The role of the left Supramarginal Gyrus in the Short-Term Memory network:

a Transcranial Magnetic Stimulation study

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BACKGROUND

"(it is more likely that) evolution has applied the same solution to a problem, maintaining serial order, that crops up in a range of different domains" (Baddeley, 2012)

The cognitive strategies for the retention of order information seem to be shared among different domains of Short-Term Memory (STM)
(Hurlstone et al., 2013)

For example, evidences have been found in:

- Verbal STM
(Hurlstone et al., 2013)

- Visuo-spatial STM
(Ginsburg et al., 2017)

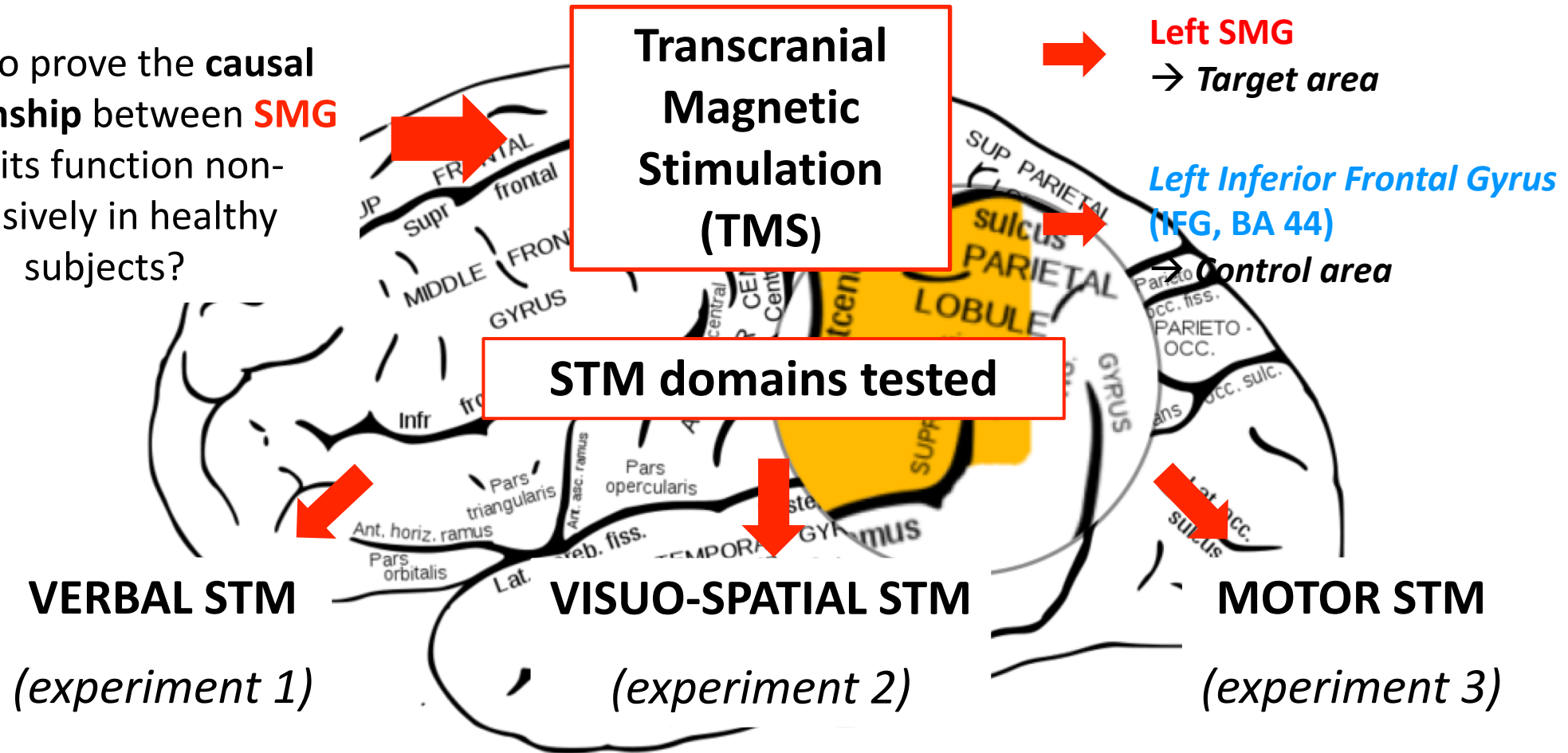- Auditory STM
(Gorin et al., 2018)

It is plausible to assume that our brain could be equipped with a dedicated mechanism for these functions. In a perspective of saving cognitive resources, such mechanism would be ideally **amodal, supporting the retention of the serial order of any kind of information,** regardless of its specific content (e.g. verbal, spatial, motor, sensory).

Recent evidences on patients suggest that, at least in auditory-verbal STM, the **left SupraMarginal Gyrus (SMG, BA 40)** may be responsible for the storing of order information
(Papagno et al., 2017)

What are the anatomo-functional correlates of this mechanism?

How to prove the **causal relationship** between **SMG** and its function non-invasively in healthy subjects?

Transcranial Magnetic Stimulation (TMS)

Left SMG
→ *Target area*

Left Inferior Frontal Gyrus (IFG, BA 44)
→ *Control area*

STM domains tested

VERBAL STM

(experiment 1)

VISUO-SPATIAL STM

(experiment 2)

**MOTOR STM**

(experiment 3)

! **Same experimental 'structure' and type of task (i.e., span task) in all three experiments** thus to make the results of each experiment perfectly comparable

- 20 right-handed healthy participants in every experiment;
- 3 randomized and counterbalanced sessions separated at least by 24 hours;
- Every subjects participated in only one experiment of the study.

repetitive TMS
- 1 Hz (inhibitory) off-line;
- 10 minutes (600 pulses);
- 100% resting Motor Threshold;
- Left **IFG** and left **SMG** coordinates found by means of neuronavigation
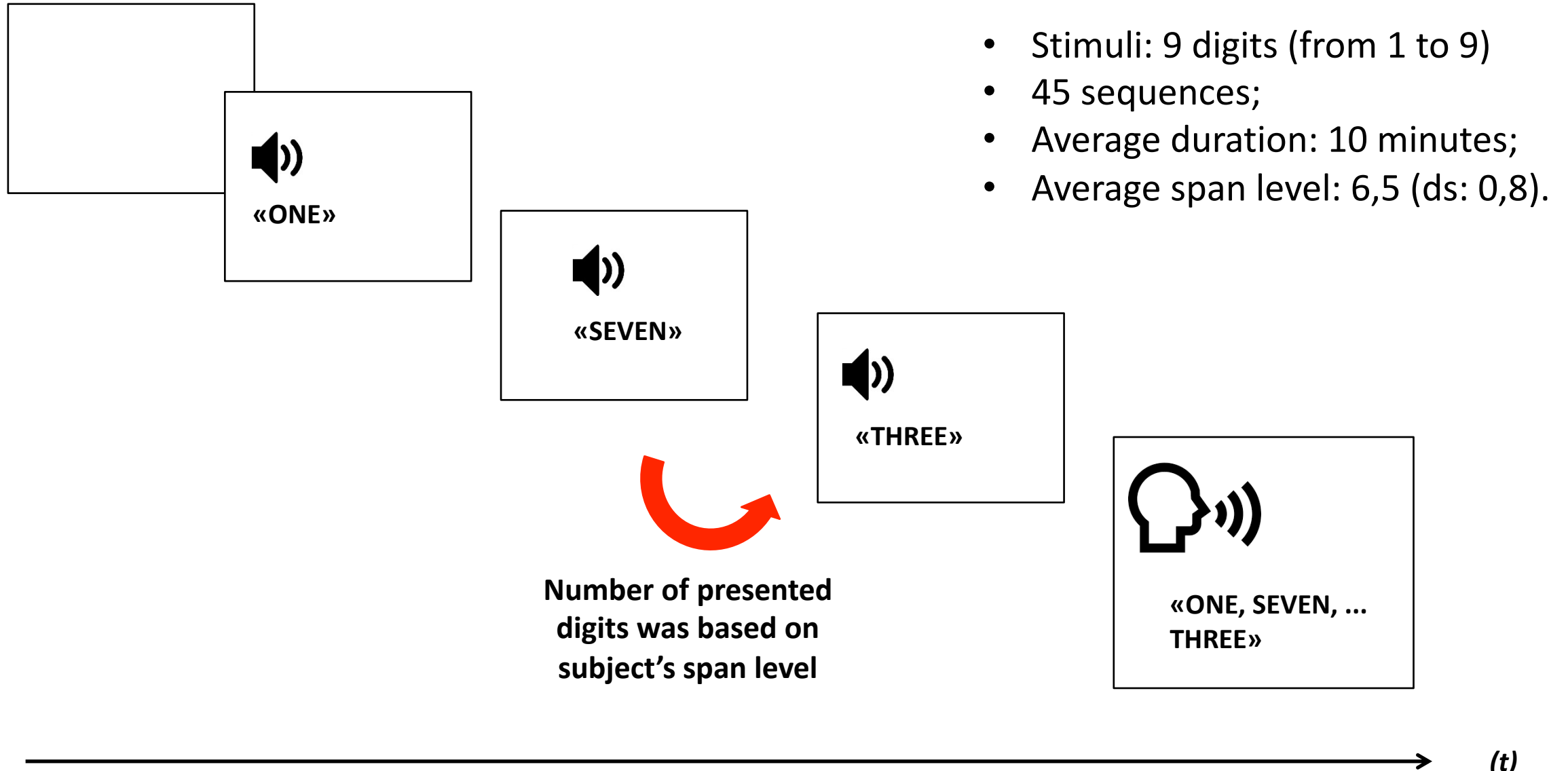
(Romero et al., 2006, 2010).

BASELINE session

Left IFG

Left SMG
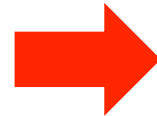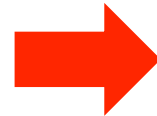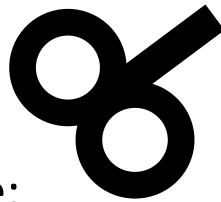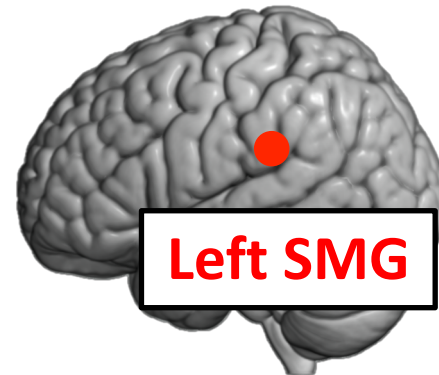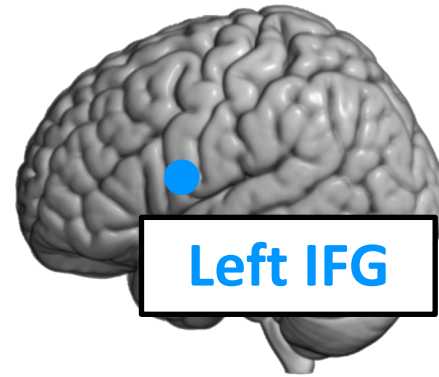
Experimental task
- Auditory-verbal digit span (*Experiment 1*)
- Computerized Corsi span (*Experiment 2*)
- Finger tapping span (*Experiment 3*)

Auditory-verbal DIGIT SPAN task
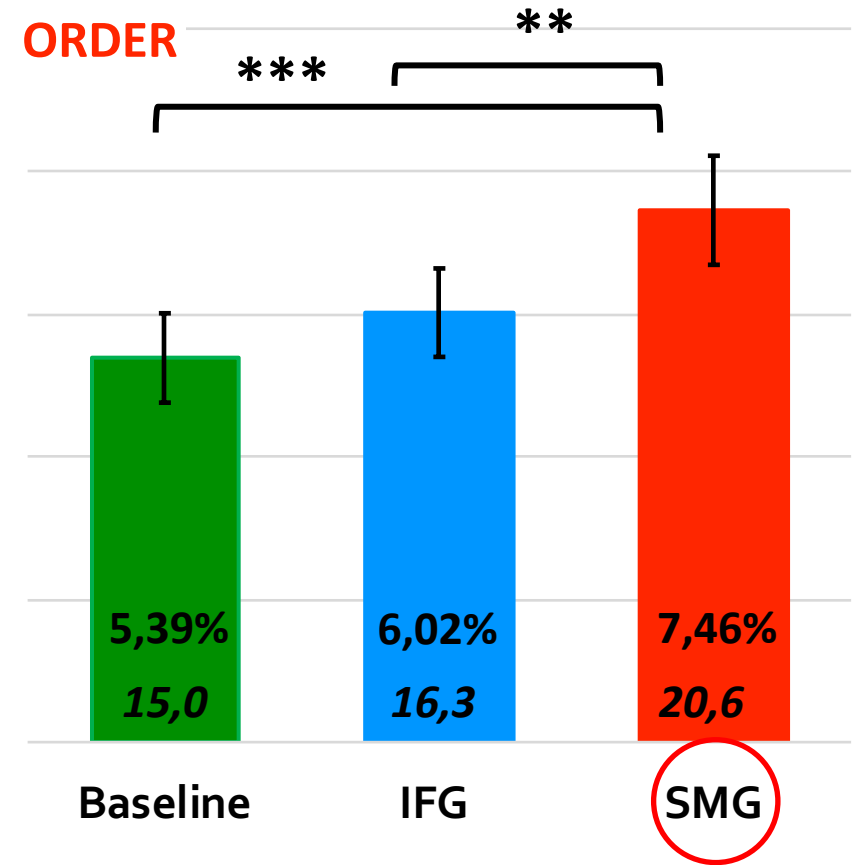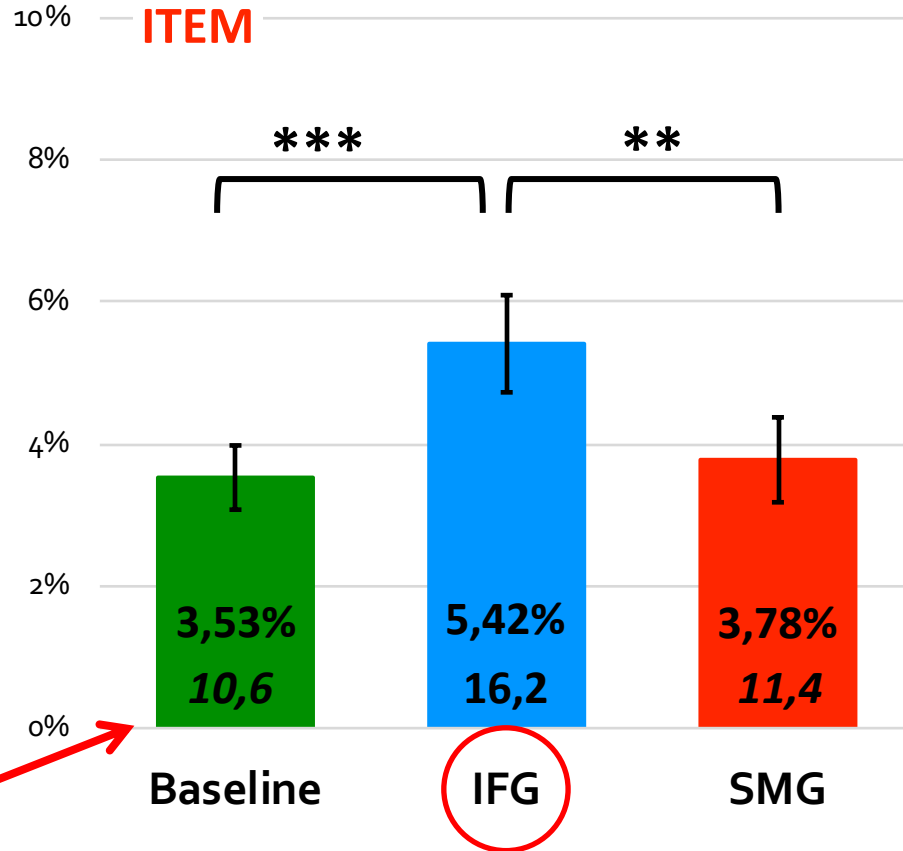
- Stimuli: 9 digits (from 1 to 9)
- 45 sequences;
- Average duration: 10 minutes;
- Average span level: 6,5 (ds: 0,8).

«ONE»

«SEVEN»

«THREE»

Number of presented digits was based on subject's span level

«ONE, SEVEN, ... THREE»

(t)

Dependent variables: proportion of item and order errors
Analysis: repeated measures Analysis of Variance (rm-ANOVA)
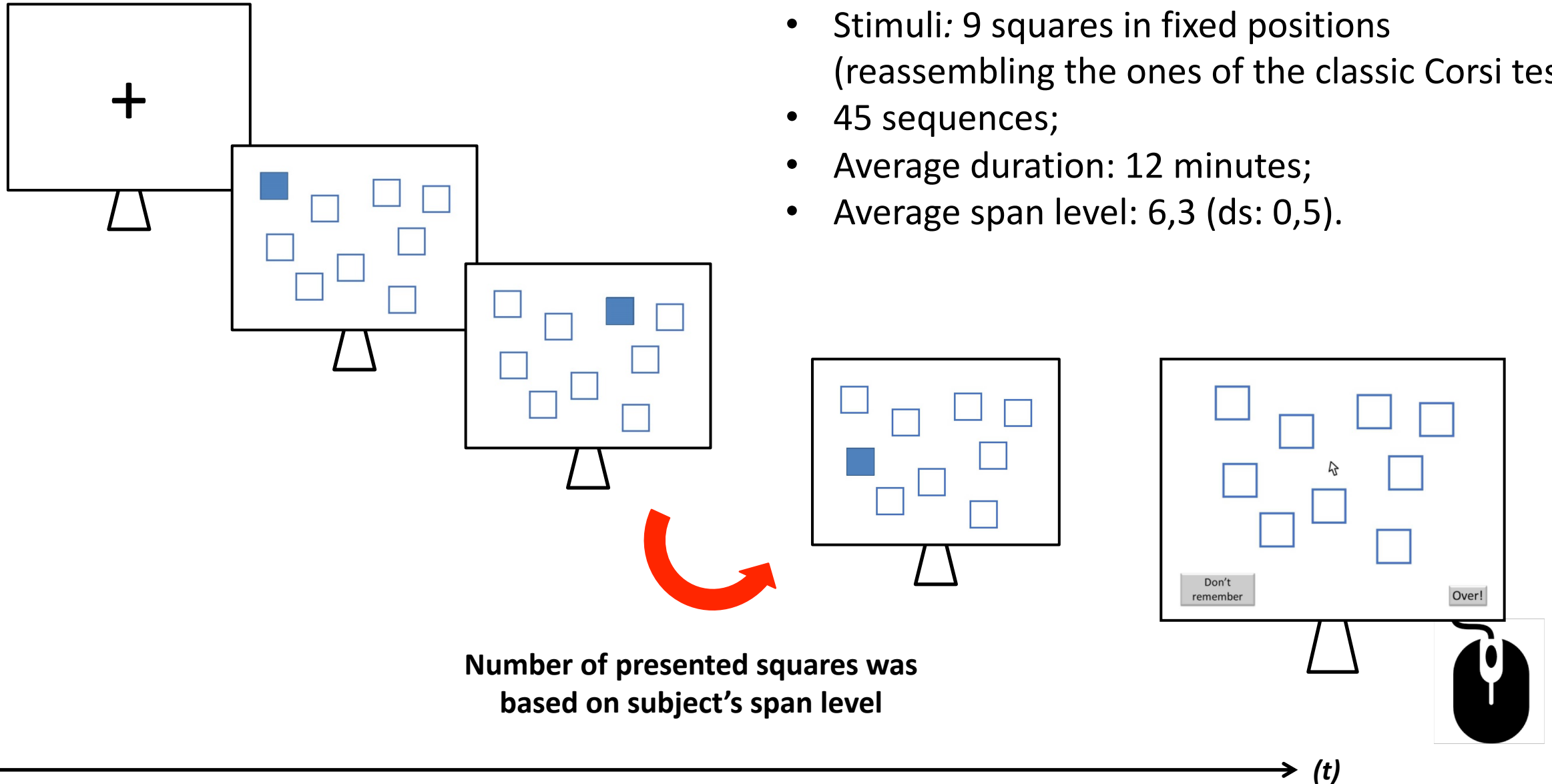*factors*: **3** (session) * **2** (type of error)
Post-Hoc correction: Bonferroni

(!) Omissions, substitutions and **repetitions** of stimuli were considered **item errors**

(!) ~~of~~ stim~~~~ors

	F	p	ηp²
Session * error type	15,58	**<,001**	,45

! ITEM and ORDER errors were scored using the same method in all the experiments
(St. Aubin et al., 1999; Papagno et al., 2017)

* p < 0.05
** p < 0.01
*** p < 0.001
Bonferroni post-hoc

! Raw number of errors

ITEM chart — *** between Baseline/IFG, ** between IFG/SMG
Baseline: 3,53% / 10,6
IFG: 5,42% / 16,2
SMG: 3,78% / 11,4

ORDER chart — *** between Baseline/IFG, ** between IFG/SMG
Baseline: 5,39% / 15,0
IFG: 6,02% / 16,3
SMG: 7,46% / 20,6

Computerized CORSI SPAN task

- Stimuli*:* 9 squares in fixed positions (reassembling the ones of the classic Corsi test);
- 45 sequences;
- Average duration: 12 minutes;
- Average span level: 6,3 (ds: 0,5).

Number of presented squares was based on subject's span level
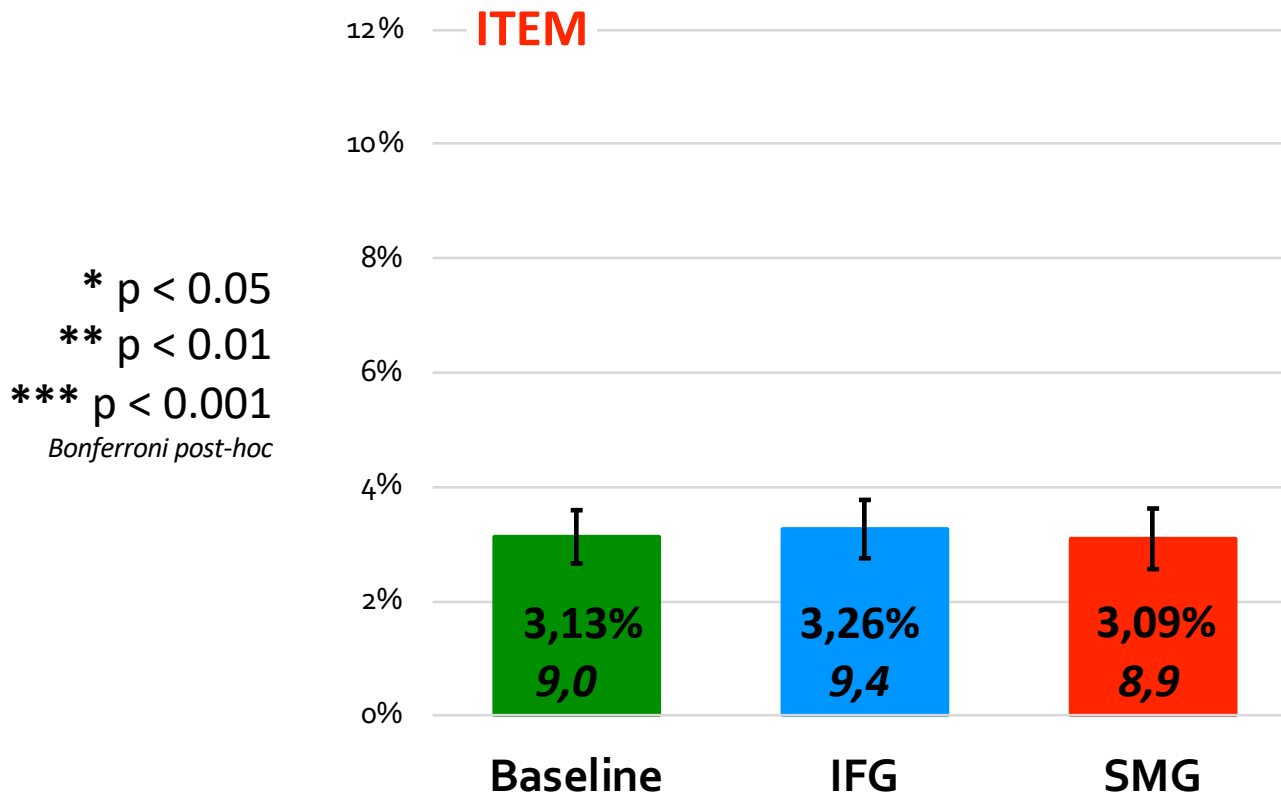
Don't remember

Over!

(t)

EXP 2 – visuo-spatial STM

RESULTS

Dependent variables: proportion of item and order errors
Analysis: repeated measures Analysis of Variance (rm-ANOVA)
    factors: 3 (session) * 2 (type of error)
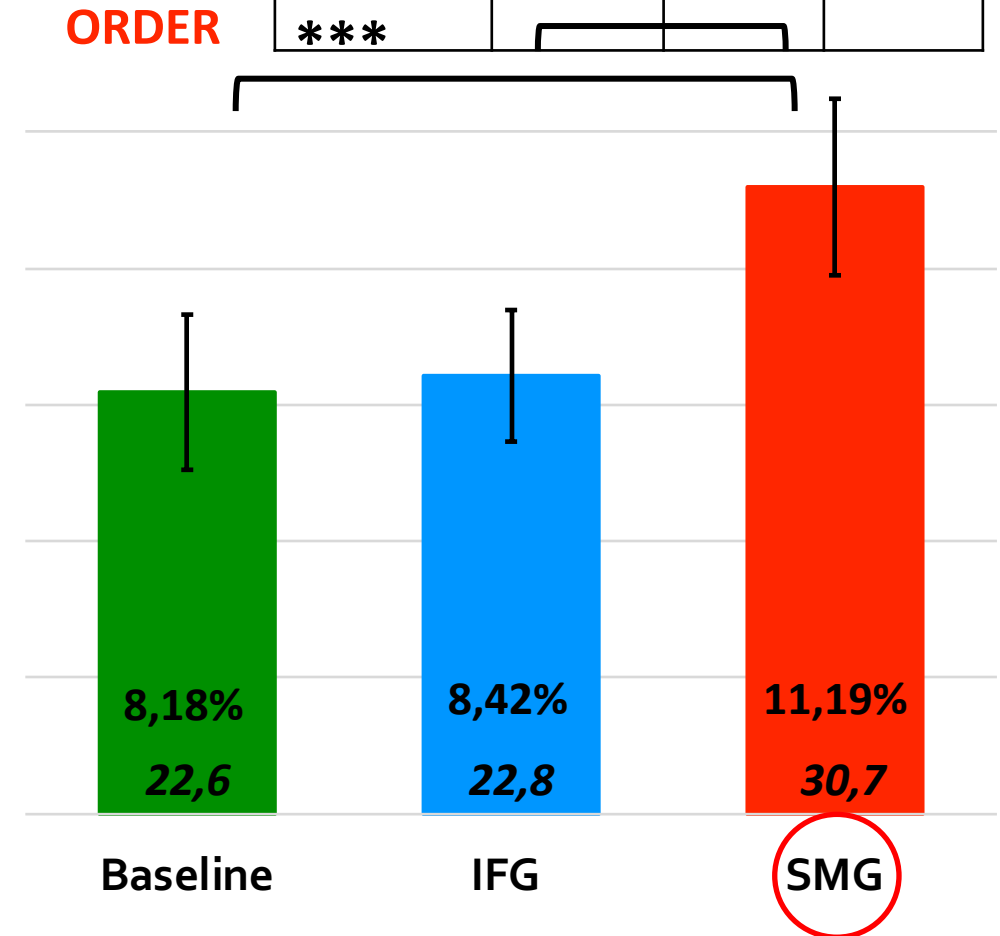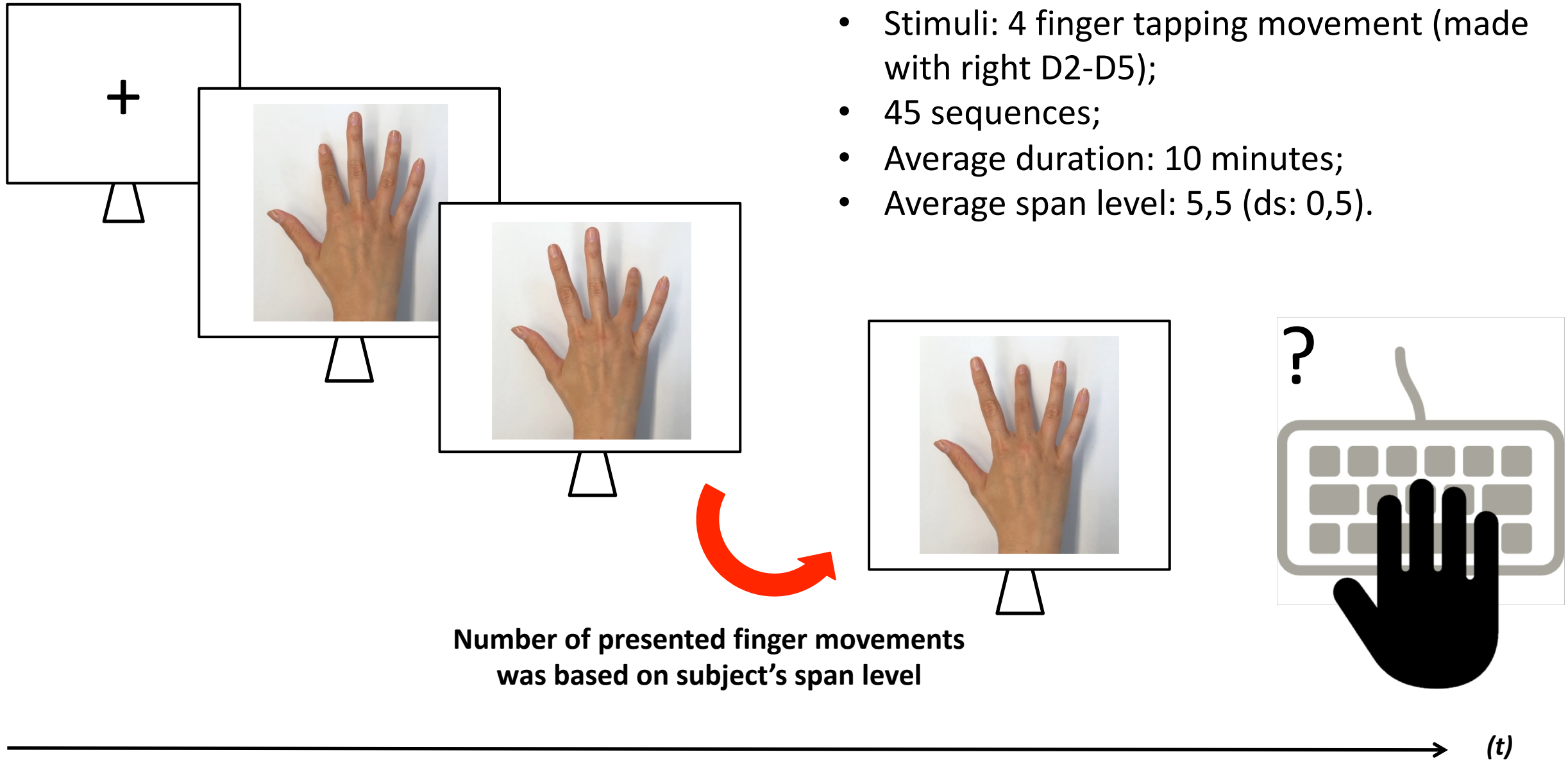   Post-Hoc correction: Bonferroni

	F	p	ηp²
Session * error type ***	6,89	**,003	,27

ORDER

* p < 0.05
** p < 0.01
*** p < 0.001
Bonferroni post-hoc

ITEM

Baseline	IFG	SMG
3,13%	3,26%	3,09%
9,0	9,4	8,9

Baseline	IFG	SMG
8,18%	8,42%	11,19%
22,6	22,8	30,7

Finger tapping MOTOR SPAN task

- Stimuli: 4 finger tapping movement (made with right D2-D5);
- 45 sequences;
- Average duration: 10 minutes;
- Average span level: 5,5 (ds: 0,5).

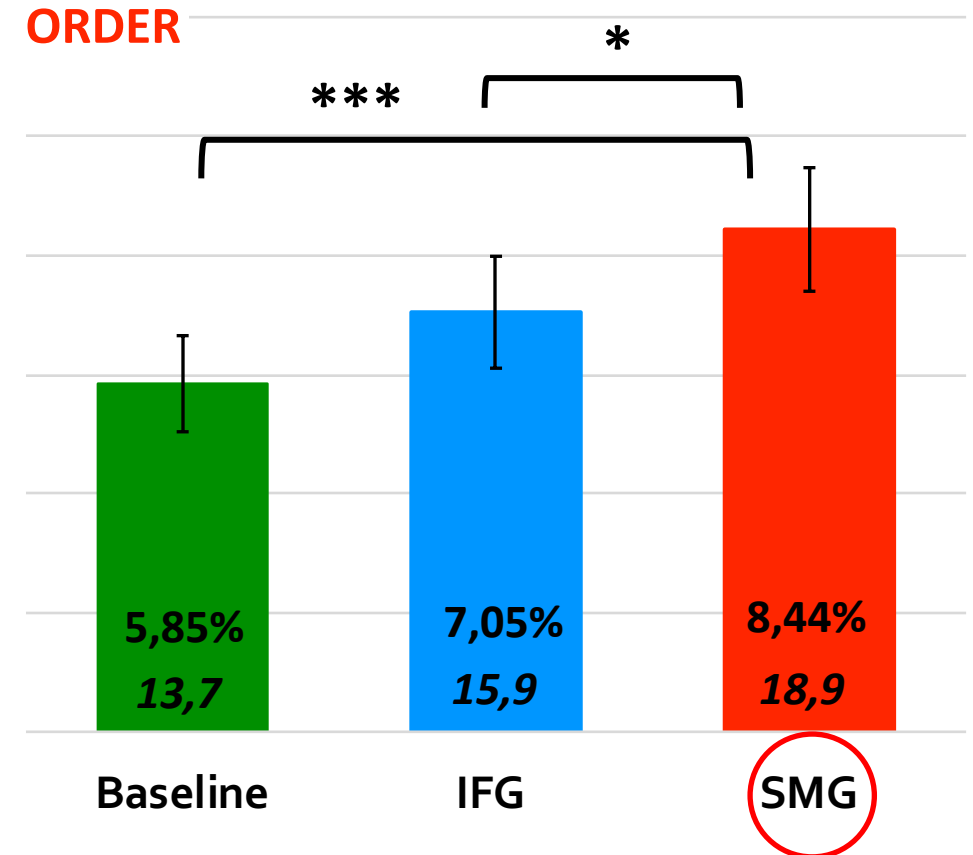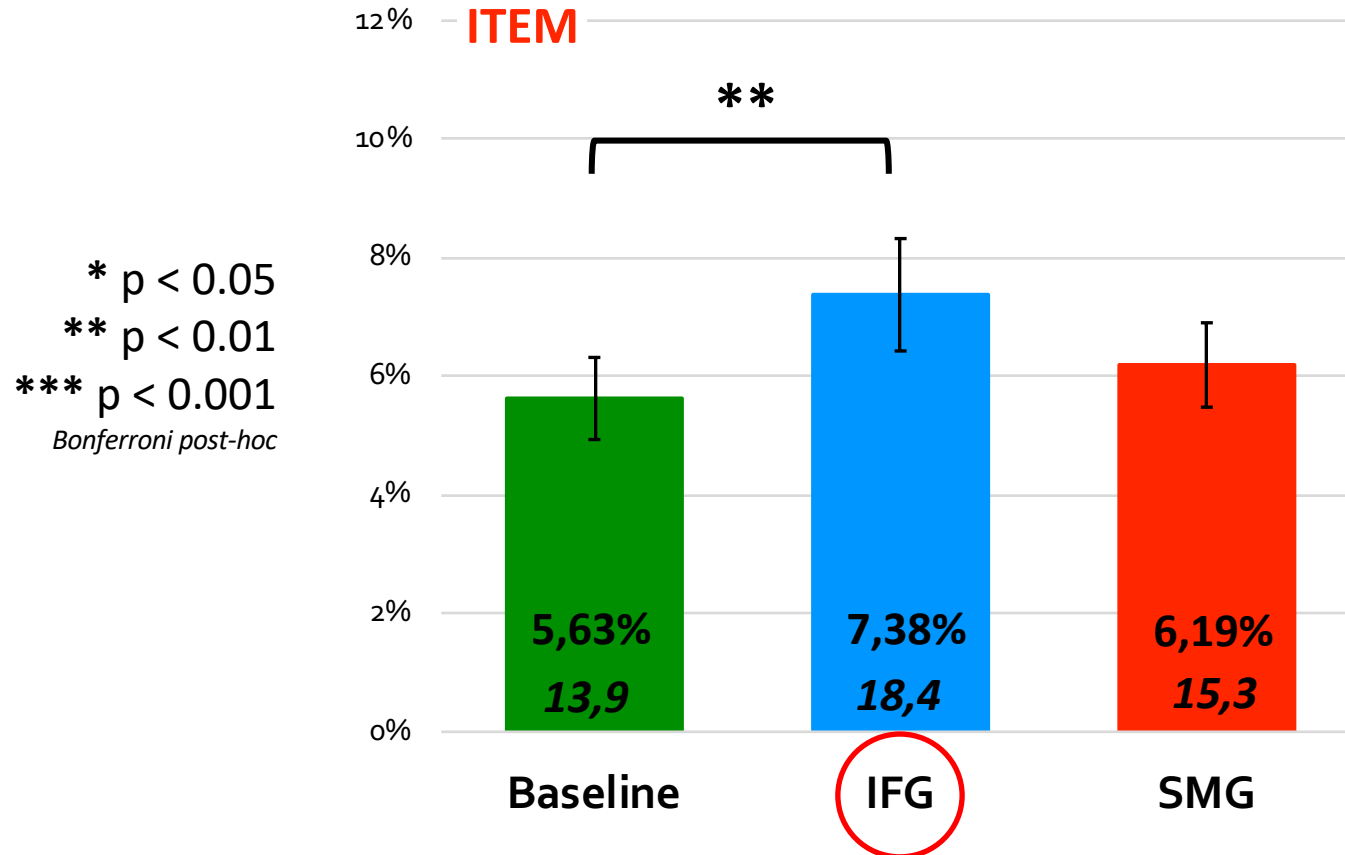**Number of presented finger movements was based on subject's span level**

(t)

EXP 3 – motor STM

Dependent variables: proportion of item and error orders
Analysis: repeated measures Analysis of Variance (rm-ANOVA)
  factors: **3** (session) ***** **2** (type of error)
  Post-Hoc correction: Bonferroni

	F	p	ηp^2
Session * error type	10,17	**<,001**	0,35

* p < 0.05
** p < 0.01
*** p < 0.001
Bonferroni post-hoc

ITEM

	**	
Baseline	IFG	SMG
5,63%	7,38%	6,19%
13,9	18,4	15,3

ORDER

***	*
Baseline	IFG	SMG
5,85%	7,05%	8,44%
13,7	15,9	18,9

AIM: **assessed SMG selectivity for order processing** and not a more general role of this cortical area in STM or in attentional processing
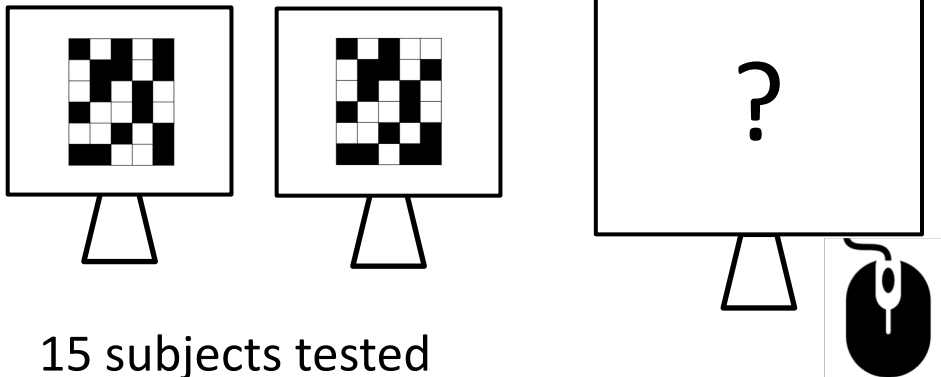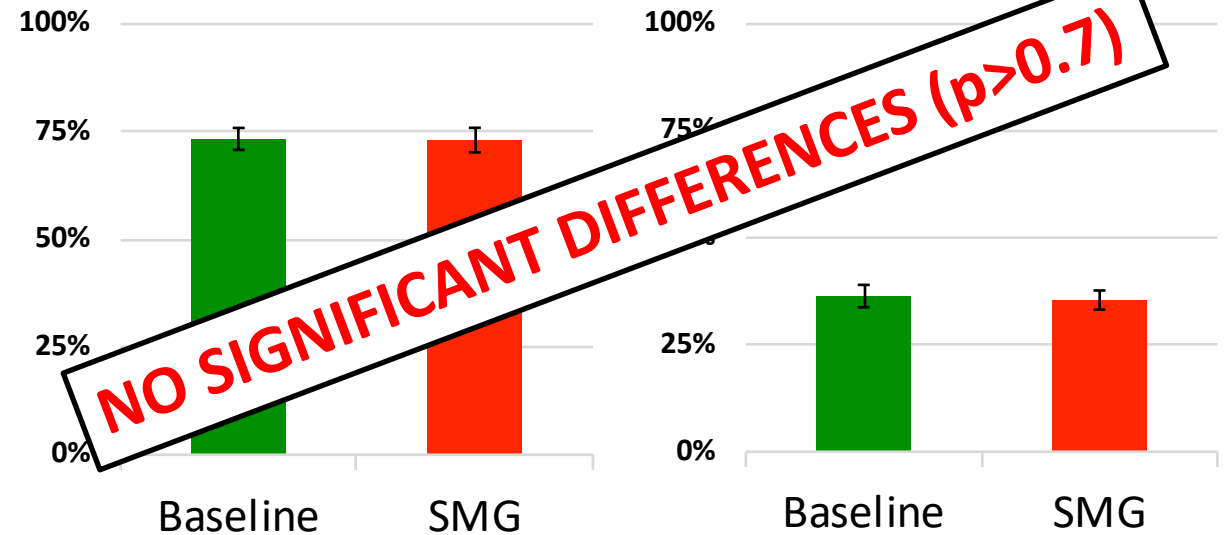
STM task where no order information has to be retained

⟶

If **SMG** is specialized in storing order information no modulation of subject's performance should be found after rTMS

Visual-pattern span task

?

- 15 subjects tested
- rTMS only over **SMG**

NO SIGNIFICANT DIFFERENCES (p>0.7)

100%

75%

50%

25%

0%

Baseline   SMG

Accuracy

100%

75%

25%

0%

Baseline   SMG

Proportion of errors in trials where the two matrices were different

CONCLUSIONS

1) Stimulation of **SMG** selectively **impaired *ORDER* errors in ALL the STM domains tested** (i.e., verbal, visuo-spatial and motor)
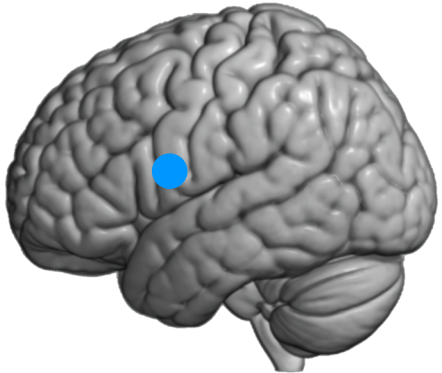
Theoretical importance → novel insights on the anatomo-functional bases of STM network

First causal demonstration that **SMG** is a **key area for the storage of sequential information in STM independently from the material type to be stored**

Clinical importance → novel insights in disorders where order information is crucial

2) Stimulation of **IFG** selectively **impaired *ITEM* errors only in VERBAL and in MOTOR STM**

IFG is a key area of the Mirror Neuron System and of the Action Observation Network (AON)
(e.g., Caspers et al., 2010; Hamzei et al., 2015)

IFG is a key area for verbal STM and item retention
(e.g., Paulesu et al., 1993; Papagno et al., 2017)

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Dott. Alberto Pisoni   Prof. Nadia Bolognini   Prof. Costanza Papagno

THANK YOU FOR THE ATTENTION!

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