Disorders of Higher Motor Control

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The term apraxia

- has been used in 1881 for the first time by Heymann Steinthal.
- He described an aphasic patient who grasped the pen upside down when trying to write and manipulated the knife as a fork.
- Steinthal proposed that the locus of the problem was between the movements and the objects to be manipulated.

Asymbolia

- Finkelburg (1870) had argued that apraxic and aphasic disturbances have a common cause and used the concept of *asymbolia* to describe this condition.

- But Steinthal distinguished *apraxia* from *asymbolia* because the former concerns not only meaningful signs but also concrete objects.

- The fact that aphasia and apraxia have later been shown in double dissociation invalidates the *asymbolic* argument.

Clinical Definition

- Apraxia refers to a deficit of the motor activity that emerges specifically during the execution of intentional actions.

- It is not due to:
- deafness or aphasia
- primary sensory weakness (blindness or tactile anesthesia) or agnosia (visual or tactile)
- paresis, tremor, ataxia, ipokinesis (Parkinson) or iperkinesis (Còrea)
- impaired spatial orientation
- impaired body schema
- frontal inertia or dementia

Clinical classifications

- Apraxias are classified according to the body segment that is involved:
  - Bucco-facial apraxia
  - Trunk apraxia
  - Limb apraxia
- The fact that the apraxic deficit can affect one body part at the time speaks against the asymblolic account of this disorder.

Bucco-Facial Apraxia

- This affects the muscles of mouth, tongue, pharynx and larynx.
- Patients with BFA have difficulties in protruding the tongue, whistling, protruding the lips (kissing), swallowing etc.
- This can be observed either when the P is requested to do it verbally by the examiner or when P is asked to copy what the experimenter does.
- The same movements that the P cannot perform when requested can be executed spontaneously in other circumstances (voluntary-automatic dissociation).
- It is often associated with speech apraxia (or anarthria) because of the anatomical contiguity of the areas involved, however double dissociations between the two have been also reported.
- ABF is caused by lesions of the anterior insula in the left hemisphere.

Trunk Apraxia

- Geschwind suggested a possible dissociation between limb movements and those that executed by the axial musculature (e.g. trunk), preserved in patients with limb apraxia.
- Afterwards, dissociations between axial movements and movements performed by other body parts have been confirmed but only on verbal command.
- Yet other studies failed to observe spared performance of axial movements, thus weakening the Geschwind's hypothesis.
- Trunk apraxia is associated with bilateral frontal lesions that can also cause *gate apraxia*.

Limb Apraxia

- In right handed patients, a lesion of the left hemisphere can produce apraxia of both upper limbs.
- The movements of the lower limbs can be affected too, but they are only rarely tested.
- The upper limb tested is normally the one ispilateral to the lesion.

Clinical classification based on the function affected

- Following the model of Liepmann that I will now present, apraxias can be distinguished depending on which function (task) is reduced in the patient.

Liepmann

In 1900 he published a detailed single case report of a left handed patient (*Regierungsret*) afflicted by syphilis who had apraxia when he performed an imitation task with the left but not the right hand.

- The autopsy revealed that 2/3 of the CC were completely destroyed, and subcortical cysts in the left frontal and parietal lobes interrupted most of the remaining connections between the left central region and other cortical regions (callosal apraxia).

- In 1905, Liepmann observed 20/41 patients with right hemiplegia and apraxia, and 42 patients with left hemiplegia non of whom had apraxia thus establishing that the left hemisphere was specialized for motor control.

Ideational Apraxia

- At the basis of a purposeful action there is a movement formula.
- This is a visual or acoustic image of an action and not a kinetic memory.
- The MF is the product of the entire cortex but the posterior regions may play a critical role when the MF is provided by a visual image.
- A failure to create an appropriate MF leads to Ideational Apraxia.
- According to Liepmann, IA is mainly caused by diffuse brain lesions and dementia.
- He did, however, consider the possibility that occipito-parietal lesions might cause IA.

Ideomotor Apraxia (AIM)

- The 2nd step from intention to action requires connecting the movement formula to the motor innervations.
- Failure to this mechanism leads to Ideomotor Apraxia (motor or ideo-kinetic apraxia).
- It can be evidenced by faulty imitation of movements.
- It does not affect routine actions (i.e. knocking the door).
- IMA is caused by interruption of fibers from the whole cerebral cortex to the motor center for the affected limb.

Limb-kinetic apraxia

- Loss of purely cinematic memories of an extremity leads to LKA.
- This form of apraxia affects purposeful as well as routine use of objects.
- LKA results from lesions to the *central region*.

Clinical classification based on the function affected

- IMA
- IA
- LKA

Disconnection Account of Apraxia

Geschwind 1965, Disconnection syndromes in animals and man

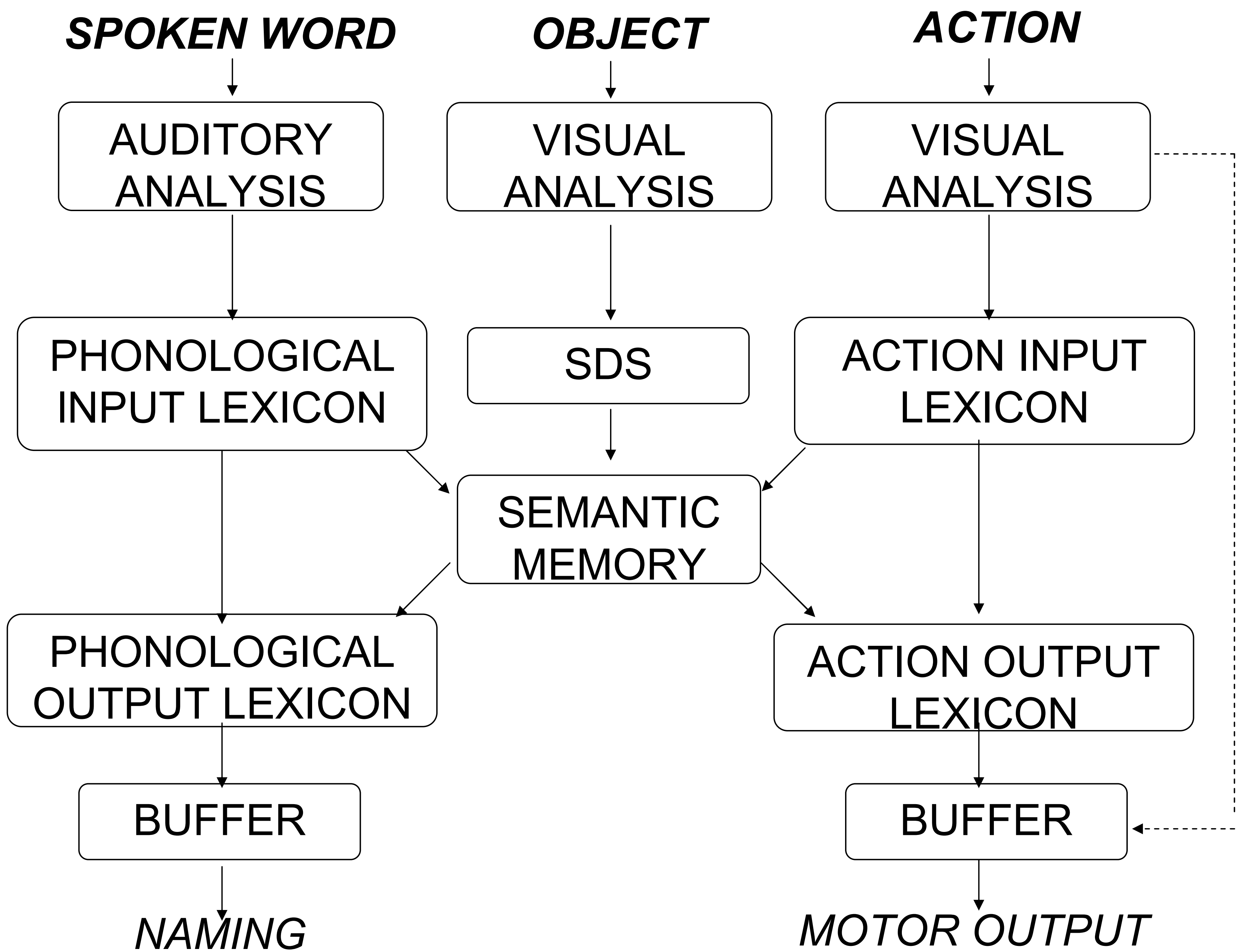
- Failure to gesture to verbal command (or imitation):
  - The verbal command is processed in the Wernicke area, and from here the info is sent to the ipsilateral premotor cortex, through the *fasciculum arcuatum*.
  - To move the R hand, the info needs to be sent from the left PMC to the left M1;
  - to move the L hand, the info needs to be sent, through the CC, from the left to the right PMC, that in turn projects to the right M1.
  - Lesions of the left posterior parietal cortex in the LH disconnect the Wernicke's area (or the visual associative cortex) from the PMC, thus preventing the verbal command (or visual stimulus) to be executed.

Rothi et al. (1991)

- proposed a model of comprehension (input) and of production (output) of actions inspired to models of language production.

- Such model can explain a number of phenomena:

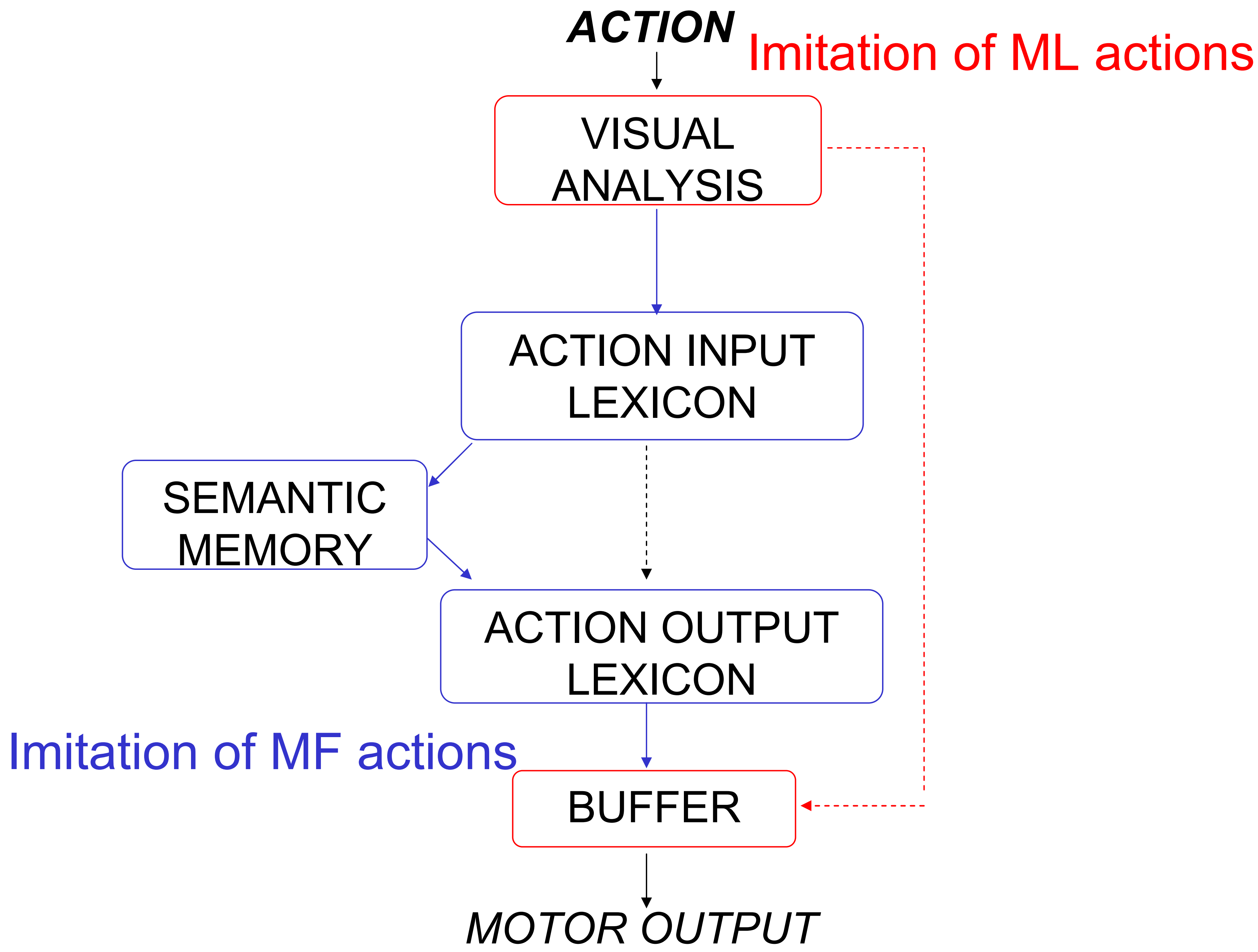
- Input/output dissociation
- modality-specific apraxias (e.g.verbal/visual)
- Imitation of meaningless actions


SPOKEN WORD
OBJECT
ACTION
AUDITORY ANALYSIS
VISUAL ANALYSIS
VISUAL ANALYSIS
PHONOLOGICAL INPUT LEXICON
SDS
ACTION INPUT LEXICON
SEMANTIC MEMORY
PHONOLOGICAL OUTPUT LEXICON
ACTION OUTPUT LEXICON
BUFFER
BUFFER
NAMING
MOTOR OUTPUT

TESTING A COGNITIVE MODEL OF PRAXIS

- IMA
  - IMITATION (MF-ML)
  - PANTOMIMING TO VERBAL COMMAND
  - PANTOMIMING SEEN OBJECTS

- IA
  - OBJECT USE



ACTION
Imitation of ML actions
VISUAL ANALYSIS
ACTION INPUT LEXICON
SEMANTIC MEMORY
ACTION OUTPUT LEXICON
Imitation of MF actions
BUFFER
MOTOR OUTPUT

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Neuropsychological evidence for a strategic control of multiple routes in imitation

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Participants

Table 1 Demographic variables

	N	Education		♂	♀	Age	
		Mean	SD			Mean	SD
LBD	22	9.82	5.13	12	10	69.69	9.91
RBD	10	9.50	3.37	5	5	62.60	10.30
Controls	20	10.84	3.30	12	8	65.00	13.98

The demographic variables of all participants (patients and healthy controls) who took part in the study.

Stimuli & Procedure

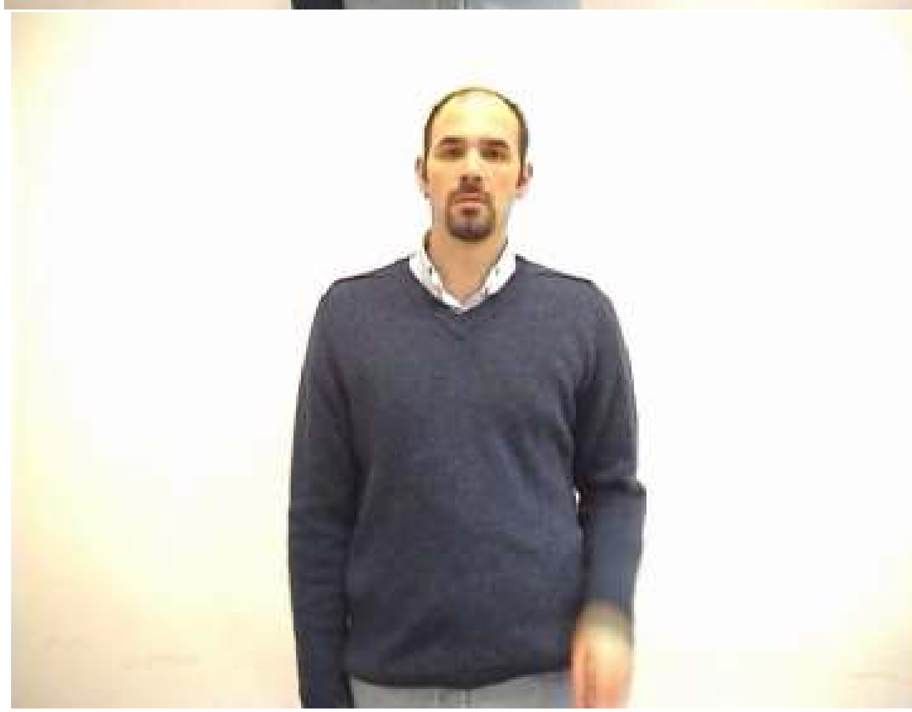
- Stimuli & Task
  - Imitation of 20 MF & 20 ML actions
- Procedure
  - mixed and separate lists in 2 different days.
- Hands
  - examiner/right
  - patients/ipsilateral to the lesion.
- Accuracy & Error analysis

Single Case Analysis

Mixed Lists

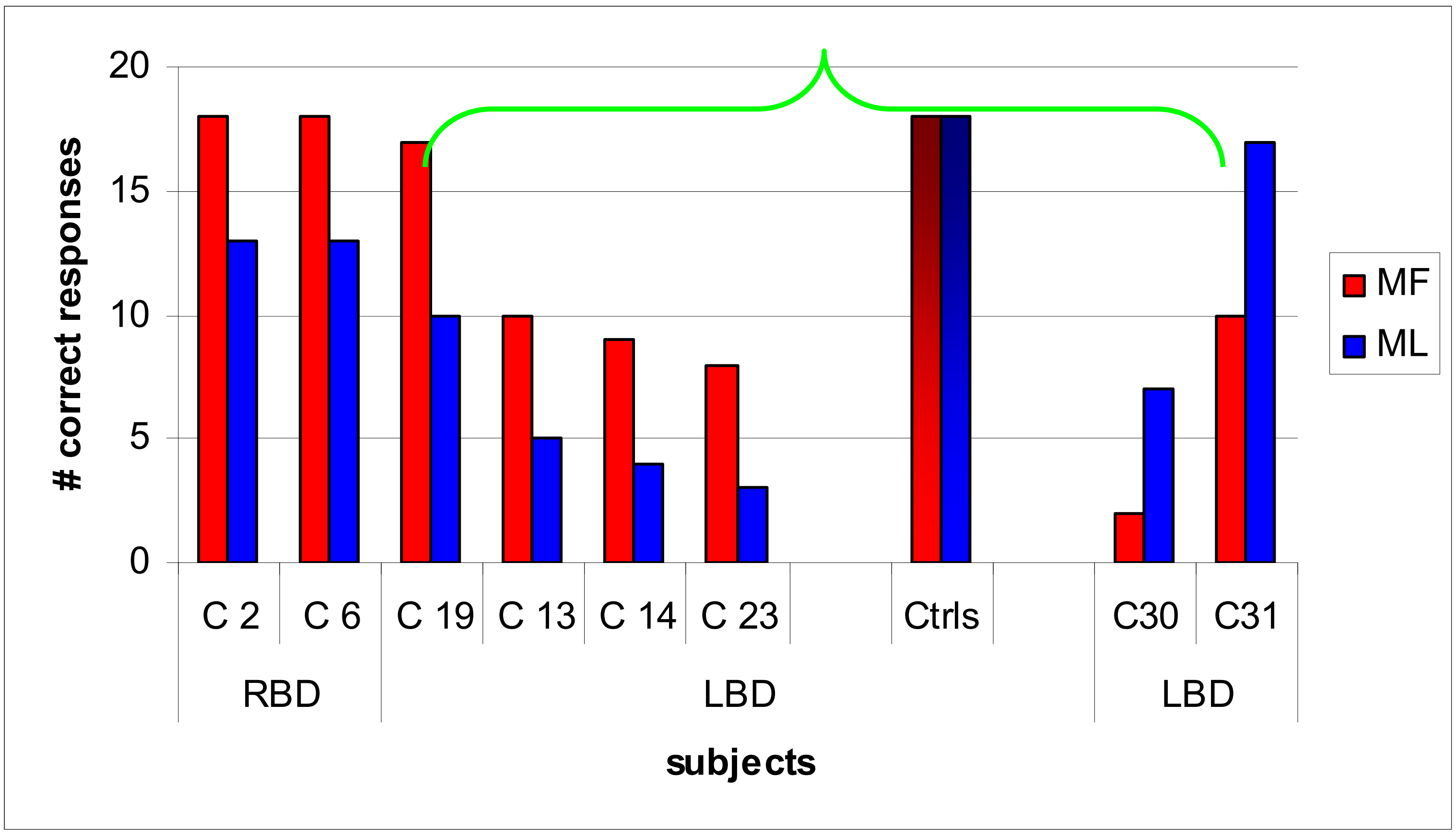
- None of the patients showed a dissociation in imitation of mixed MF and ML actions.
- In the mixed condition, patients select the sub-lexical route for imitating both MF and ML actions.
- As the brain damage reduces the patients' resources, the sub-lexical route is selected because it allows to reproduce both action types.
- If the route is damaged, imitation of both MF and ML actions may result impaired.
- The same findings have been reported by De Renzi *et al.* (1980), Cubelli *et al.* (2000) and Toraldo *et al.* (2001) where a mixed list was employed.



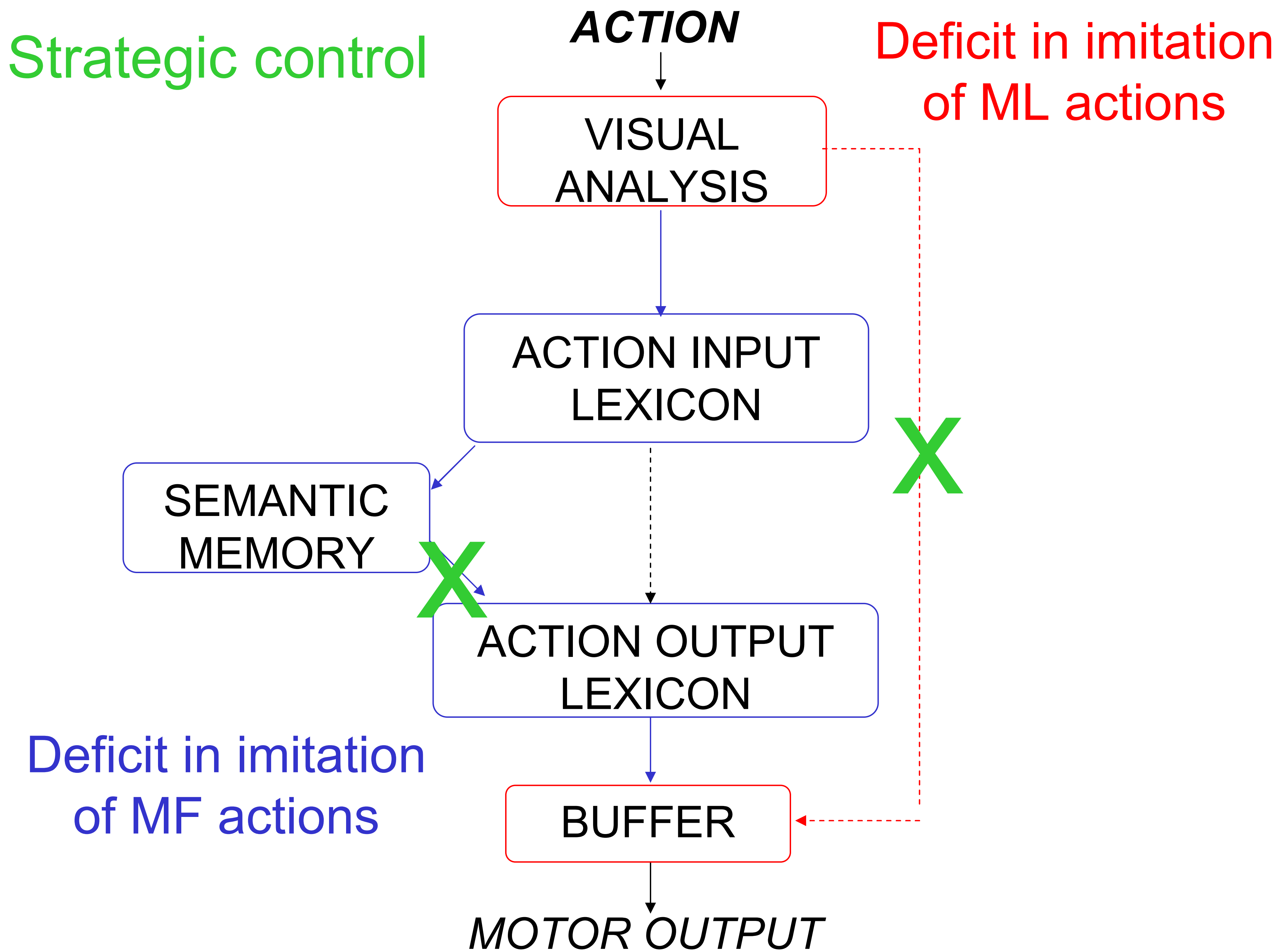



Blocked Lists

MF > ML   ML > MF



Action recognition (C 31 = 100% and C 30 = 95%)


Strategic control
ACTION
Deficit in imitation of ML actions
VISUAL ANALYSIS
ACTION INPUT LEXICON
X
SEMANTIC MEMORY
X
ACTION OUTPUT LEXICON
Deficit in imitation of MF actions
BUFFER
MOTOR OUTPUT

Two imitation routes & strategic control

- When MF and ML actions are presented in separate blocks, patients select the route depending on the stimulus type.
- Depending on which route is damaged, patients show a selective deficit in imitation of either MF or ML actions.
- Patients with selective imitation deficits have been reported before:
  - Goldenberg & Hagmann 1997; Peigneux *et al.* 2000; Bartolo *et al.* 2001.

IMA & BODY SCHEMA

IMPAIRED IMITATION OF ML ACTIONS

Patients	**LK**	**EN**
ML hand positions	**11/20***	**3/20***
ML finger configurations	19/20	**11/20***

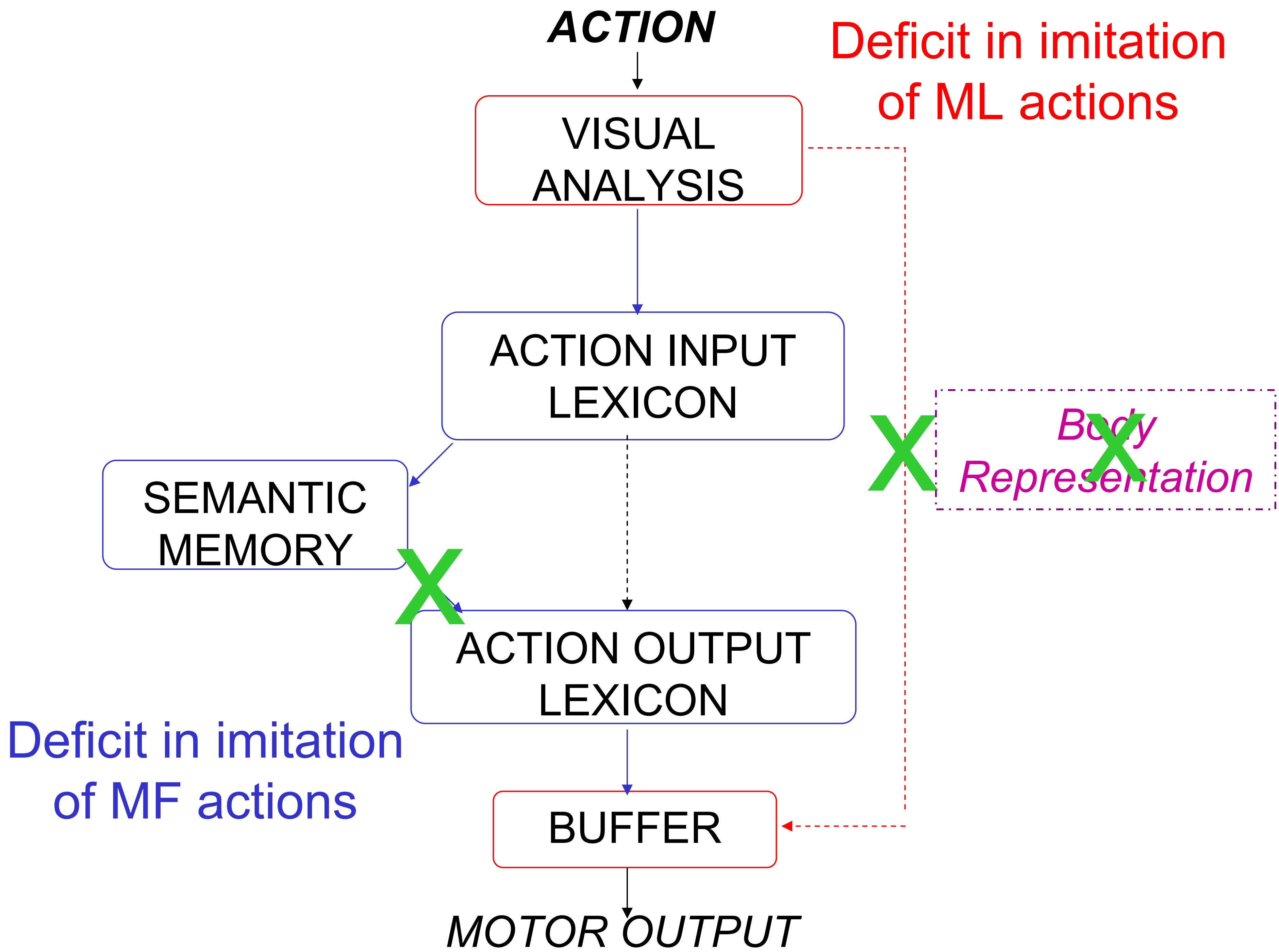
PRESERVED IMITATION OF MF ACTIONS

	LK	**EN**
Pantomimes of object use	17/20	18/20

IMPAIRED IMITATION OF ML POSITIONS

	LK	**EN**
ML hand positions on mannikin	**10/20***	**5/20***

Goldenberg & Hagmann 1997



ACTION
Deficit in imitation of ML actions
VISUAL ANALYSIS
ACTION INPUT LEXICON
Body Representation
SEMANTIC MEMORY
ACTION OUTPUT LEXICON
Deficit in imitation of MF actions
BUFFER
MOTOR OUTPUT

Journal of Experimental Psychology:
Human Perception and Performance
2004, Vol. 30, No. 6, 1107–1116

0096-1523/04/$12.00 DOI: 10.1037/0096-1523.30.6.1107

The Strategic Control of Multiple Routes in Imitation of Actions

Alessia Tessari and Raffaella Ida Rumiati
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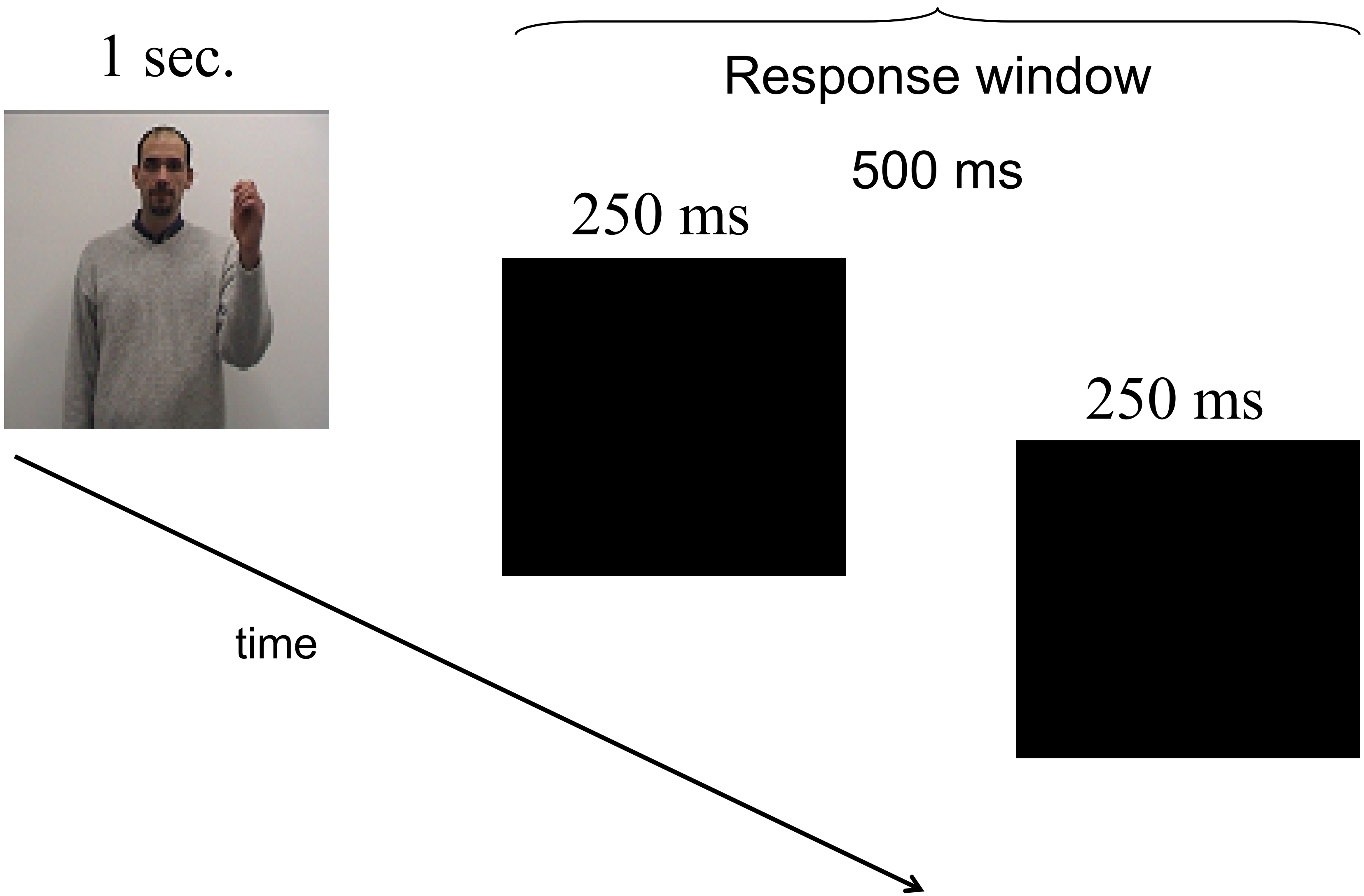
- In 3 experiments, we investigated:
  - the existence of these two putative processes for action reproduction
  - whether they can be strategically selected to achieve the best performance depending on:
    - *type of stimulus (MF-ML)*
    - *composition of the list (blocked-mixed)*
    - *information about the experiment list*
    - *relative proportion of the two stimulus types.*

Events in a Trial



Without time constrains, subjects perform at ceiling.

[redacted]

Methods

- 20x4 MF actions = pantomimes of object use
- 20x4 ML actions = as MF but not recognized.

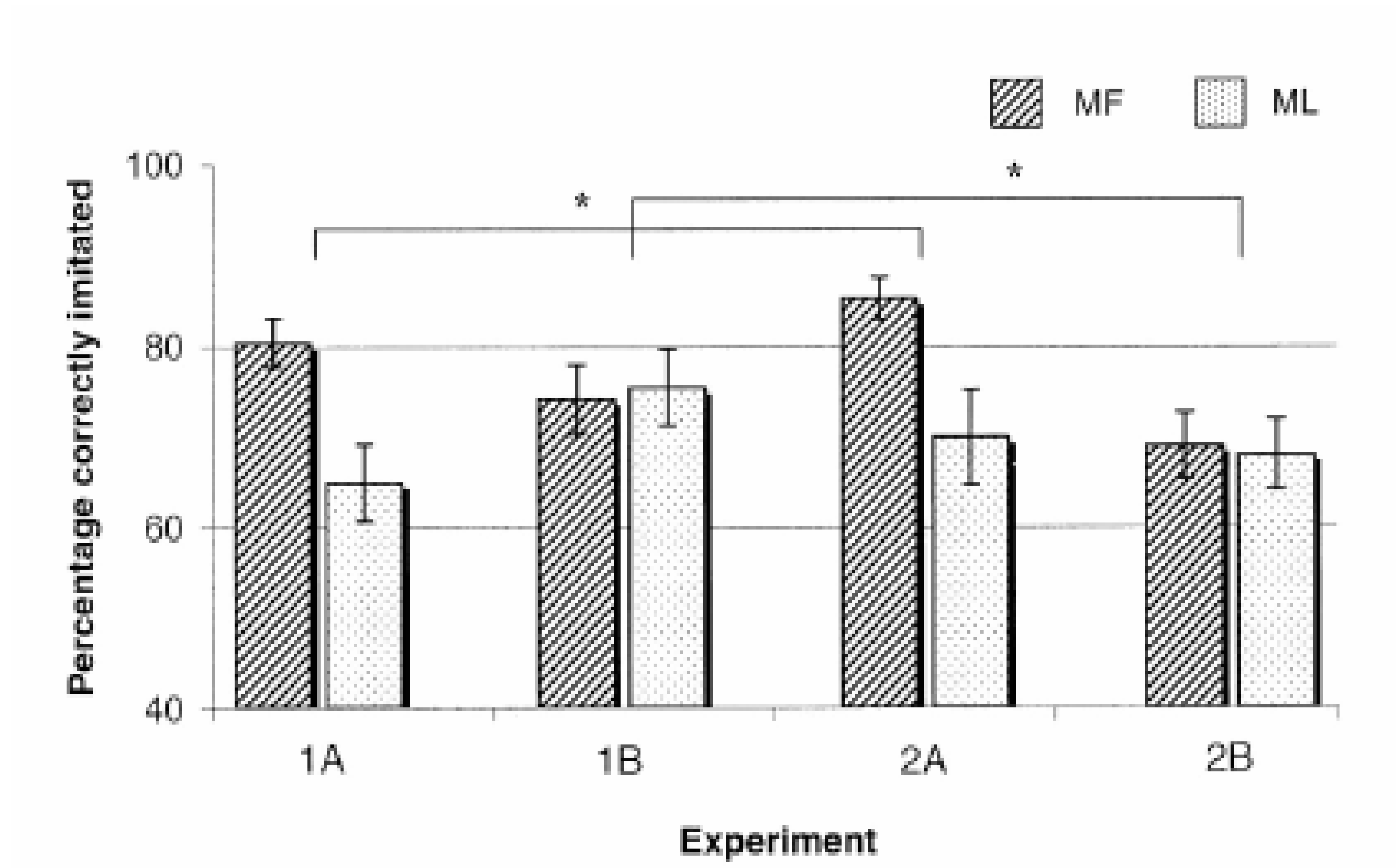
- The model demonstrates the action with the left hand (movie).

- Subjects execute it with the right hand.

- Imitation performance was video-recorded and later scored by 2 independent raters.

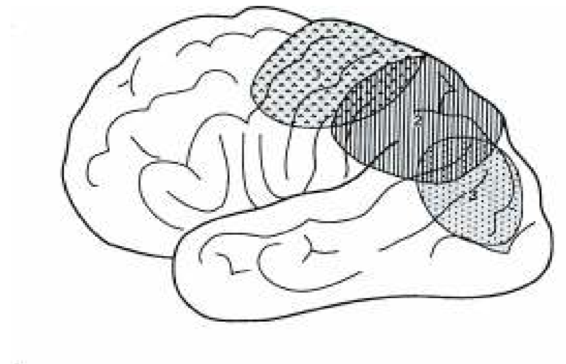
- Two dependent variables: Accuracy and Errors.

Experiments 1 (without) & 2 (with)

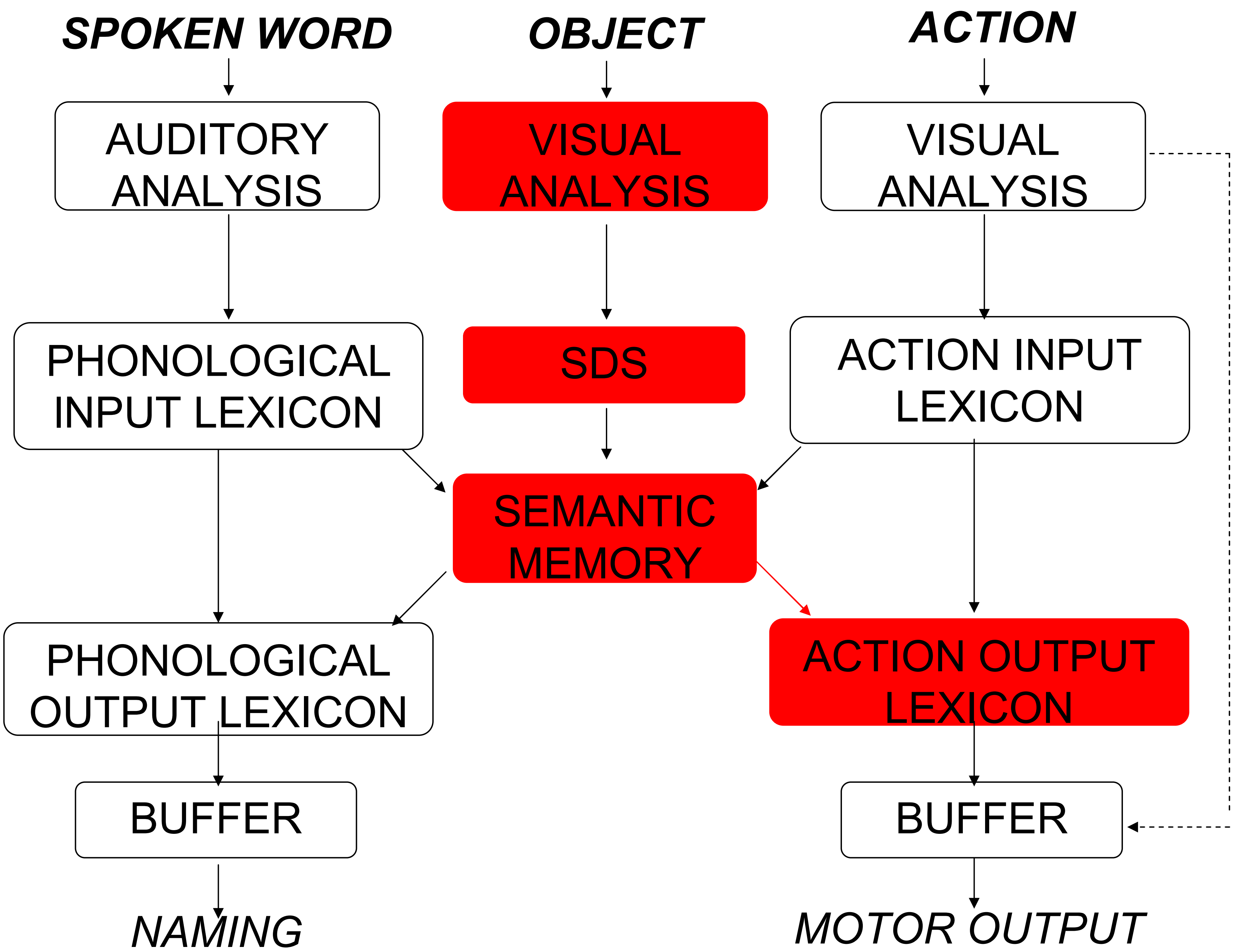


- Blocked : Experiment 2A > Experiment 1A ($p < .05$)
- Mixed : Experiment 1B > Experiment 2B ($p < .05$)

AIM anatomy



- Lesion studies addressing the question of the anatomical basis of IMA failed to unveil the specific lesion correlating with this form of apraxia.
- It is most frequently associated with LH brain-damage, though there have been a few patients with apraxia as a result of a RH or subcortical lesion (Basso et al. 1980; De Renzi et al. 1982).
- Critical areas are: left parietal and premotor cortex.


SPOKEN WORD
OBJECT
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ACTION OUTPUT LEXICON
BUFFER
BUFFER
NAMING
MOTOR OUTPUT

Ideational Apraxia

- Humans skilfully use a very large range of objects by making a series of object-specific movements.
- After LBD, however, right-handers may experience a reduced ability to use objects and tools in everyday life.
- This failure to use common objects and tools is a key symptom of IA.
- Early reports of this deficit describe patients trying to use a pair of scissors as a spoon or taking the wrong side of a smoking pipe to the mouth (Pick).
- IA has been observed in patients without IMA, defined as a failure to imitate actions, and vice versa (e.g. De Renzi et al. 1968; De Renzi & Lucchelli,1988; Ochipa *et al*.,1992).
- This suggests that IA cannot simply be a more severe instance of IMA.

De Renzi et al. 1965

(n = 160)	**I M A -**	**I M A +**
I A -	104	**11**
I A +	**11**	34

Testing IA

- Actual use of common objects in isolation or in a context.

- Poeck argued that IA can be observed only when objects are used in a complex context.

- De Renzi & Lucchelli (1988) showed a strong correlation between *single* tool use and use of objects in a *complex context* (e.g. lighting a candle).

IA AS A FAULTY REPRESENTATION OF THE SEQUENCE

- LH brain-damaged patients were reported with an impairment in performing everyday actions as well as in sequencing photographs depicting those actions (Poeck).

- According to this view, IA arises from a representational damage to the sequential organization of actions with objects.

IA as amnesia of obejct use

- De Renzi & Lucchelli proposed that IA is due to a difficulty in accessing the semantic repertoire of functional features of objects.

- However these authors did not test patients' semantics and visual processing.

COGNITIVE NEUROPSYCHOLOGY, 2001, 18 (7), 617–642

A FORM OF IDEATIONAL APRAXIA AS A SELECTIVE DEFICIT OF CONTENTION SCHEDULING

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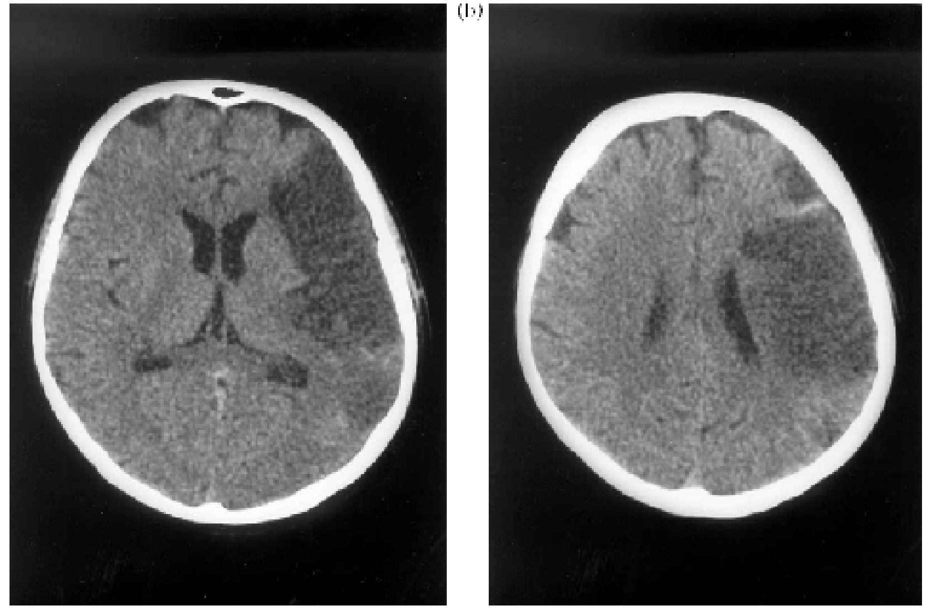
PATIENTS

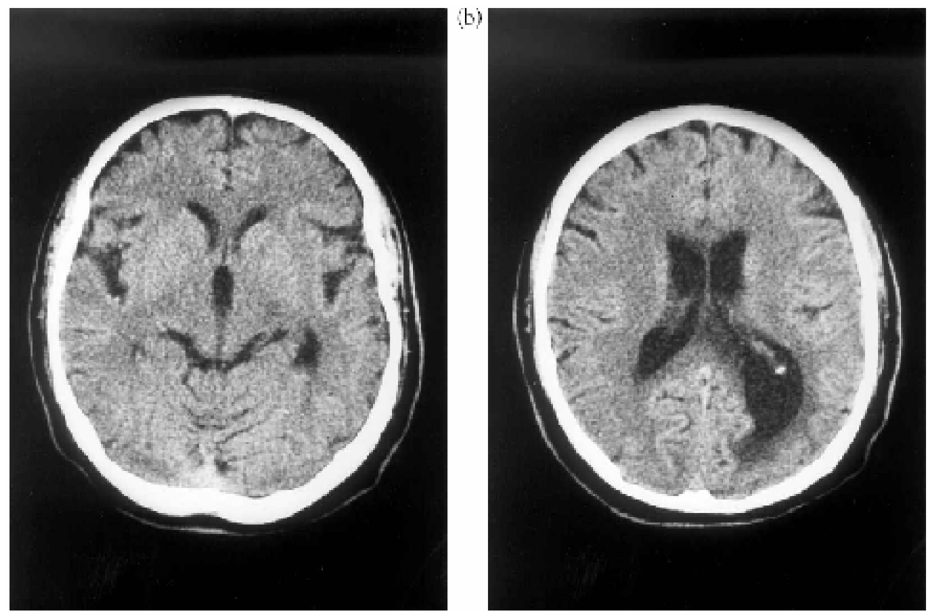
DR

- no visual agnosia
- no memory deficits
- Broca's aphasia with mild comprehension problems



FG

- no visual agnosia, STM but not LTM memory deficits, normal language production and comprehension.



Assessment of praxic abilities

	FG	DR	
Imitation	50/72	34/72	cut off < 53-62
	57/72	43/72	
Real use	**4**/14	**6**/14	cut-off < 14
	13/14	**8**/14	cut-off < 14
Pantomime	**16**/28	**6**/28	mean 20.20±2.93

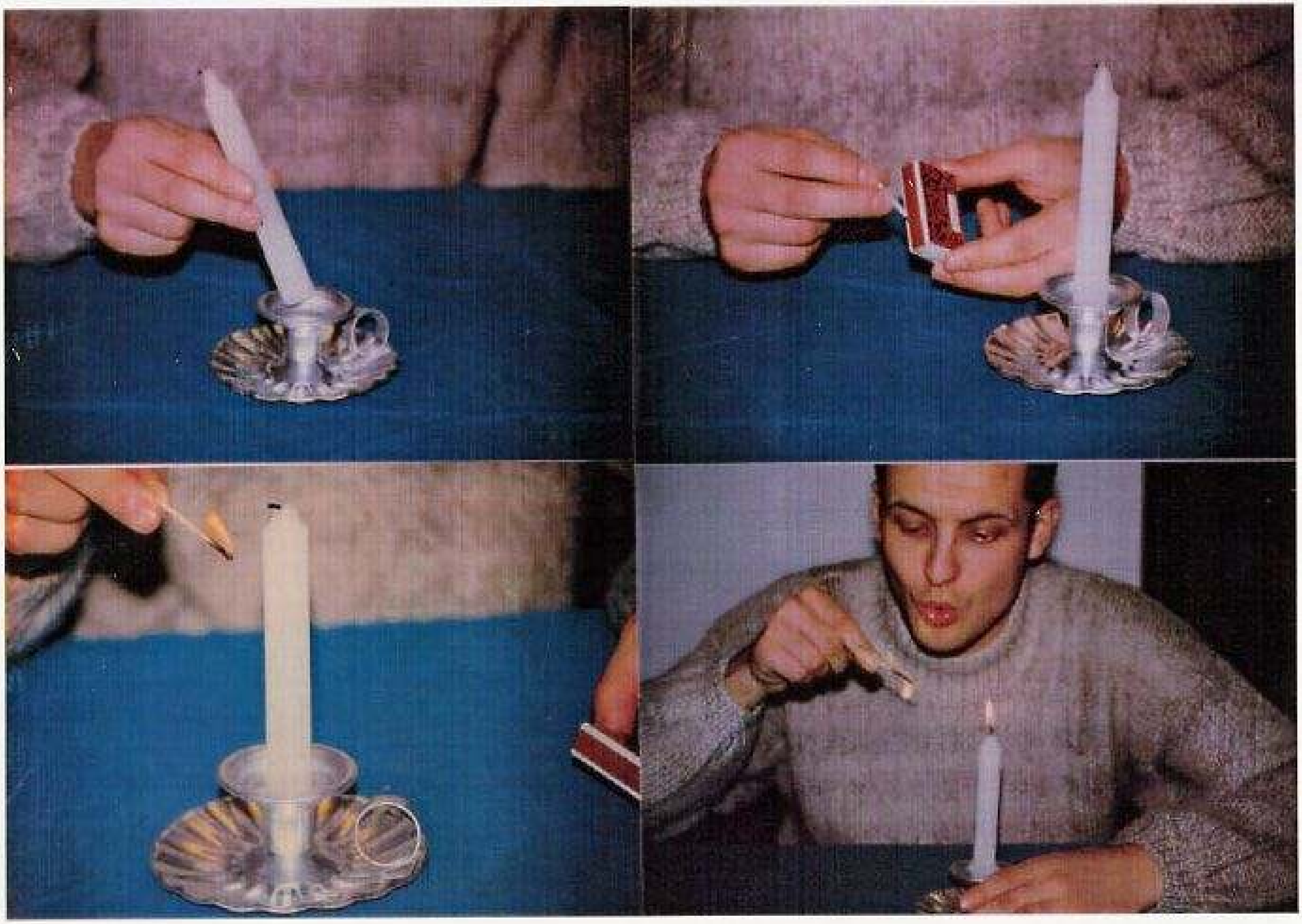


Table 2. *Summary of the Accomplishment Score obtained by patients DR, FG, and WH2 in the production and sequencing tasks*

	Task	*Hand*	*Sessions* I	II	III	IV
DR	Production	Left	2/10	3/10	4/10	4/10
	Sequencing		9/10	9/10	9/10	9/10
FG	Production	Left	0/10	1/10	2/10	2/10
	Sequencing		5/10	6/10	10/10	9/10
WH2	Production	Both	8/10	8/10	9/10	9/10
	Sequencing		7/10	4/10	6/10	6/10

Conceptual Errors

Mislocation of an action (II)

- FG often (18.5%) selected the correct target-object on which to operate with an instrument-object in hand but got the exact location wrong:
  - e.g. striking a match inside the matchbox

Object Misuse (II)

- DR often (40%) selected an appropriate action to the object in hand but inappropriate to the context:
  - e.g. pressing the knife on an orange rather than performing a sawing movement

Table 4. *Errors made by FG in performing the MOT*

Error type	*Sessions*					
	I	*II*	*III*	*IV*	*Total*	*%*
Sequence						
Step omission	5	1	1	1	8	(6.5)
Action addition	3	1	3	4	11	(9)
Anticipation	5	2	2	1	10	(8)
Perseveration	4	2	4	3	13	(10.5)
Conceptual						
Misuse						
Type 1	3	–	–	–	3	(2)
Type 2	3	–	–	2	5	(4)
Mislocation						
Type 1	3	3	4	–	10	(8)
Type 2	7	5	6	5	23	(18.5)
Tool omission	1	2	1	2	6	(5)
Pantomime	2	1	–	–	3	(2)
Perplexity	8	6	5	4	23	(18.5)
Toying	4	2	2	2	10	(8)
Total	48	25	28	24	125	(100)

Table 3. *The different types of errors made by DR in performing the MOT*

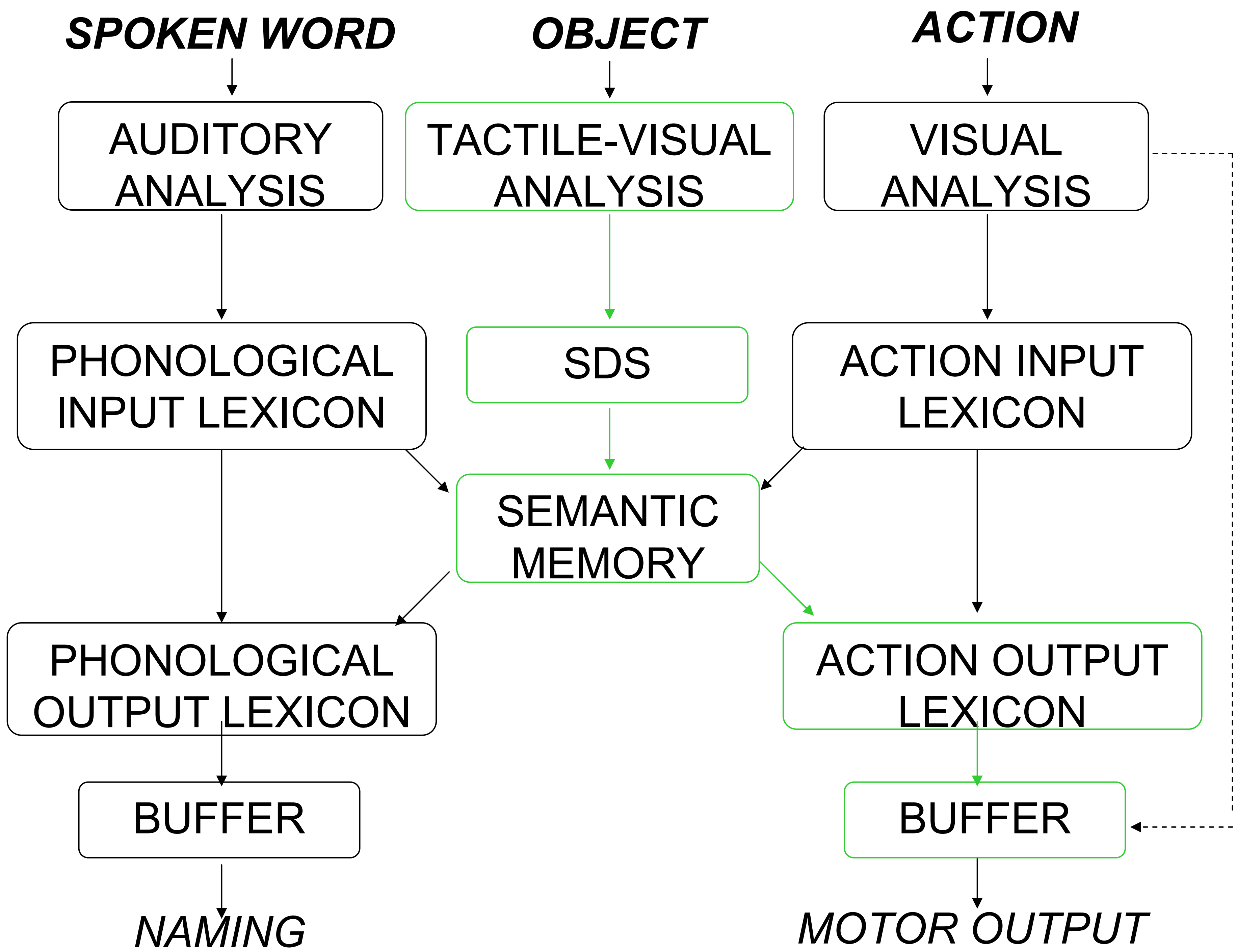
Error type	*Sessions*					
	I	*II*	*III*	*IV*	*Total*	*%*
Sequence						
Step omission	4	4	1	2	11	(22)
Action addition	1	–	–	–	1	(2)
Anticipation	–	1	1	1	3	(6)
Perseveration	–	1	1	2	4	(8)
Conceptual						
Misuse						
Type 1	–	–	–	–	–	
Type 2	8	4	4	4	20	(40)
Mislocation						
Type 1	2	2	1	2	7	(14)
Type 2			–	–	–	–
Tool omission	2	–	–	1	3	(6)
Pantomime	–	–	–	–	–	
Perplexity	–	–	–	1	1	(2)
Toying	–	–	–	–	–	
Total	17	12	8	13	50	100

NO Visual Agnosia

	DR	FG
Object identification	100%	100%
Action identification	100%	100%

NO Loss of functional-semantic knowledge

Function-to-object match (out of 4)	100%	100%
Object-to-function match (out of 3)	100%	100%


SPOKEN WORD
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PHONOLOGICAL INPUT LEXICON
SDS
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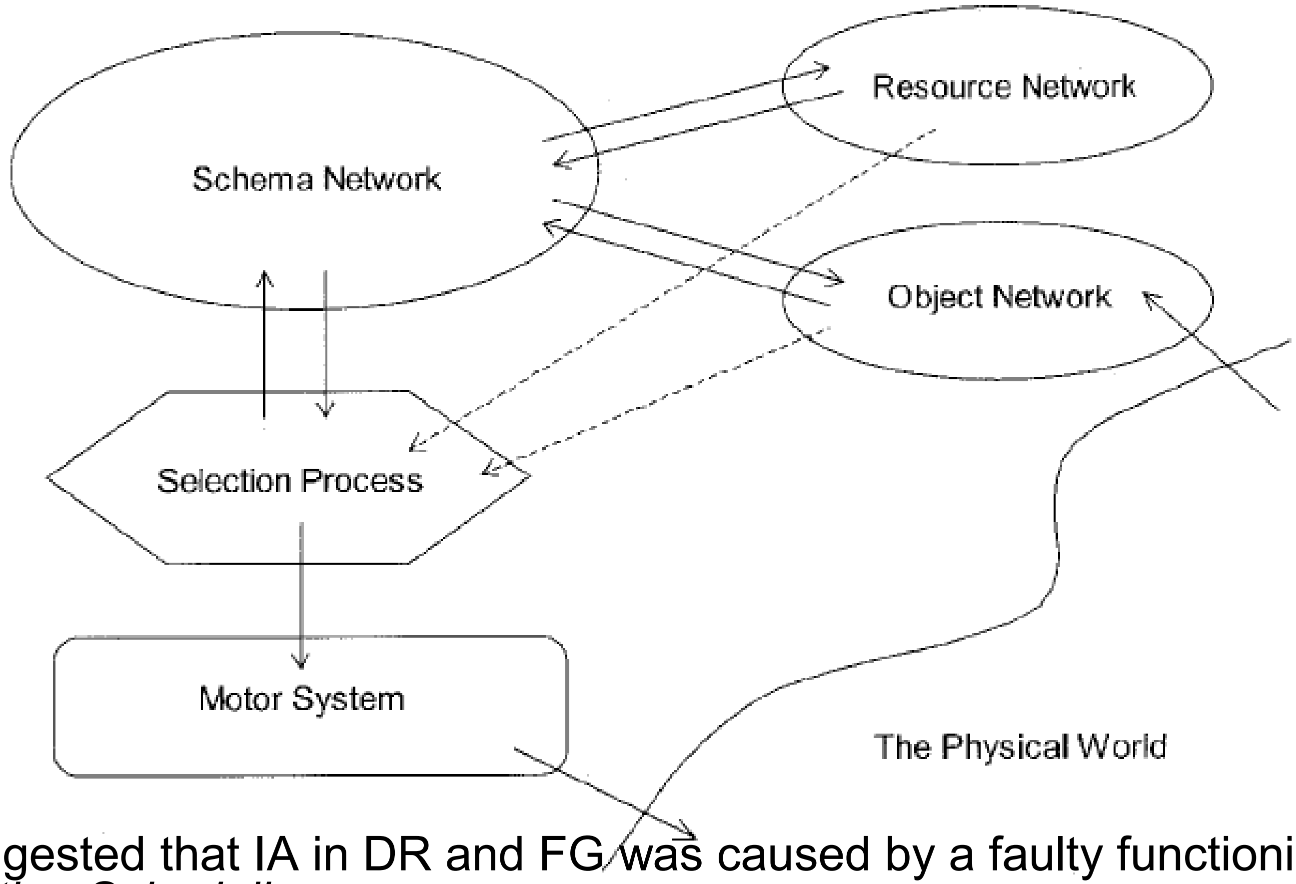
SEMANTIC MEMORY
PHONOLOGICAL OUTPUT LEXICON
ACTION OUTPUT LEXICON
BUFFER
BUFFER
NAMING
MOTOR OUTPUT



- We suggested that IA in DR and FG was caused by a faulty functioning of the *Contention Scheduling.*
- The CS is competition mechanism that allows routine actions to be produced without conflict
- It does so by activating relevant and inhibiting irrelevant action schemata at appropriate times set by environmental triggers.
- In particular, IA in DR and FG can be interpreted as a damage to, or a disconnection between, components within the CS such as the *object-trigger system* and the *action schemata*.

Rumiati et al. (in prep.)

- In a follow-up study we investigated whether FG’s and DR’s failure to use objects was determined by a loss of finer functional knowledge of parts of objects.
- Moreover we aimed at demonstrating that object use is not dependent upon declarative, functional-semantic knowledge.
- We therefore compared performance of the apraxic patients with that of DL and AM with a semantic deficit, on a number of key tests.

Patients with a semantic deficit

	DL	AM
Gender	male	female
Handedness	right	right
Age	71 yrs	76 yrs
Education	5 yrs	5 yrs
Aetiology	Probable SD	Probable DAT

Diagnosis of SD

- Omissions and semantic paraphasias in naming and spontaneus speech;
- Semantic loss
  - word-picture matching tasks
  - associative matching tasks (pict. & words)
- Amnesia (words & faces)
- Spared Repetition

Neither apraxia nor agnosia!

- Both DL and AM had Left-Temporal Atrophy as shown by:
  - 1999 CT-scan negative
  - 2000, 2002 SPECT: lower concentration of the marker in the left temporal lobe.
- DL suffered from Semantic Dementia, and AM, from DAT.

Battery of 22 objects

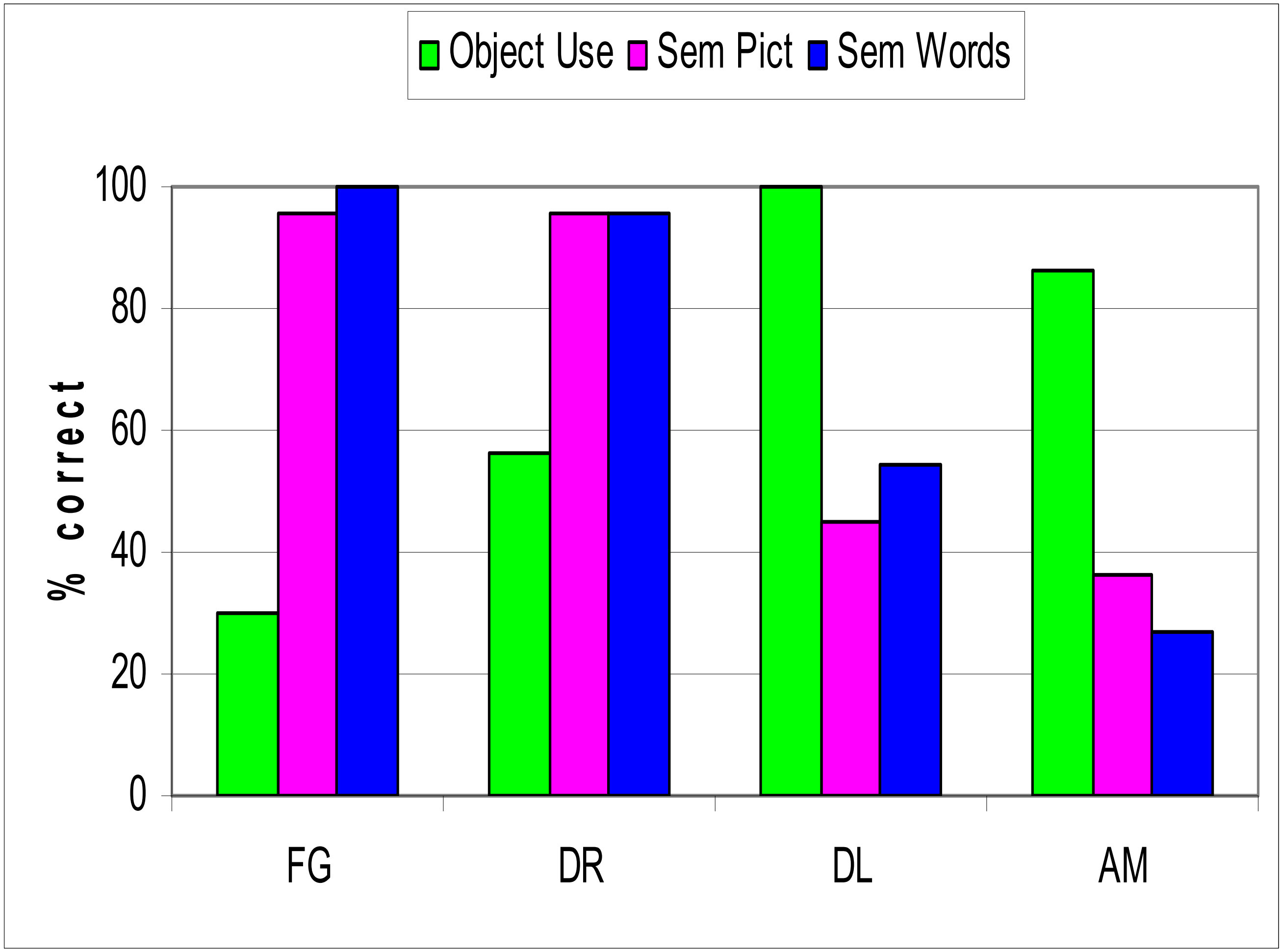
- General semantics
- Functional semantics of parts
- Object use
- Object & action recognition

Questionnaire

HAMMER

1. supraordinate info: is it an object, a vegetable or an animal?
2. category info: is it a tool, a musical instrument or a gem?
3. subordinate perceptual info: is it made of glass, of metal or of cement?
4. subordinate structural info: is it smaller than a screw? (yes/no)
5. functional info: is it used for cutting, screwing or sticking nails?
6. the protypical user of the object: is it used by the painter, the carpenter, the glazer?

Object Use vs. General Semantics



N = 22

Functional semantics of parts

Which part is it used for lighting?

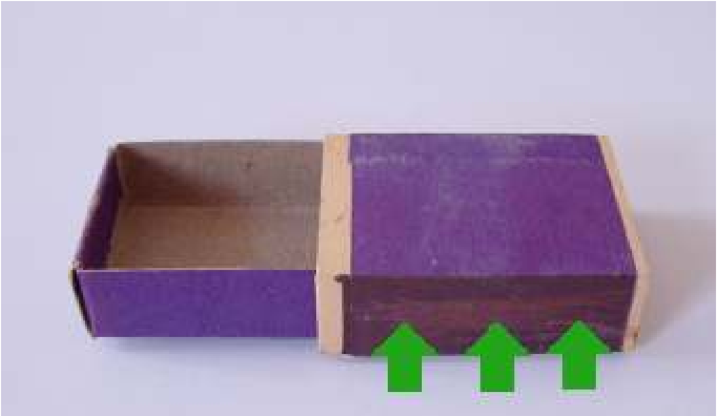

1.


2.


3.


4.

Which part do you scratch?

1.


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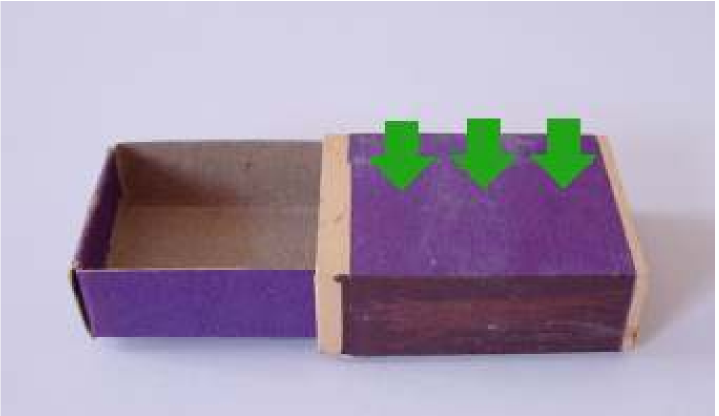

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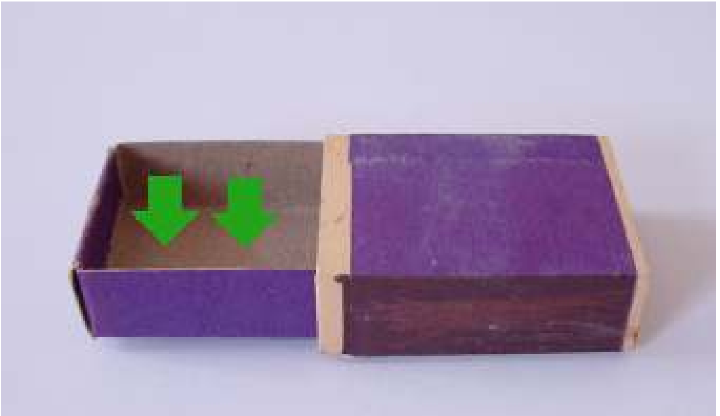

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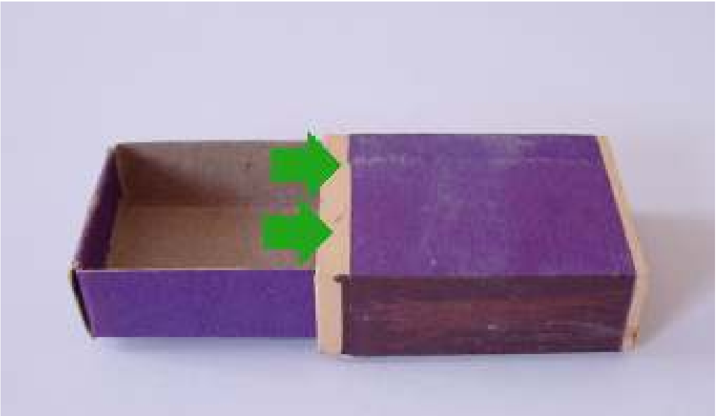
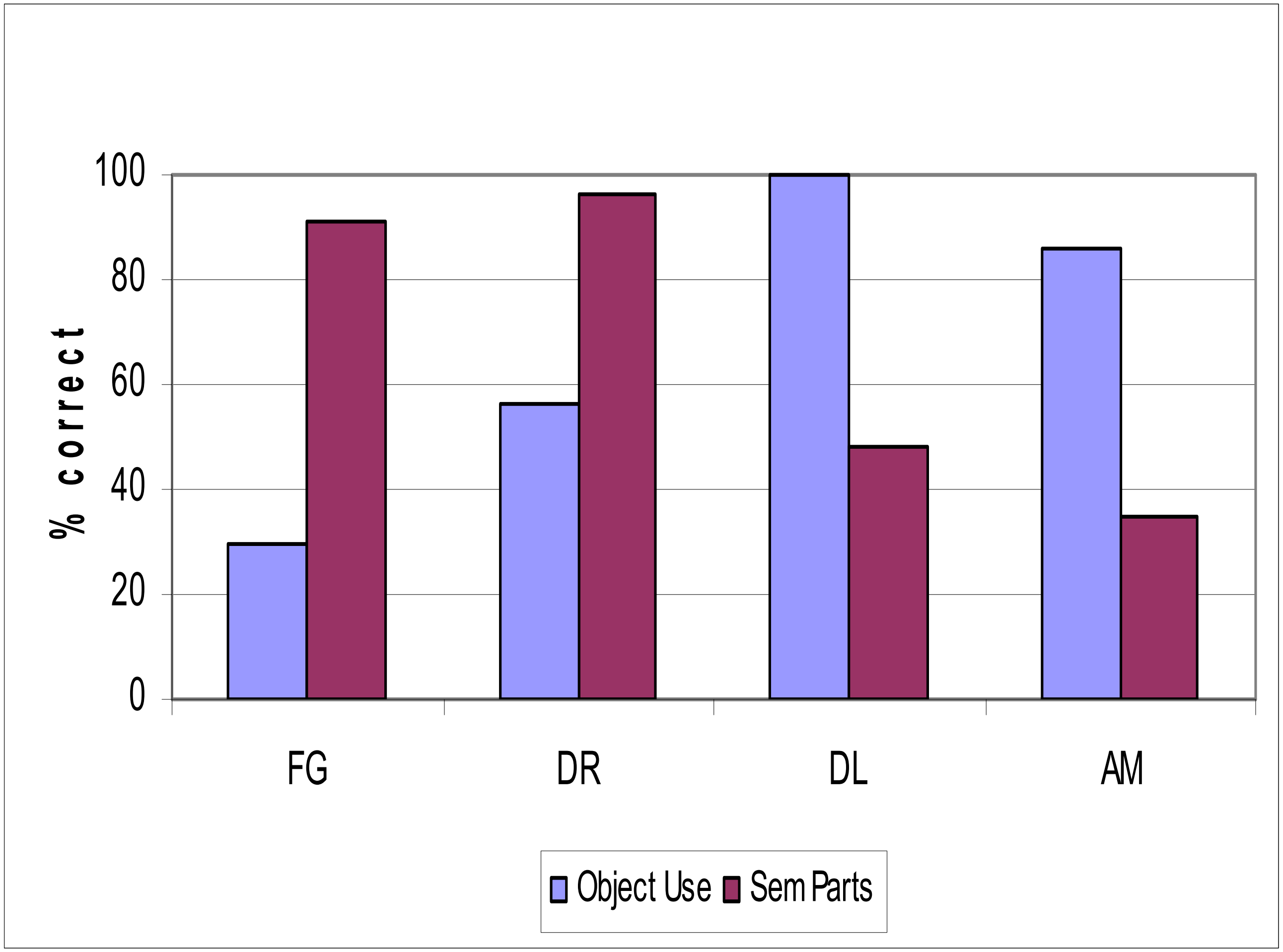


Object Use vs. Semantics of Parts



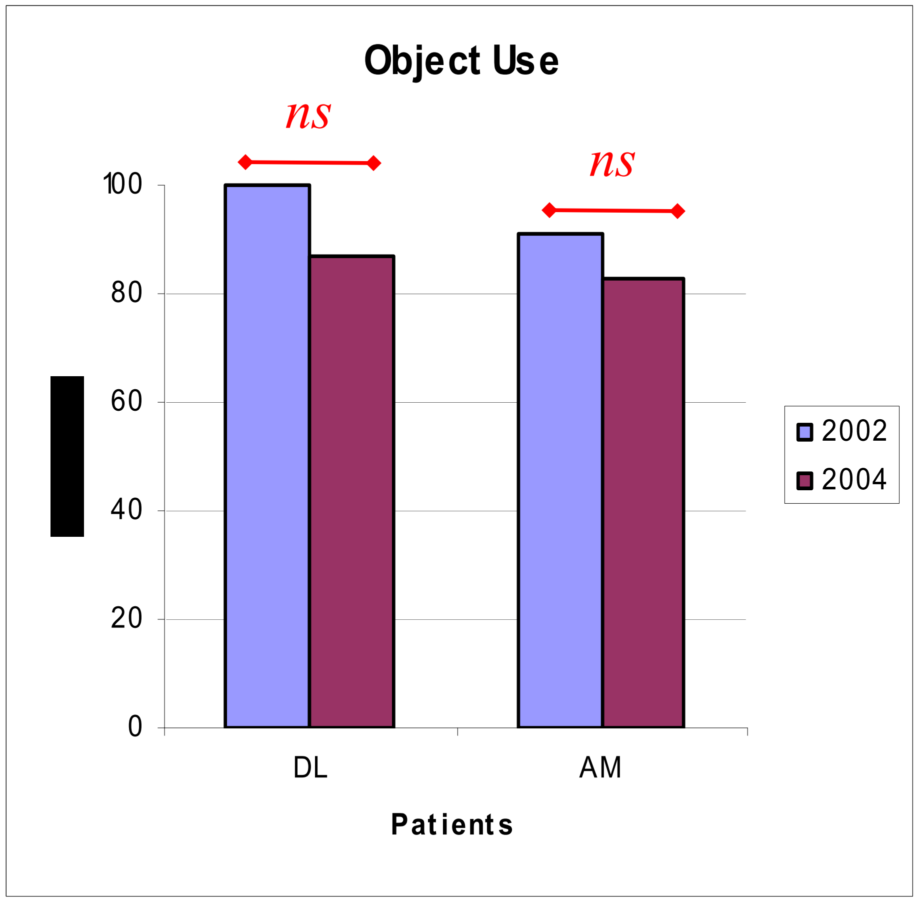
N = 23

Summary

- Apraxic patients failed to use objects that they could identify without hesitation in a word-to-object matching test.

- Of these objects, FG and DR retained:
  - – semantic and functional knowledge
  - – functional knowledge of an object’s parts

Negri et al. 2007

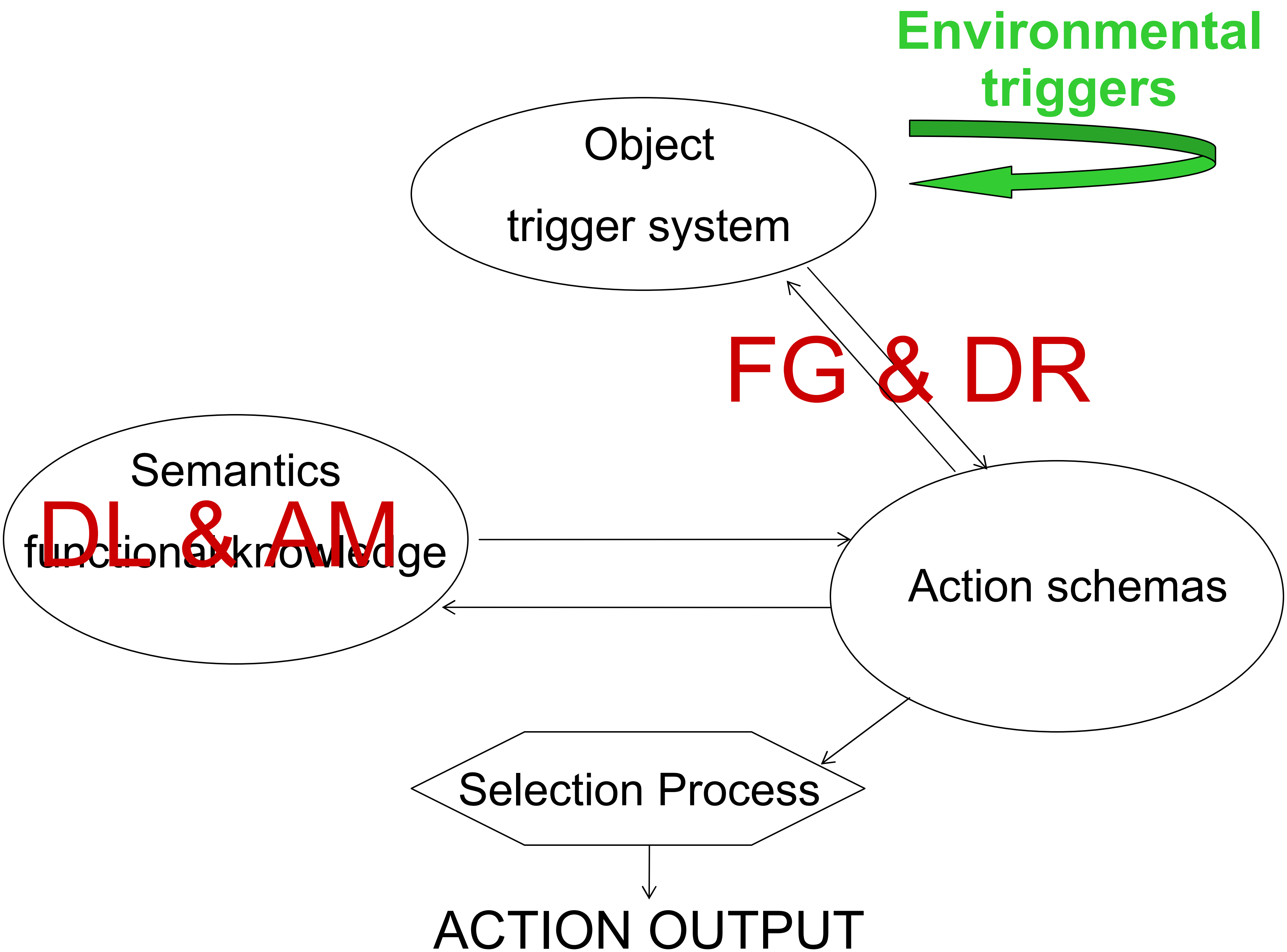


Object Use & Semantics

	Object Use			
	AM		DL	
Experiment	**2002**	**2004**	**2002**	**2004**
General Semantics/words	<.01	<.001	<.001	n.a.
General Semantics/pictures	<.01	<.001	<.001	<.05
Functional Semantics of Parts	<.01	<.05	<.01	n.s.

Conclusions

- The tests used contacted patients' semantic properties and motor-based properties:
  - semantic-functional properties are affected in DL + AM
  - motor-based properties are affected in FG + DR (output).
- We suggest that these two sets of properties are organised in modules of a distributed object representation.

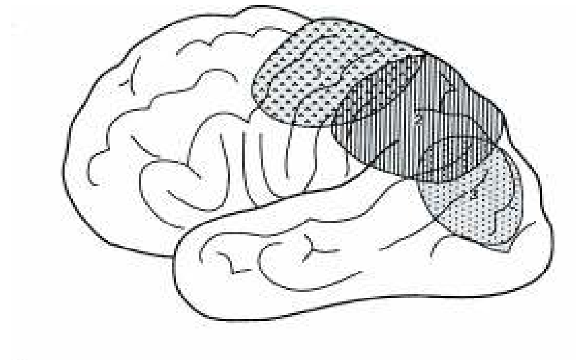

Environmental triggers
Object
trigger system
FG & DR
Semantics
functional knowledge
DL & AM
Action schemas
Selection Process
ACTION OUTPUT

- These two subsets of properties are likely to have different neural bases.
- Patients with a semantic deficit had an atrophy of the left temporal lobe, whereas the lesion of the apraxic patients overlapped in the left inferior posterior cortex (BA 40).

Where in the brain?

- Neuropsychological attempts to analyse the neural bases of skilful object use and imitation have proved difficult because:
  - patients tend to have rather large lesions and additional deficits, e.g. action and object agnosia, or deficit in action imitation.
  - it is difficult to collect a large series of patients with selective deficits.

IA, 3



- IA of both limbs can be observed after a vascular lesion in the left-hemisphere of right-handers suggesting that is a focal symptom.

- Liepmann (1900-1920) left occipito-parietal junction
- De Renzi & Lucchelli (1988) left temporo-parietal junction

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NeuroImage 21 (2004) 1224–1231

Neural basis of pantomiming the use of visually presented objects

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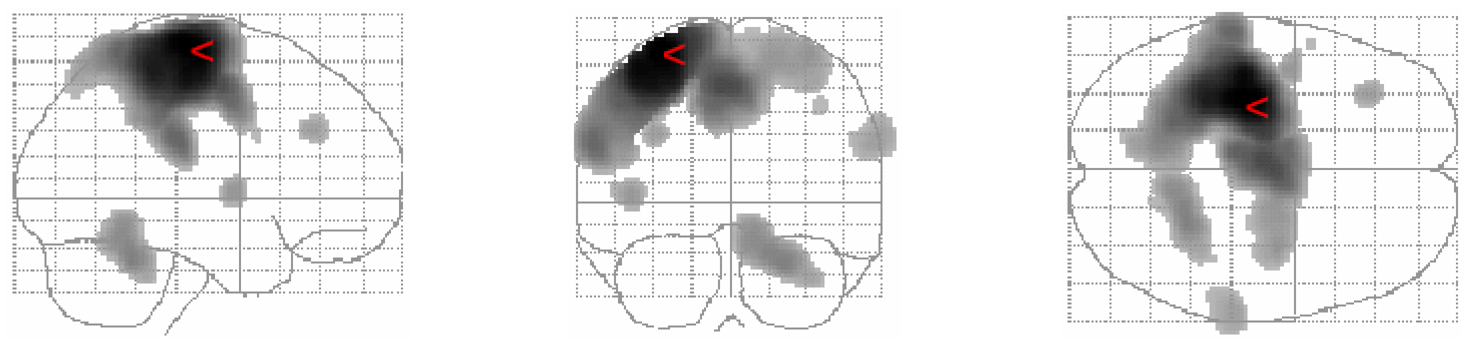
		Stimulus	
		Objects	Actions
Response	Naming	NO	NA
	Imitation	IO	IA

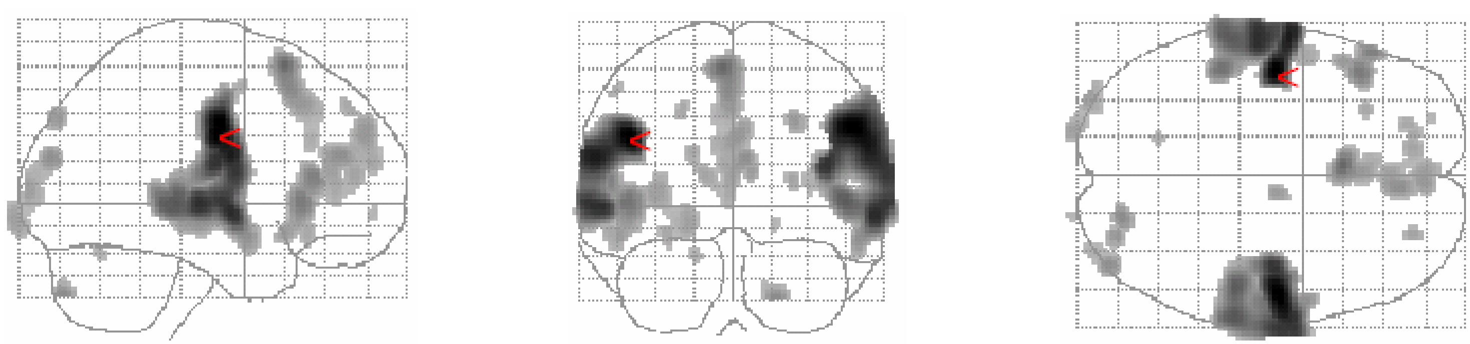
- 14 male subjects (mean age 26.14 ± 6.05)
- right-handed
- 90 different videotaped actions/objects were showed on a screen installed ahead of the subjects in the PET-scanner
- 12 PET-scans with 3 repeats per condition were carried out for each subject
- For each rCBF measurement, subjects viewed a white screen for 15 sec, then the stimulus sequence for 90 sec (each trigger 2.5 sec plus 0.5 sec ISI)
- Subjects performed the production task using the right hand

Main effect: Response

Imitation > Naming

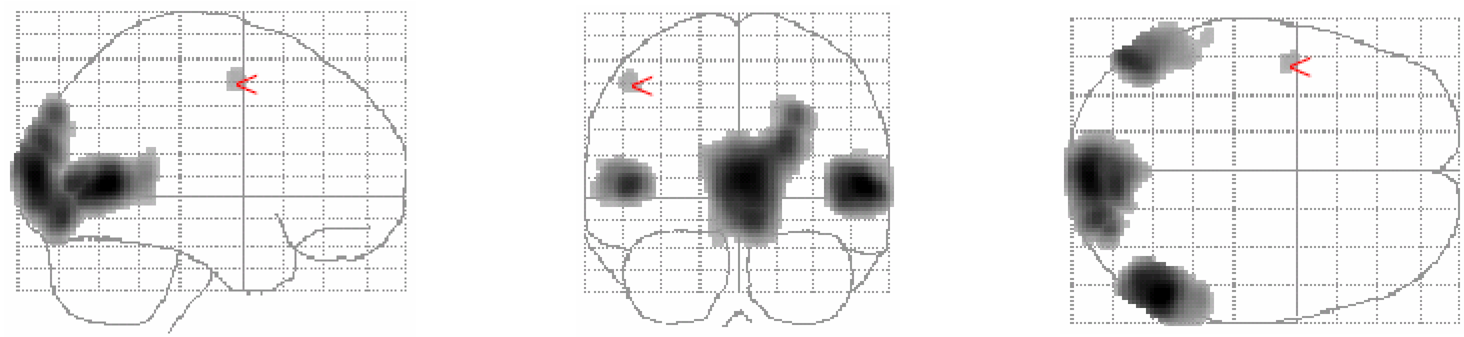


Naming > Imitation

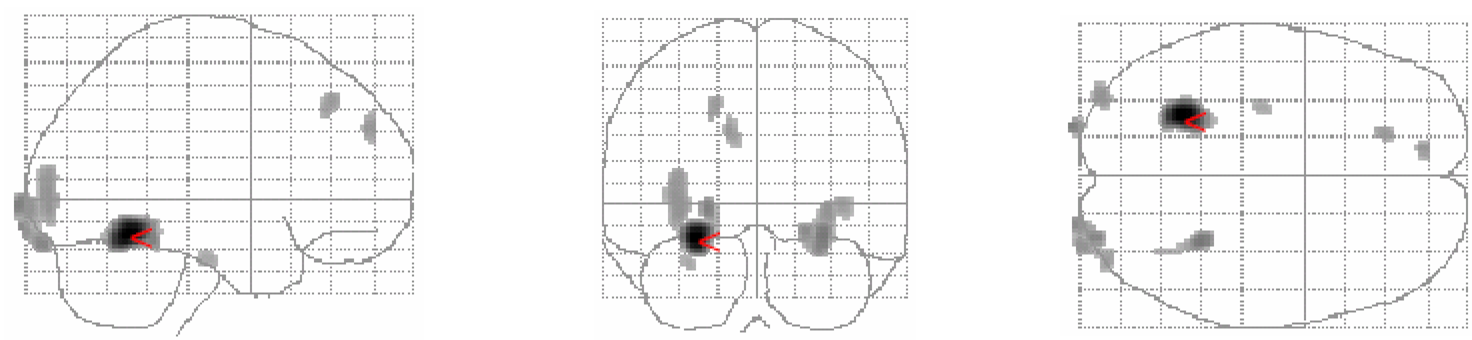


Main effect: Stimulus

Action > Object



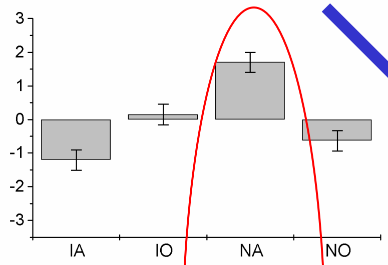
Object > Action



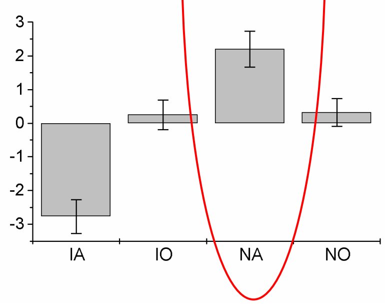
Interaction

(IO - IA) - (NO - NA)

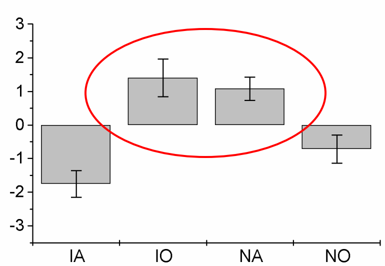
DLPFC
-48, +8, +44; T=5.46

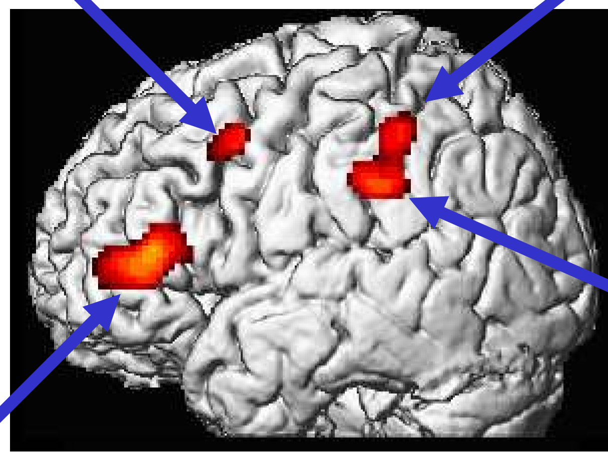


AAC
-4, +30, +34; T=5.55



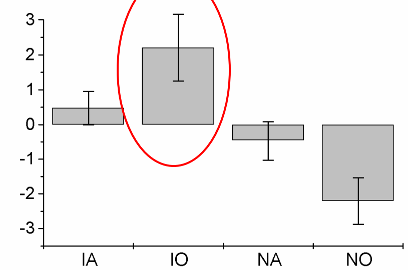
VLPFC
-44, +46, +6; T=6.46



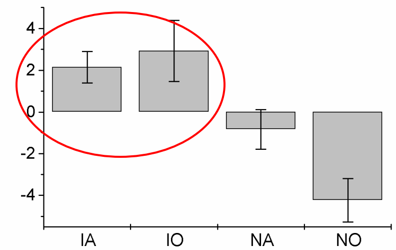


$p \leq .05$

d IPL
-52, -44, +46; T=5.19

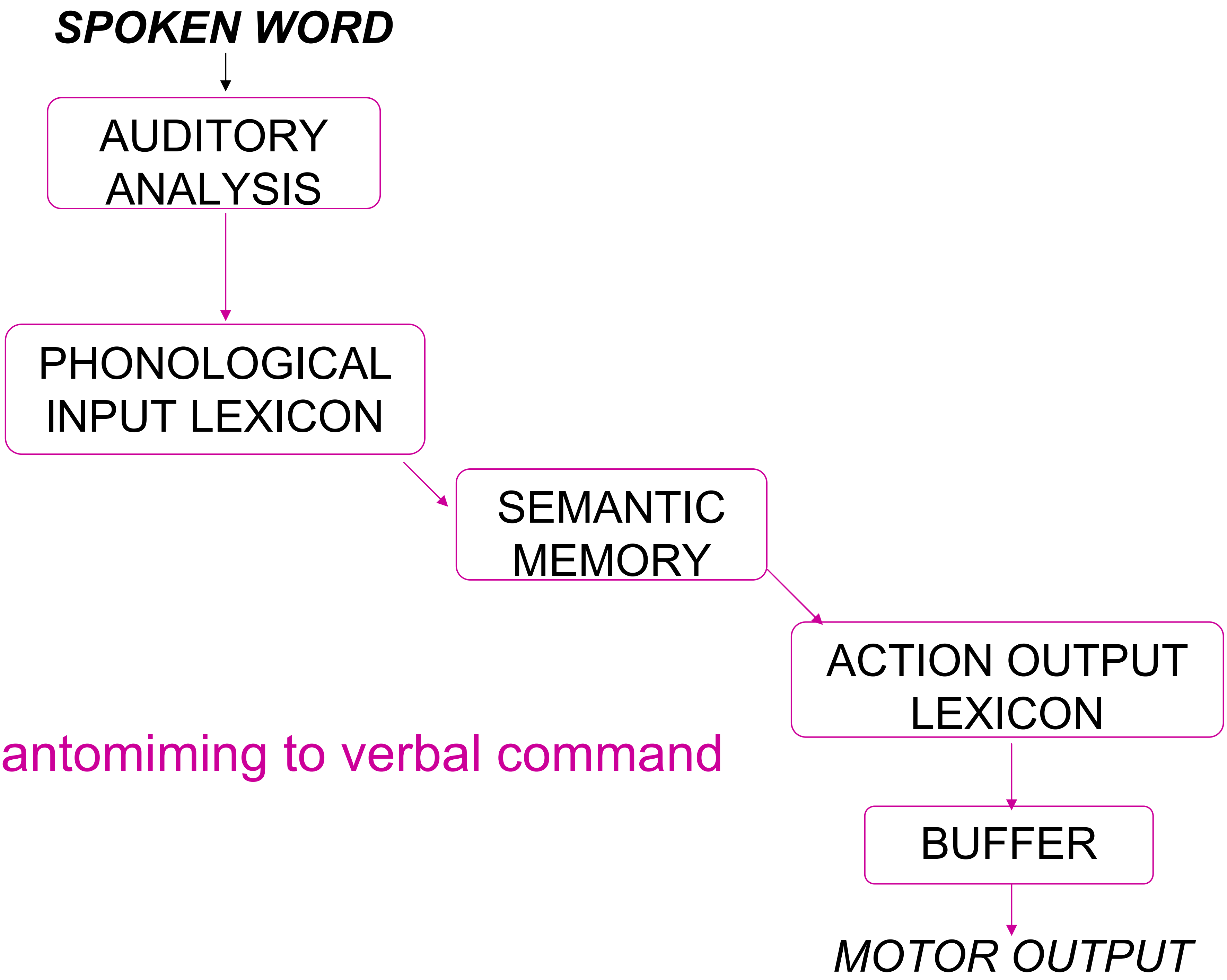


v IPL
-58, -32, +30; T=5.30

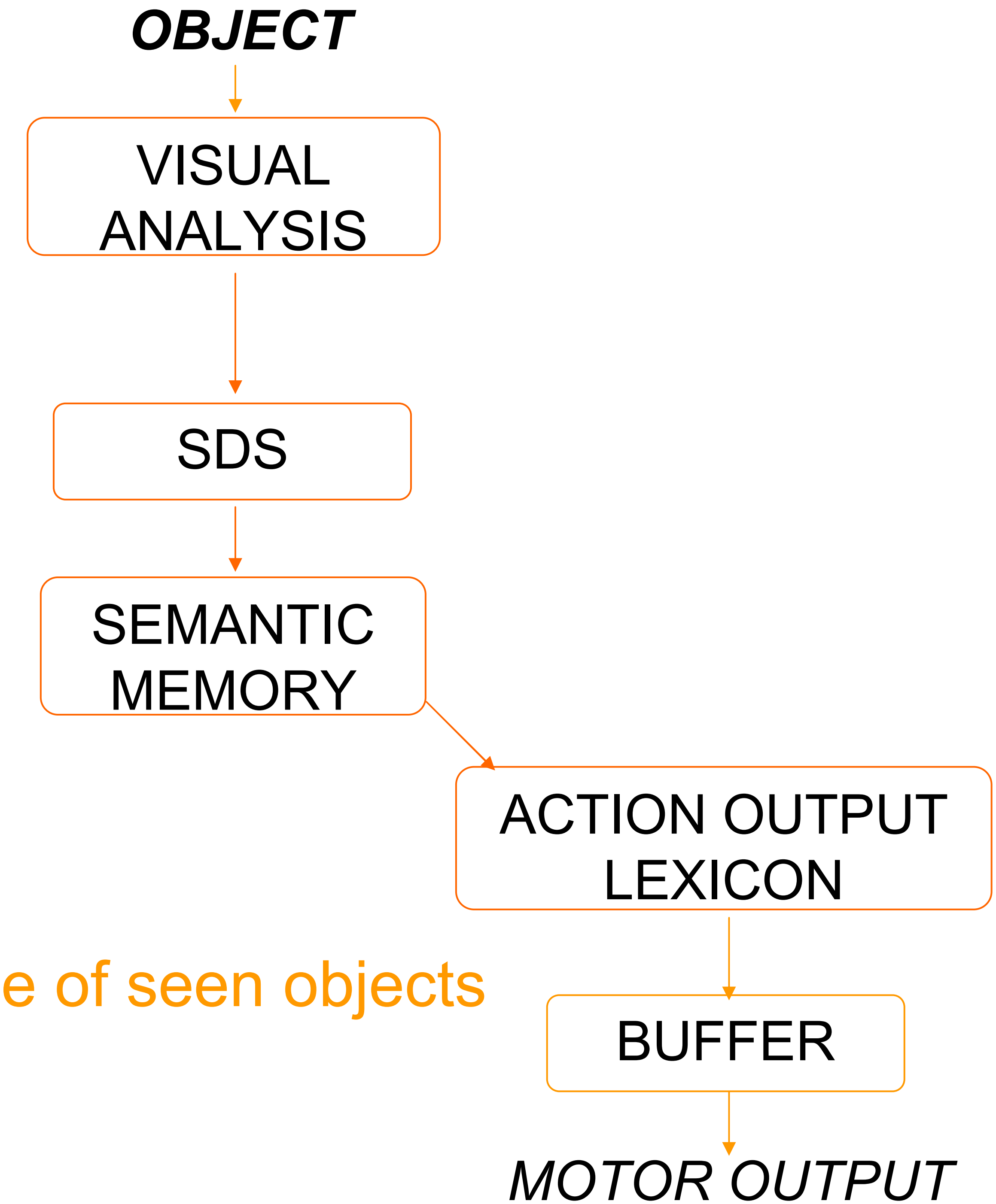


Conclusions

- Our findings suggest a close link between seen objects and the motor information associated with actual use.
- In right-handed individuals, the key brain structure for an object system that triggers actions is in the left dIPL (BA 40).
- This provides an explanation of why left parietal damage may result in impaired tool use despite preserved lexical and semantic knowledge.



Pantomiming to verbal command



Pantomiming the use of seen objects