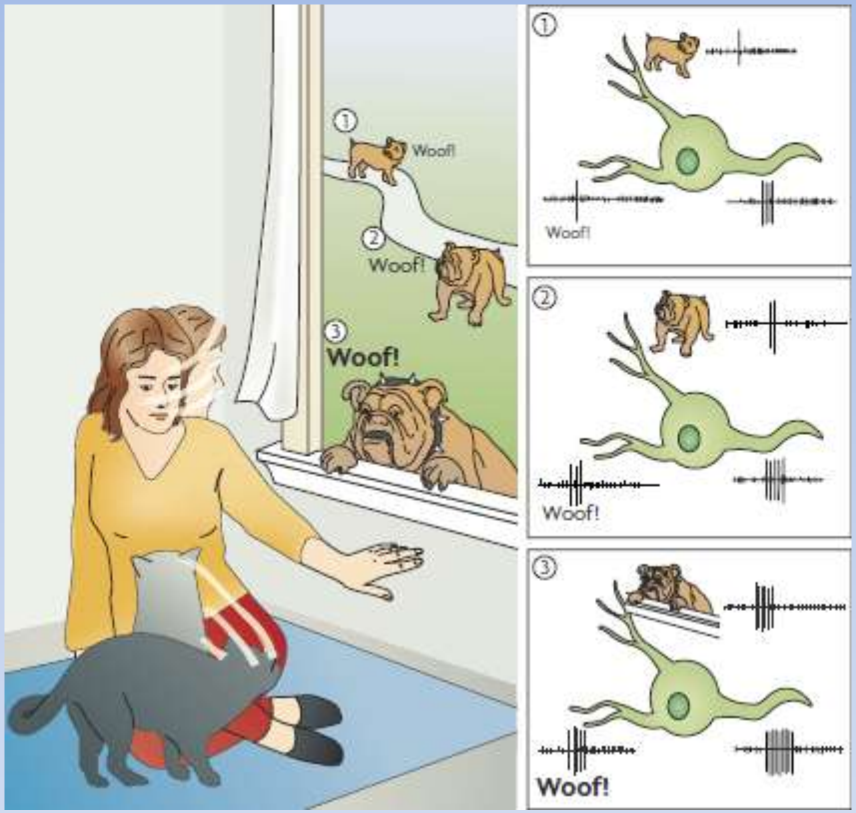
Multisensory integration (MSI)





(Stein and Stanford, 2008)

<u>Multisensory integration</u>:

- Auditory stimuli
- Visual stimuli
- Somatosensory stimuli

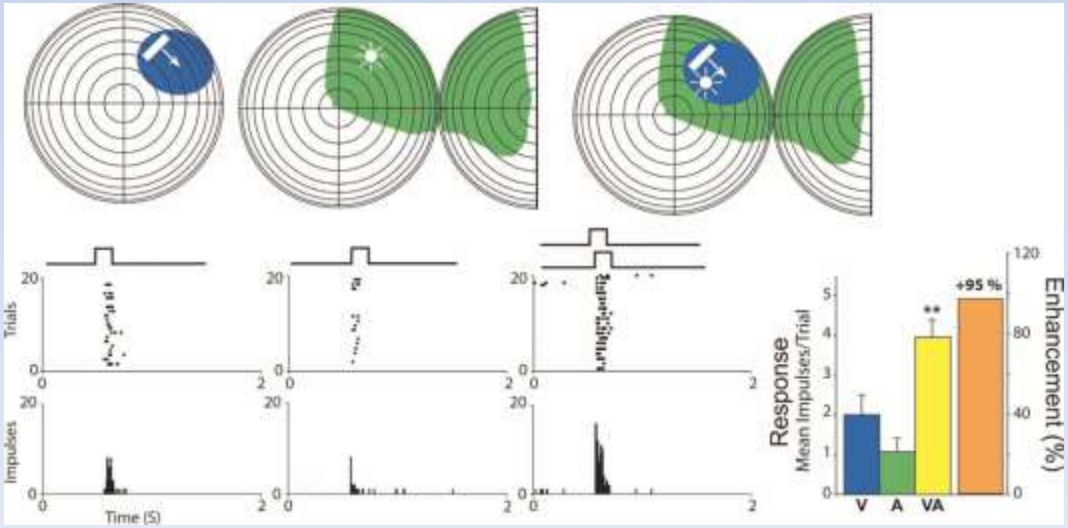
Attentive Responses and Orientation (Stein and Meredith, 1993)

Multisensory regions (Superior Colliculus)

Non-linear Behavior of SC neurons

- Multiple Receptive Fields (RFs)
- Multisensory Enhancement
- Inverse Effectiveness
- Multisensory Depression

A representative visual–auditory multisensory neuron. *Top:* Visual and auditory receptive fields are shaded in blue and green. *Bottom:* Neuronal responses for visual (blue), auditory (green), and cross-modal (yellow) conditions. To the right: Bar graphs summarizing the mean response to all three conditions with the proportional enhancement observed in the cross-modal condition represented in orange. **(Figure 1 in Stein et al., 2009)**



Multisensory regions (Superior Colliculus)

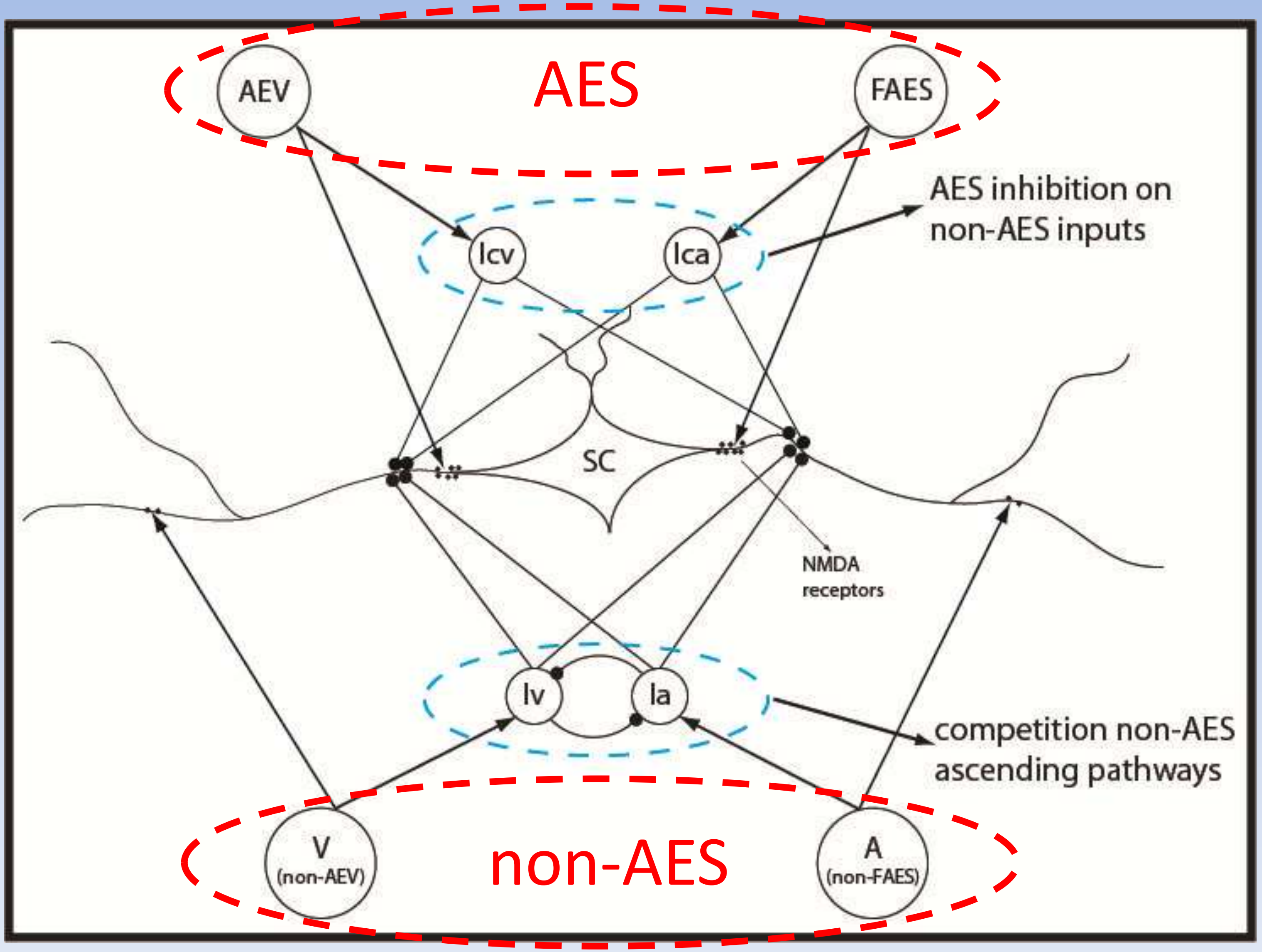
Aim of the model

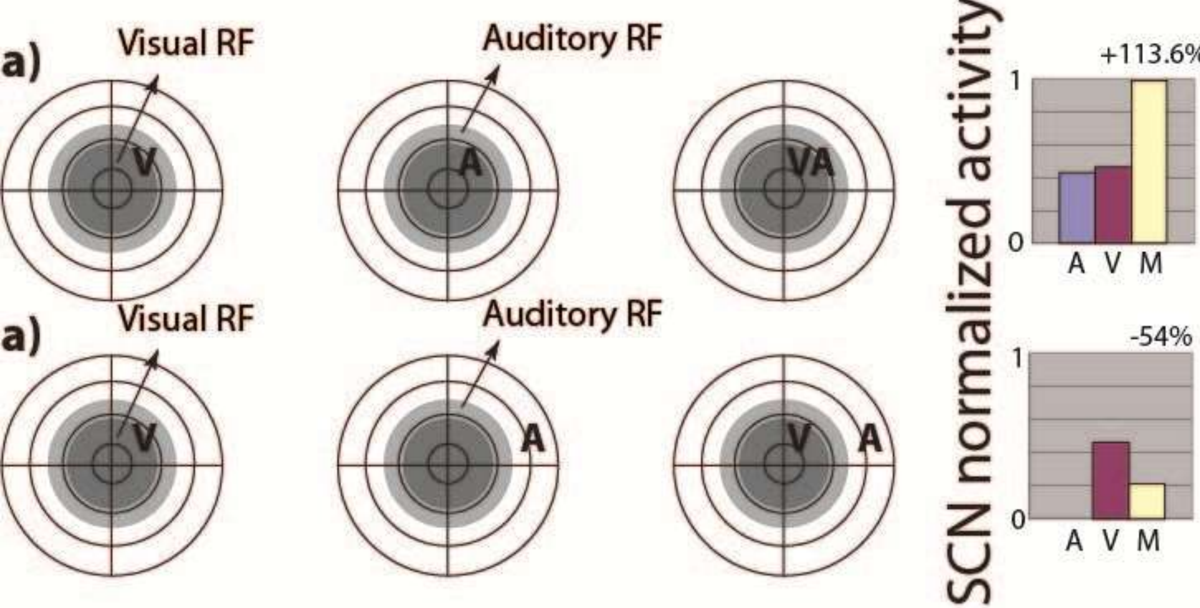
Reproduction and interpretation of SC multisensory integration

Neurobiologically plausible neural mechanisms

- Inputs Specificity
- Topological Organization
- RFs in Spatial Register
- Intra-area Inhibitory Synapses
- Competitive Mechanisms

Multisensory regions (Superior Colliculus)

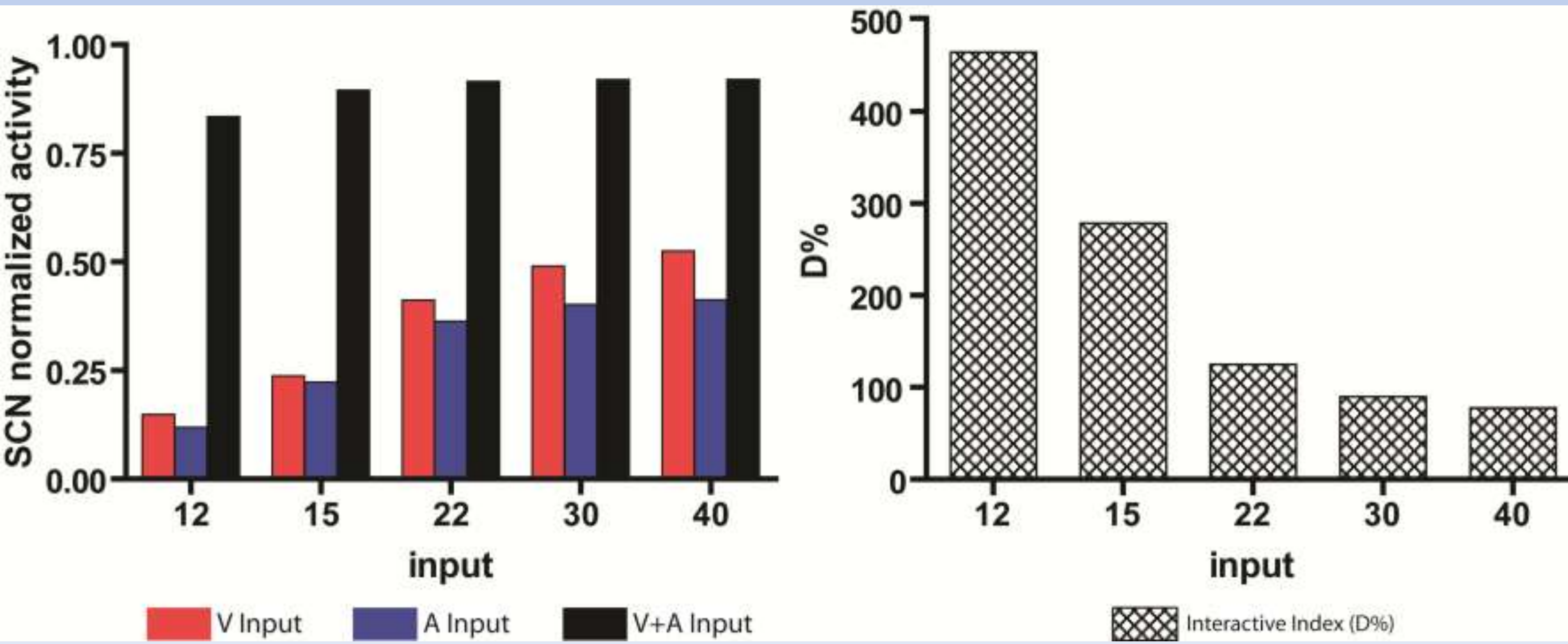




Enhancement

Depression

Inverse Effectiveness



Development of MSI abilities

- **SC multisensory integrative (MSI) capabilities not present at birth**
- **protracted period of postnatal development**

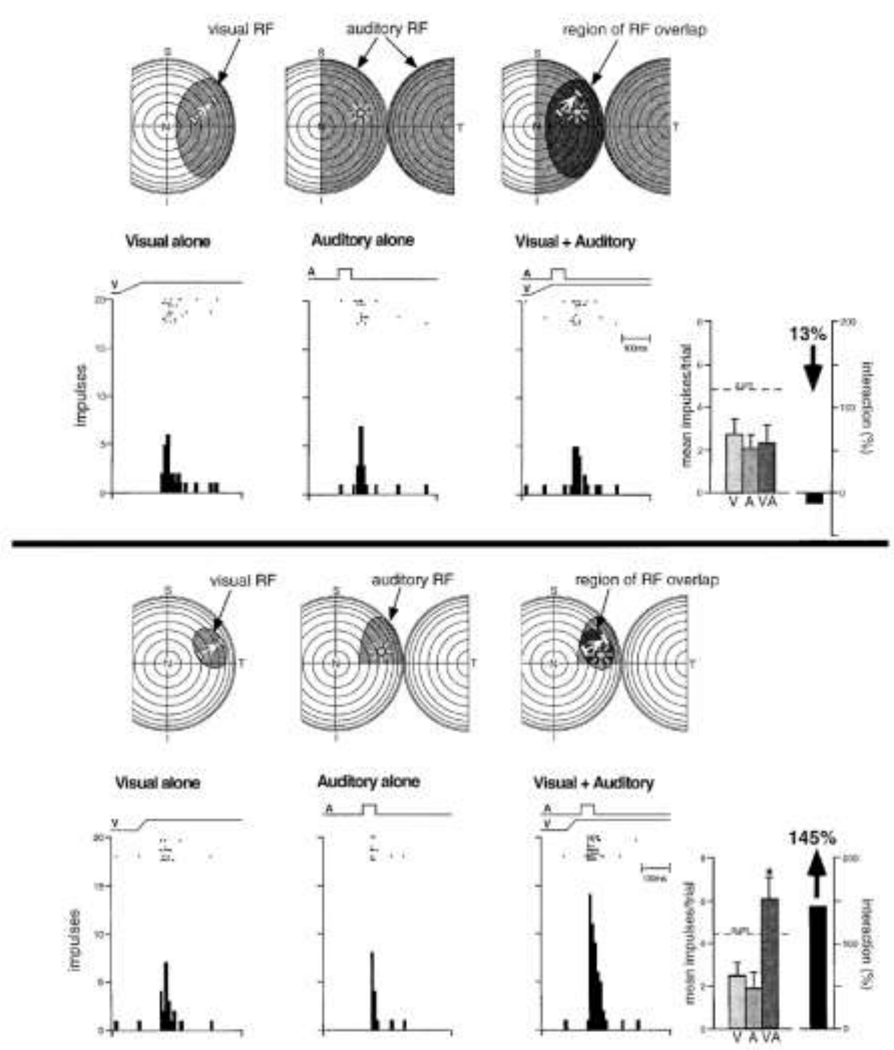


Figure 10. A mixture of multisensory neurons incapable of integrating cross-modality cues (*top*) and those that had adult-like multisensory integration (*bottom*) was evident in the same animals. Note the large receptive fields in the "nonintegrating" neuron in this 35 dpn animal, and the adult-like receptive fields in the integrating neuron. * $p < 0.05$. See Figures 4 and 6 for conventions.

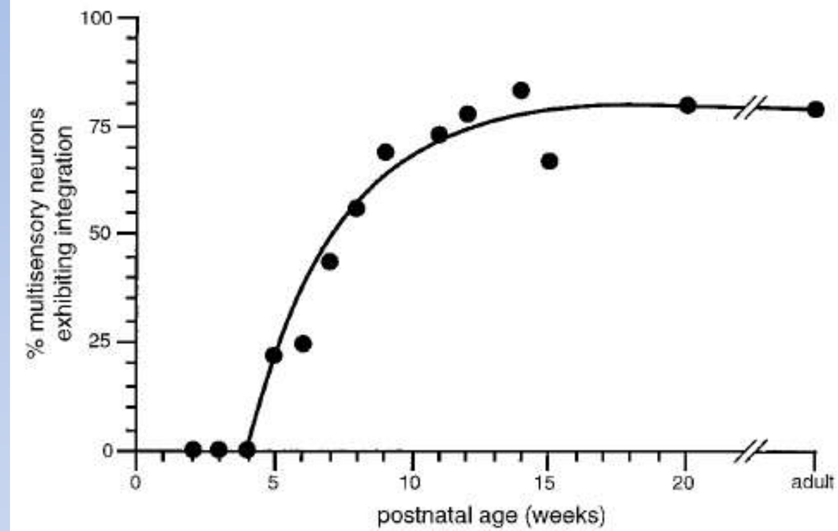


Figure 9. Once initiated, the development of multisensory neurons capable of integrating cross-modality stimuli is rapid. The percentage of the multisensory population exhibiting significant ($p < 0.05$) integration is plotted here as a function of postnatal age. Note the delayed onset of multisensory integration, followed by the rapid rise in the proportion of neurons capable of such integration beginning at 5 weeks and reaching the adult-like proportion at 9–10 weeks.

Wallace M.T. and Stein B.E. (1997)
Wallace M.T. et al. (1996)

Development of MSI abilities

- **SC multisensory integrative (MSI) capabilities not present at birth**
- **protracted period of postnatal development**

Two features are most prominent in its **maturation**:

1. Functional connections develop between association cortex (Anterior Ectosylvian Sulcus, AES) and multisensory SC neurons;
2. The circuit acquires the statistics of cross-modal events.

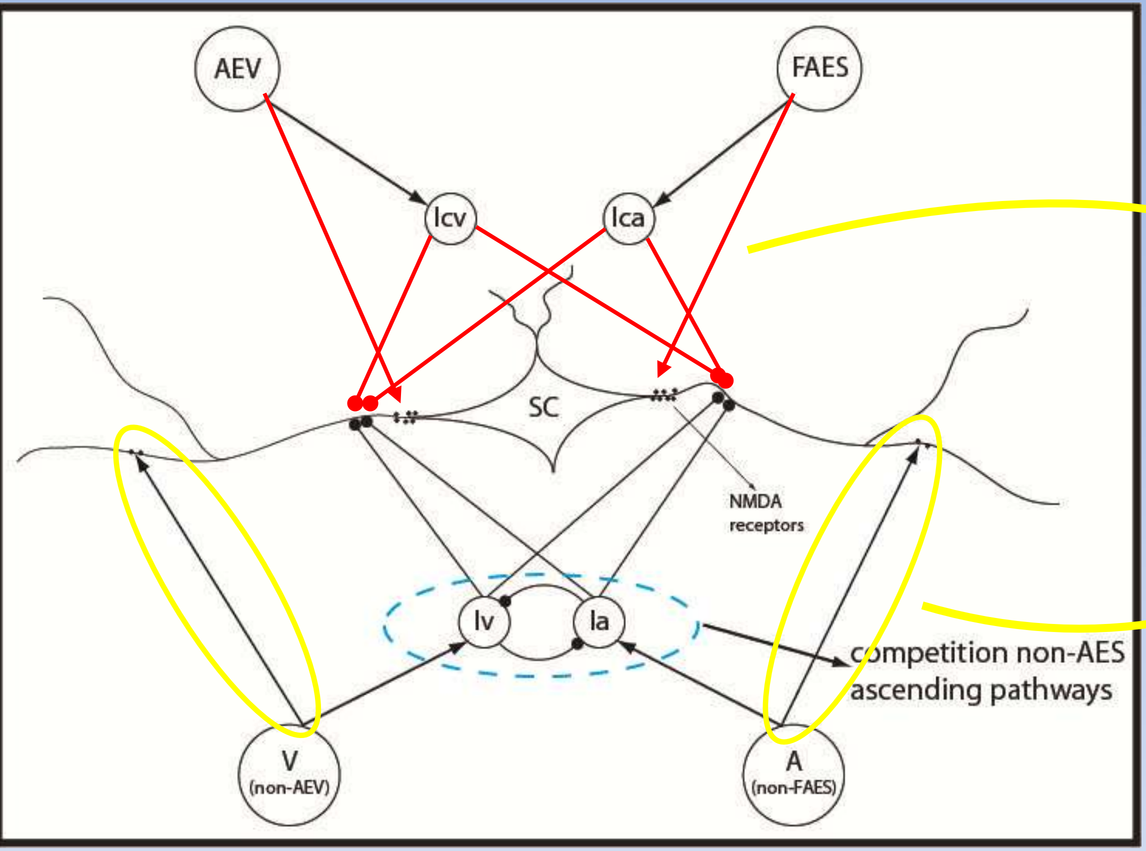
Model Purpose

Cuppini et al. (2010) + limited set of **biologically realistic assumptions**

- Describe the likely maturational events underlying this process.
- Evaluate potential mechanisms underlying the acquisition of MSI
- Specify how they are incorporated via the structural changes in the SC circuitry.

The visual-auditory neuron is used as an exemplar.

Structure of the model



Different unisensory input sources

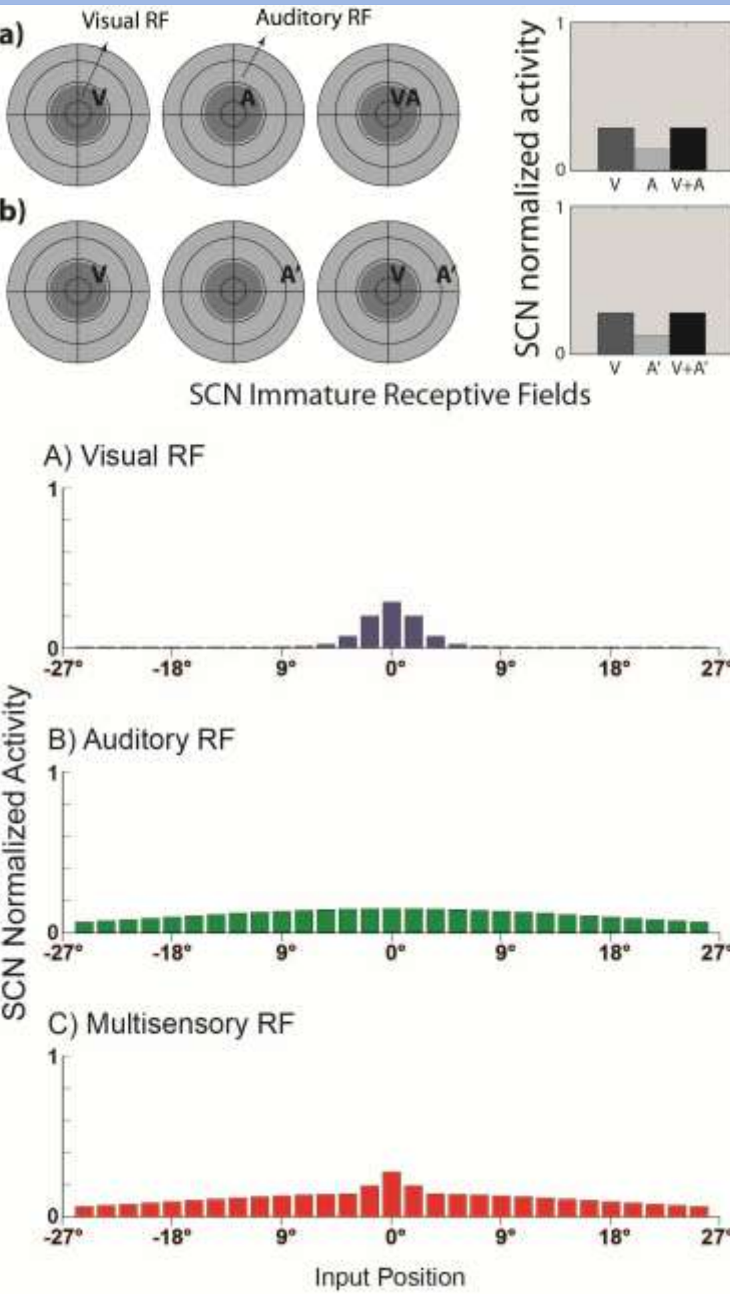
Inhibitory interneurons populations (Competitive mechanisms)

- Maturation of AES projections
- Narrowed non-AES projections

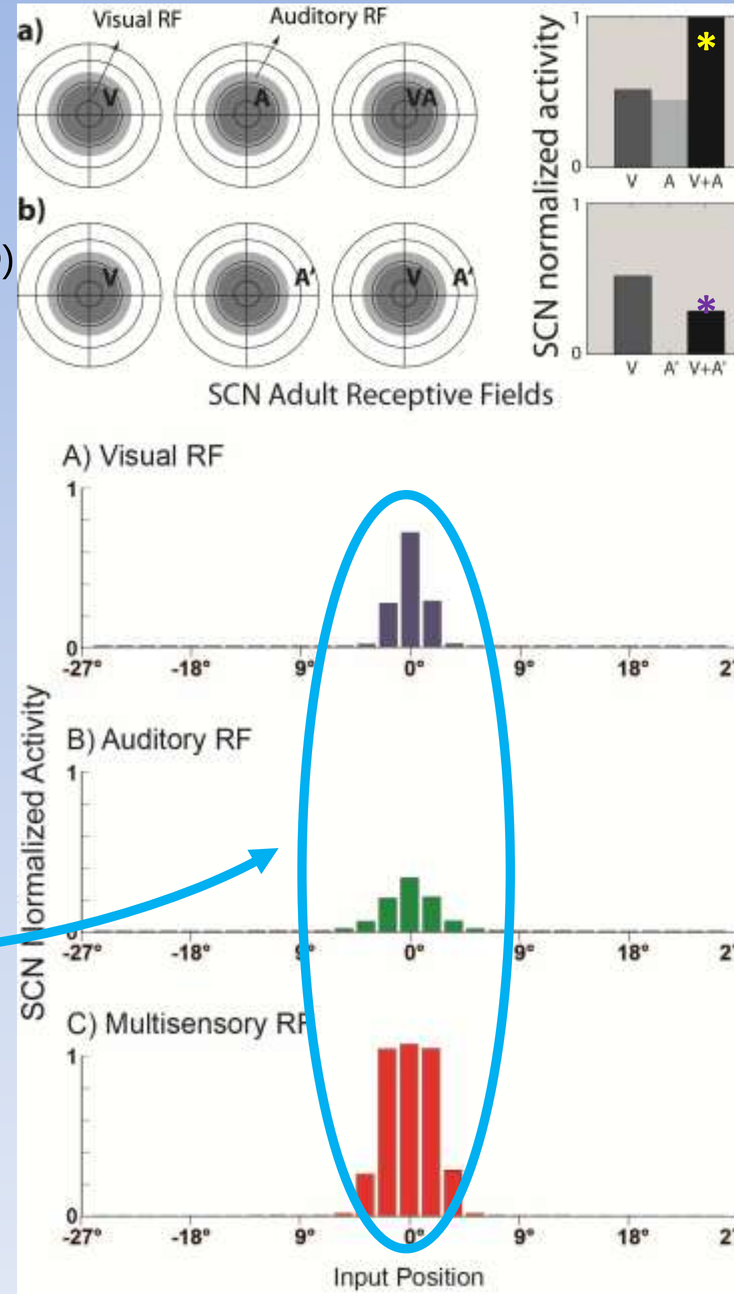
Structural assumptions

1. Ineffective AES projections
2. Large RFs (Widespread weak non-AES projections)
3. Competition between ascending pathways

Immature Phase



Adult Phase



Simulated Development

Hebbian Rules (LTP - LTD)

100.000 iterations

80% Cross-modal stimuli

⇩

Multisensory Integration:

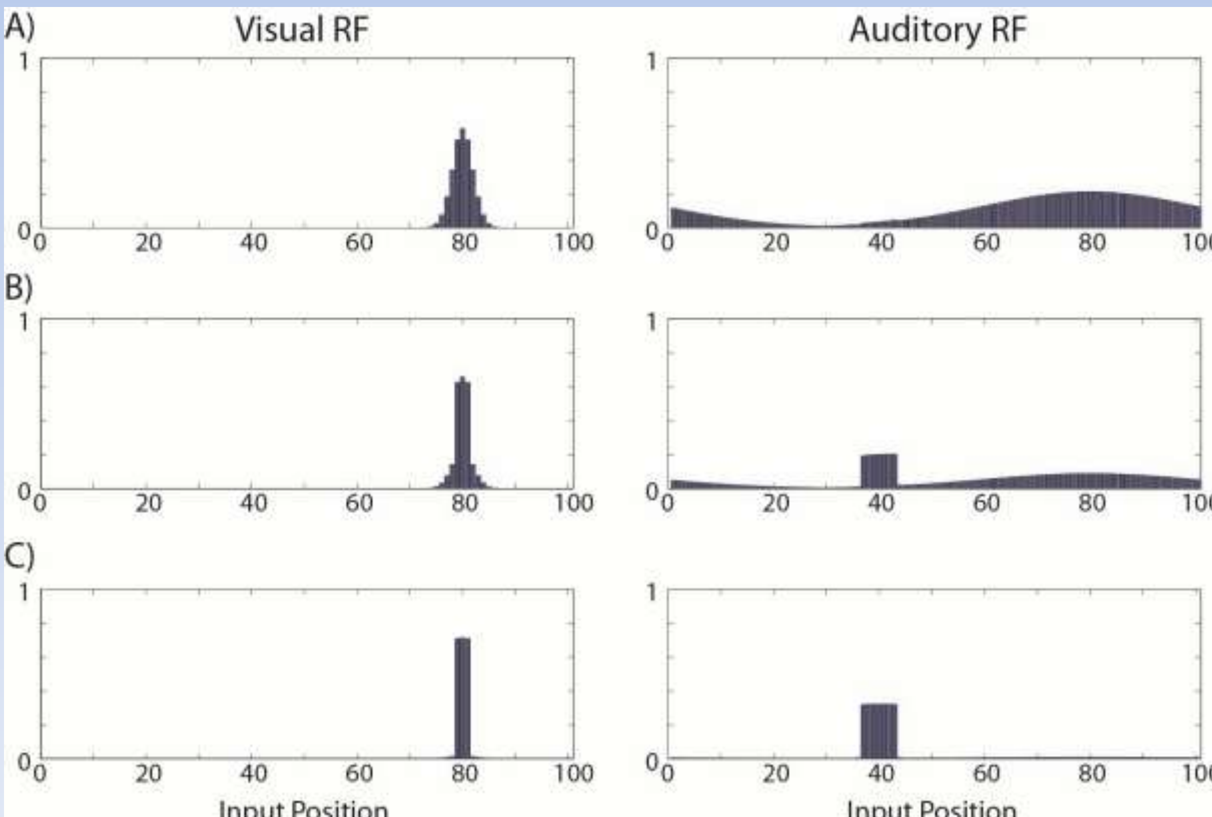
1. Cross-modal Enhancement *

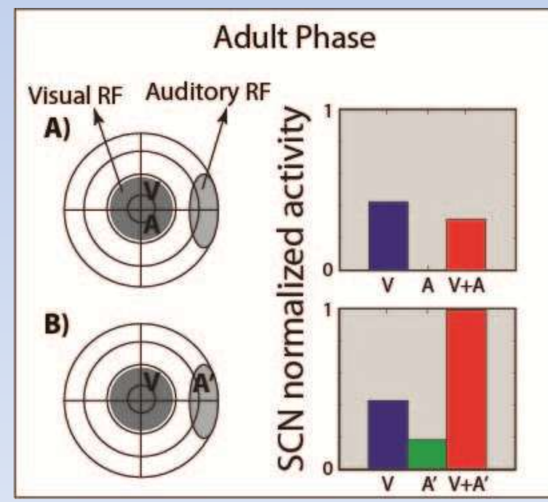
2. Multisensory Depression *

Aligned RFs

Different Sensory Experiences

- Simulated dark-reared development
- Modality-specific training – NO cross-modal experience
- Different cross-modal/modality-specific input ratio
- Disparate Development





Conclusion

MATHEMATICAL MODEL

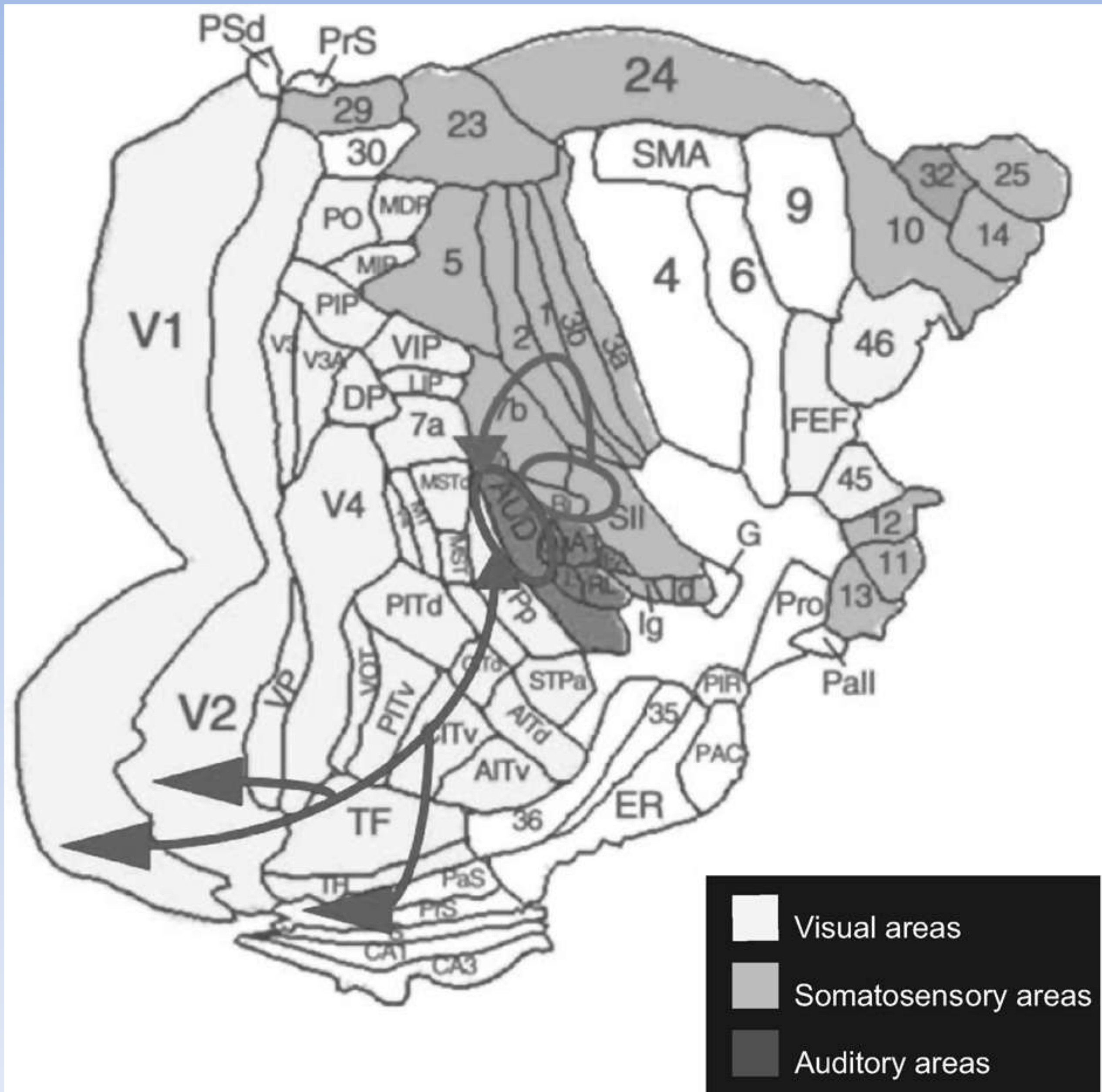
Circuitry knowledge — Literature MSI knowledge — Hebbian learning rules

- Mechanisms by which the statistics of normal experience are incorporated
- Statistics affects the strength of the synapses among the components of the circuit.

The maturation of multisensory integration is strictly related with the cross-modal experience during the maturation process.

These observations can be generalized to multisensory SC neurons with other modality convergence patterns.

Multisensory interactions



Cortical sensory areas

Anatomical connections among cortical sensory areas in macaque monkey. Flattened representation of macaque monkey cortex, depicting direct connections between different sensory cortical regions (auditory to visual, and somatosensory to auditory) found by Falchier et al. [24]. Reprinted from Cappe C, Rouiller EM, Barone P. Multisensory anatomical pathways. Hearing Research 2009;258:28–36, with permission from Elsevier.

Publications :

E. Magosso, C. Cuppini, A. Serino, G. di Pellegrino, M. Ursino. "A theoretical study of multisensory integration in the superior colliculus by a neural network model", *Neural Netw* 21(6): 817-829, 2008. ISSN 0893-6080 (IF 1.951)

M. Ursino, C. Cuppini, E. Magosso, A. Serino, G. Di Pellegrino. "Multisensory integration in the superior colliculus: a neural network model", *J Comput Neurosci* 26: 55-73, 2009. ISSN 0929-5313 (IF 1.928)

C. Cuppini, M. Ursino, E. Magosso, B.A. Rowland, B.E. Stein. "An emergent model of multisensory integration in superior colliculus neurons", *Front Integr Neurosci* 22: 4-6, 2010

C. Cuppini, B.E. Stein, B.A. Rowland, E. Magosso, M. Ursino. "A Computational Study of Multisensory Maturation in the Superior Colliculus (SC)" *Experimental Brain Research* 213(2-3): 341–349, 2011 DOI 10.1007/s00221-011-2714-z

C. Cuppini, E. Magosso, M. Ursino. "Organization, maturation and plasticity of multisensory integration: Insights from computational modelling studies" *Frontiers in Perception Neuroscience* 2011 doi: 10.3389/fpsyg.2011.00077

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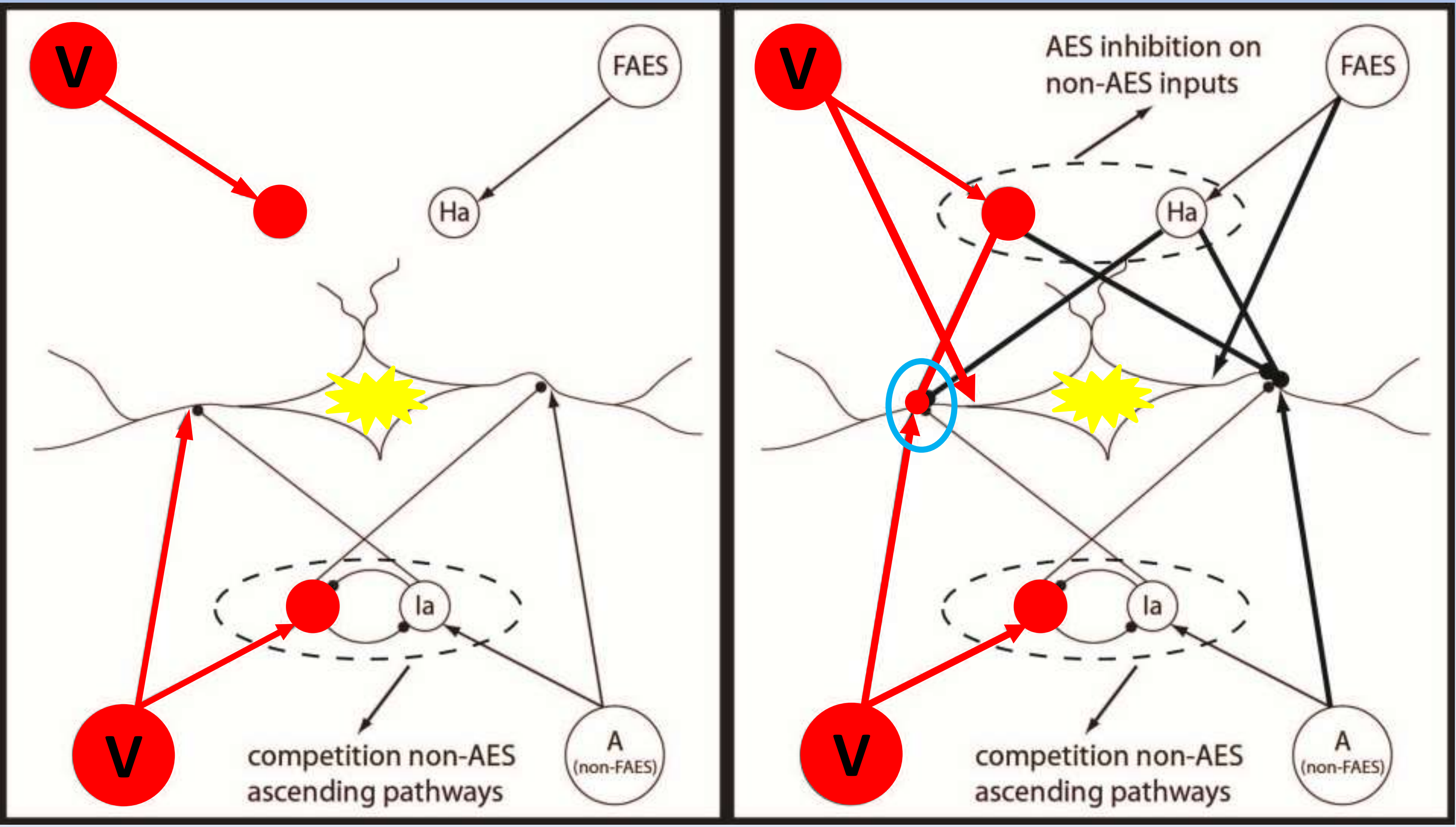
C. Cuppini, E. Magosso, A. Serino, G. di Pellegrino, M. Ursino, "A neural network for the analysis of multisensory integration in the Superior Colliculus", In: *Artificial Neural Networks-ICANN'07* (Series: *Lecture Notes in Computer Science*) Springer Berlin/Heidelberg (ISBN: 978-3-540-74693-5).

M. Ursino, E. Magosso, C. Cuppini, "Sensory fusion", In: *Perception-reason-action cycle: Models, algorithms and systems* Edited by Vassilis Cutsuridis, Daniel Polani, Amir Hussain, Naftali Tishby, John Taylor. Springer (USA). (accepted)

Modality-specific stimulation



Cross-modal stimulation