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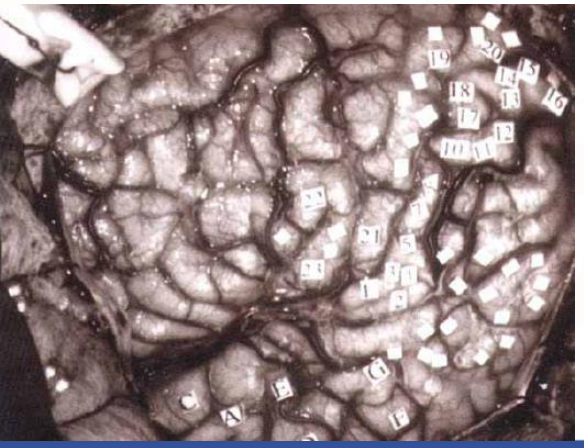
Simple Calculation In The Brain: Evidence From Direct Cortical Electro-Stimulation



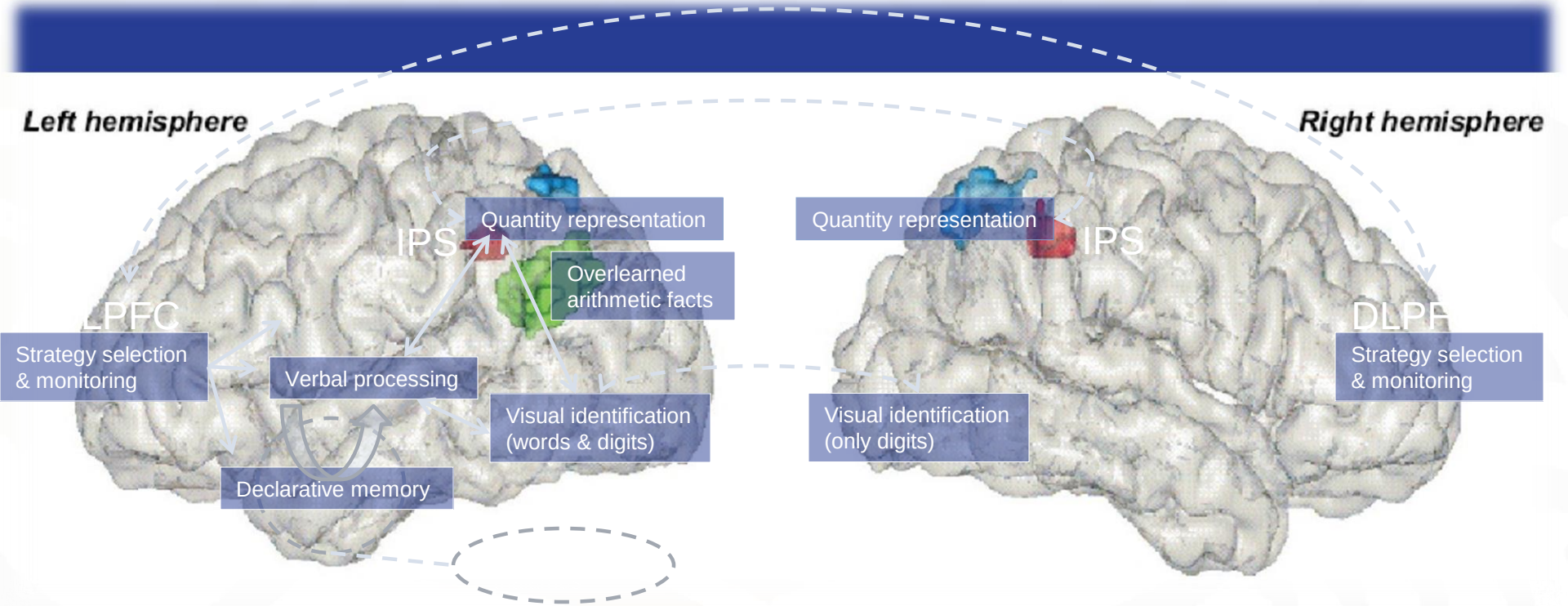
New Approaches To The Neural Basis of Mathematical Cognition.
Symposium 9

How do the Parietal Lobes contribute to Simple Calculation?

Why asking?

Why using DCE to answer?

Dehaene & Cohen (1995)



Dehaene & Cohen (1995)

(neuroimaging, clinical cases)

Number Comparison:

bilateral posterior/superior parietal

Simple Addition:

left angular gyrus, HIPS

Simple Multiplication:

left angular gyrus, HIPS

Recent data suggest that
Dehaene & Cohen's (1995)
model (and its later extensions)
may need some addition:

a few studies with
TMS and fMRI
evidenced the role of further areas.

Andres et al. (2011), Salillas et al. (2012)
(TMS)

Addition:
left angular gyrus; left and right HIPS

Multiplication:
left angular gyrus; left (and right) HIPS, right VIPS

Rosemberg-Lee et al. (2011), Price et al. (2013)
fMRI

Multiplication: right parietal (!)

TMS and fMRI
show that both
simple Multiplication and Addition
seem to require to certain extent the
contribution of the

right hemisphere!

Literature on right hemisphere acalculia seem to have already reported as much, showing problems even with simple calculation, but nobody seemed to notice: no discussion can be found.

Are these deficits specific or result from lack of general resources?

What are the respective roles of left and right Angular gyrus (ANG), Supramarginal gyrus (SMG) HIPS and VIPS

in (simple) Addition, Multiplication and Number Comparison?

A complex question!

The S. Thomas's (apostle) approach

= cortical electro-stimulation during awake surgery

Duffau's version/technique

Electro-stimulation during surgery and MATH

Whalen et al: single digit multiplication disturbed by left parietal stimulation to a much larger extent than single digit addition.

Duffau et al: multiplication in the inferior part of the angular gyrus and a distinct functional site for subtraction in the superior part immediately below the intra-parietal sulcus.

Kurimoto et al: common addition and subtraction areas in the left angular gyrus.

Roux et al: two-digits plus two-digit addition in left parietal lobe and F2 .

Pu et al: subtraction and multiplication in the left angular gyrus, in the horizontal portion of the left parietal sulcus (lHIPS) and multiplication only in left supramarginal gyrus.

SO FAR ALL LEFT HEMISPHERE PTS!

Electro-stimulation during surgery and MATH

Only one study about the right hemisphere:

Yu et al:
simple subtraction
in right parietal lobe
(no better specified, but including the angular gyrus)

Present experiment

Tasks:
Addition, Multiplication, N. Comparison

- single-digit addition with one operand (e.g., 4+7; 8+6; 5+7….).

- single-digit multiplication with one operand (e.g., 8x4; 5x6; 9x7….).

Each operation had to be solved within the four-seconds time of the stimulation.

Cortical Electro-stimulation

Each participant was presented:

A block of 14 additions, repeated three times, in random order, alternating stimulation every other trial. On each stimulation site the patient performed three additions, for a total of 22 trials with and 20 trials without.

A block of 15 multiplications was then administered with the same procedure, for a total of 24 tests with and 21 without stimulation.

Cortical Electro-stimulation

Sites:

Angular gyrus, Supramarginal gyrus,
HIPS, VIPS, Superior parietal lobe
+
subcortical parietal areas
(after removal of cortex)

Positive site = at least 2/3 interferences

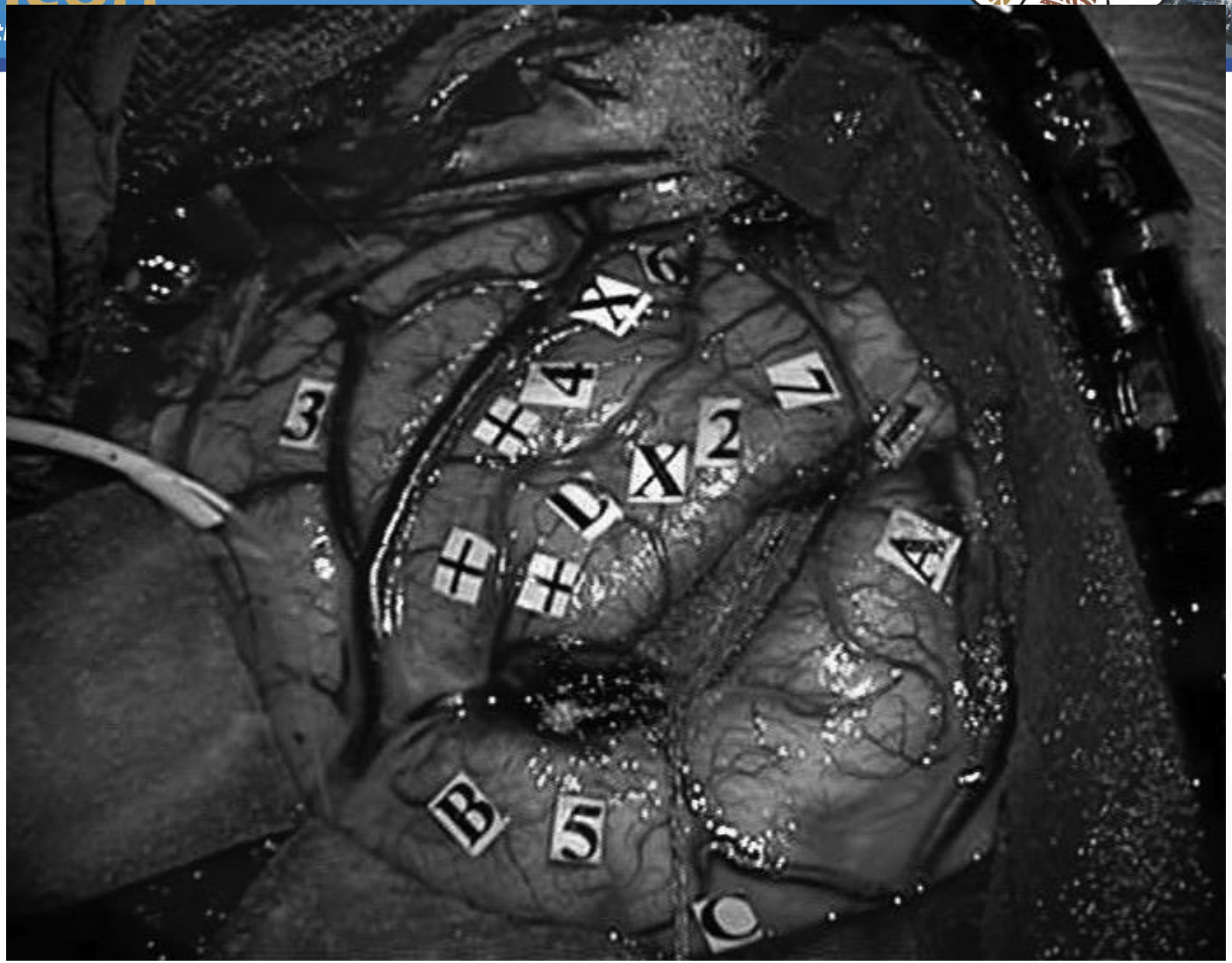
Cortical Electrostimulation

Participants:
(people with parietal gliomas):

4 Left hemisphere patients
(L1, L2, L3, L4)

5 Right hemisphere patients
(R1, R2, R3, R4, R5)

All right handed


3
4
6
7
2
B
5

Negative results

-No critical sites found in VIPS

-No critical sites found for N. Comparison

Positive sites

Site	Angular Gyrus	Supramarginal Gyrus	HIPS	Superior Lobule	Subcortical
RIGHT					
1	1M	1M	1M	1M	
2	1M	1A	1M	-	
3	1M	1M	-	-	
4	-	1M 1 A	-	-	2M 1A
5	-	-	-	1M	2M 1A
LEFT					
1	3A	2M	1M	-	
2	-	1M	1M	1A	
3	-	1M	1M	2A	
4	2M	1M	1M	1M	2M

INTERIM SUMMARY (1)

SMG/ANG: bilaterally for multiplication and addition

HIPS: bilaterally for multiplication

Subcortical: positive sites for each operation!

No single site positive for both operations

INTERIM SUMMARY (2)

Multiplication sites relatively more sparse in right parietal than in left parietal, where they appear to be more compact.

An anterior/posterior gradient ?
On the left: mult = ant add = post

Multiplication

Both hemispheres seem crucial for multiplication,
although slightly more errors after LH stimulation
but
possibly through different mechanisms revealed by
different patterns of errors.

Only about 5% of *Omission* errors

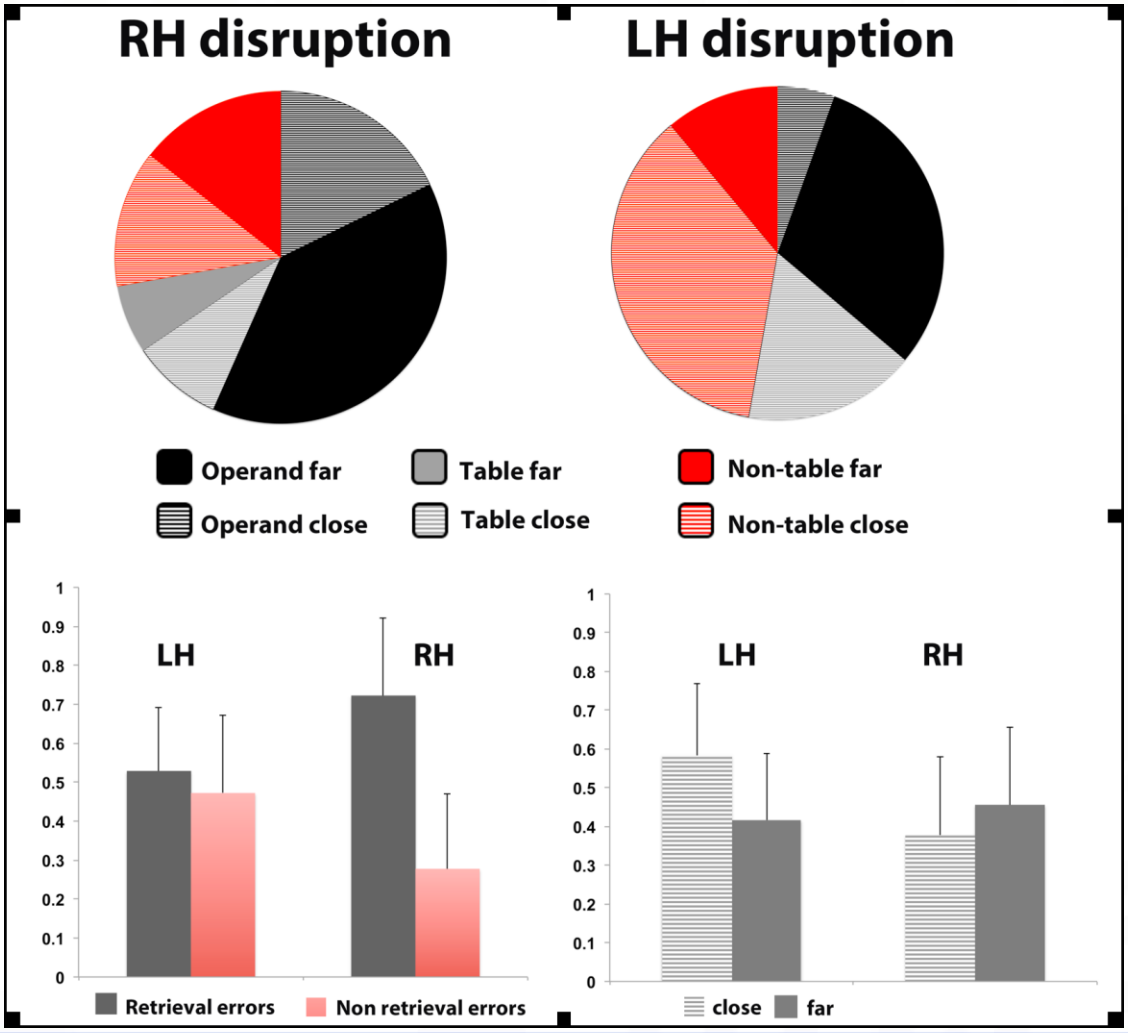
***Commission* errors in multiplication were qualitatively different after stimulation of the left and of the right hemisphere:**

"table errors" (retrieval)

vs

"non table errors" (approximation)

Errors in multiplication



RH stimulation/disruption

RETRIEVAL

errors in most cases!

LH stimulation/disruption

RETRIEVAL and APPROXIMATION
(errors 50%-50%)

many more close (distance) non-table errors

Addition

Both hemispheres involved in addition.
Not symmetrically?

-LH:
ANG, SP
posteriorly and superiorly with respect to Mult.

-RH:
SMG, HIPS
as some Mult.

DISCUSSION
(1- RH)

The clearest finding is the positive sites for multiplication on the right, including ANG, SMG, HIPS, superior parietal and subcortical parietal areas.

This is in agreement with Salillas et al. findings with TMS as well with recent fMRI findings.

DISCUSSION
(2- RH)

Positive sites for subcortical areas in calculation are found for the first time.

Further research is needed to understand the role of subcortical pathways

DISCUSSION
(3- RH)

No positive sites on VIPS
(unlike in Salillas et al. TMS study)
may mean that
right VIPS helps but is not necessary.

DISCUSSION
(4- RH)

The literature on right hemisphere acalculia must be read more carefully: not all errors have a spatial origin.

Problems with simple calculation have been observed all the time but never commented upon.

DISCUSSION
(5- RH)

Findings on the right hemisphere are also interesting for medical reasons: it adds to standard procedures for probing the functionality of right parietal areas (and subcortical parietal areas) for the purposes of awake surgery.

DISCUSSION
(6- RH)

The right sulcus region used to be the preferred way of access to posterior subcortical gliomas
because it was thought to be a relatively non-functional area.

Whether surgery on positive sites could result in permanent damage of math functions remains to be demonstrated.

DISCUSSION
(7- LH)

The relative surprise finding
is the limited amount of positive sites
for multiplication in the left ANG
(cf. Dehaene and Cohen's model).
This needs further research.
The ANG/SMG border is arbitrary:
it's safer to think that in the
left inferior parietal lobe
multiplication tends to be anterior
and addition is sustained more posteriorly.

DISCUSSION
(8)

No single site positive for both operations!
(positive sites were operation consistent)

This suggest that found cortical sites are operation-specific.

This rules out the possibility that results are determined by diminishing resources!

DISCUSSION
(9-errors)

This investigation (for the first time) included analysis of errors.

Results suggest that in Multiplication:

The left hemisphere relies more on retrieval.

The right hemisphere relies more on approximation.

RH stimulation/disruption

(9.1-errors)

retrieval errors in most cases!

Retrieval mechanisms
typical of the left hemisphere
might be spared.
The patient uses correct type of search,
... but lacks precision;
a correct solution is not reached,
resulting in table errors.

LH stimulation/disruption
(9.2-errors)

Retrieval and approximation errors
(50%-50%)
many more close (distance) non-table errors

approximation mechanism
spared because RH at work?

DISCUSSION
(10-errors)

These findings need to be compared with errors committed by left and right brain damage patients. This comparison would be of limited value, however.

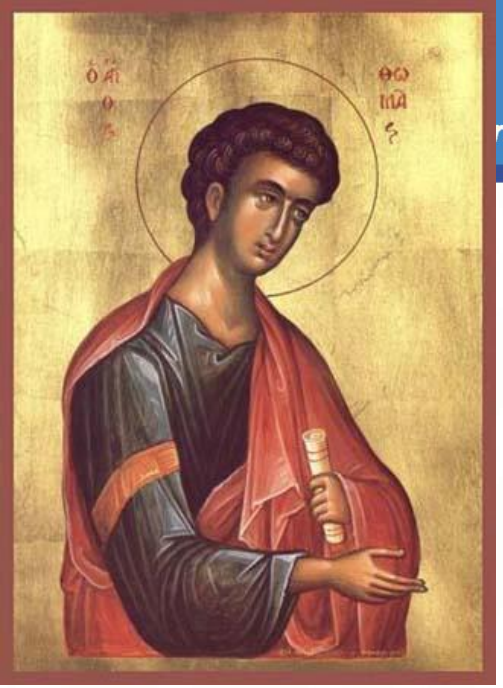
The balance in the working of the two hemisphere is likely to have undergone changes after brain lesion.

The in vivo observation provides the best opportunity to highlight what is really going on.

DISCUSSION
(11-errors)

These conclusions need further analyses and converging evidence.

Two different more basic numerical abilities, retrieval and approximation may be recruited for even simple multiplication. Their on-line interplay seems to be highlighted by DCE.



CONCLUSION

much still to do

…

S. Thomas

may put in a good word for

my next grant proposal

Thanks to

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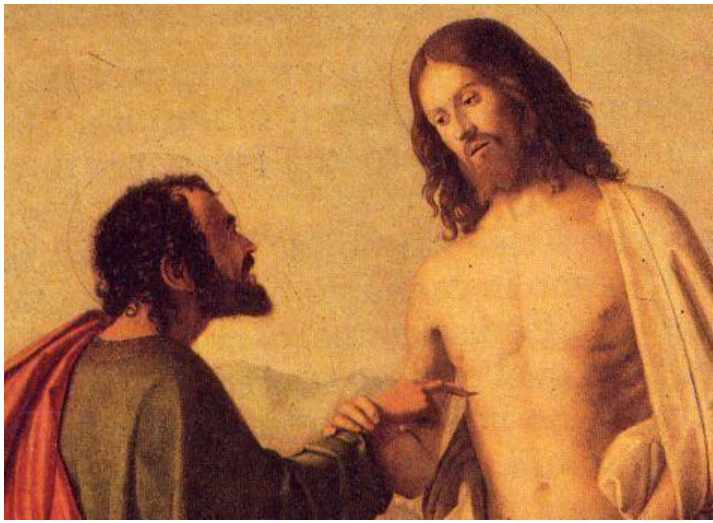

THANK YOU!

COMMISSION ERRORS - MULTIPLICATION

retrieval errors

A) operand distance: (6x8=42)
solution related on table to one of the operands; closest problem in table

B) operand (6x8=12)
same as A, but solution far in table

C) table distance (6x8=45)
valid solution to different problem, close in table

D) table (6x8=14):
same as B, but far in table

non-retrieval errors

*** non-table distance (6x8=51)**
solution not on table but very close to correct