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Research report

A brain for numbers

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ABSTRACT

Healthy human brains come equipped with several circuits that contribute to number processing. Nature and nurture interact to produce a unique combination of core skills and more sophisticated abilities, by building on a handful of auxiliary routes (e.g., verbal language, body knowledge and visuospatial attention). Transcranial magnetic stimulation (TMS) studies on number processing will be here succinctly reviewed, in light of their most stimulating and challenging contributions. New research directions will be pointed out, that might enhance their theoretical impact.

The great glory of mathematics is its durative nature; that is one of humankind's longest conversations; that it never finishes by answering some questions and taking a bow. (Barry Mazur (2003) – ''Imagining Numbers'', p. 225)

Number processing is an essential part of our culture (Bynner and Parsons, 1997). Numbers are used for counting, measuring, comparing, ordering, identifying objects, calculating. Even people who do not deal professionally with numbers use their number skills in everyday life, and acquired impairment of numerical skills is a severe handicap in working life (Butterworth, 1999). Severe difficulties in learning about numbers (dyscalculia) are probably as widespread as disorders of literacy development (dyslexia), and the best prevalence estimates for each lie between 3.6 and 6.5% (Butterworth, 2005). A deeper understanding of normal numerical skills is a necessary requirement for studying the impairment itself. TMS studies in mathematical cognition are aimed precisely to clarify the relation between the mental operations involved in normal number processing and specific brain circuits.

Within mathematical cognition, certain topics have attracted more attention (e.g., core quantity representation, the relation between finger pointing and counting or between numbers and spatial attention) probably also due to the fact that they are methodologically easier to investigate with TMS than others (e.g., complex arithmetic). Existing studies have met their objectives with mixed success and different protocols (see Table 1 for an overview), revealing the necessity of different cortical regions for number skills. Going beyond the virtual lesion metaphor, moreover, is perhaps the most intriguing open challenge in this field.

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Table 1 – Summary of reviewed TMS studies including stimulation parameters and results

Study	TMS parameters			Sites and behavioural effects				
	Frequency	Intensity	Duration	Stimulation sites	Localization method	Critical area	Task	TMS effect
Göbel et al. (2001) Exp 1	10 Hz	105% of active MT[a]	rTMS delivered pseudo-randomly, 500 ms, 100 ms before stimulus onset	PPL: $X = \pm 42$, $Y = -58$, $Z = 52$	Functional and Brainsight™	Left PPL	Comparison with 65	Slower RTs for numbers larger than and close to 65
Exp 2				SMG: $X = \pm 52$, $Y = -46$, $Z = 44$				No effect
Exp 3				PPL			Comparison with 65 (reversed response)	Generalized slowing of RTs
Sandrini et al. (2004)	15 Hz	110% of resting MT[a]	225 ms from stimulus onset	1 cm lateral to CP3 *vs* 1 cm lateral to CP4 (SMG) *vs* sham $X = \pm 48$, $Y = -47$, $Z = 52$	10/20 EEG system and SofTaxic	Left SMG	Comparison of two digits	Generalized slowing of RTs
Oliveri et al. (2004)	1 Hz offline	90% of resting MT[b]	5 min followed by 30–60 min rest before the next session	P3 *vs* P4 *vs* baseline	10/20 EEG system	P4	Comparison of two numerical intervals	Elimination of pseudoneglect
Rusconi et al. (2005) Exp 1	1 Hz offline	90% resting MT[a]	10 min, 20–25 min pause in between blocks	AG *vs* SMG	Brainsight™	Left and Right AG	Finger gnosis task	Symmetric interference with the finger schema task from left AG; asymmetric (contralateral > ipsilateral) interference from right AG
Exp 2	10 Hz	60%[c]	rTMS delivered pseudo-randomly, 500 ms from stimulus onset	AG		Left AG	Magnitude matching + arithmetic prime	Slower RTs in trials with unrelated primes
Andres et al. (2005)	Single pulse	130% of resting MT[a]	Pulses at 150, 200, 250 ms after stimulus onset	P3 *vs* P4 *vs* P3+P4 (bilateral stimulation) *vs* sham	10/20 EEG and TMS navigator (Noirhomme et al., 2004)	P3, P4 and P3+P4	Comparison with 5	Slower RTs to numbers close to 5 with TMS on P3 and P3+P4; slower RTs to far numbers with TMS on P3+P4
Göbel et al. (2006a)	5 Hz	110% of active MT[a]	rTMS delivered pseudo-randomly, 1000 ms from stimulus offset	AG/adjacent posterior part of the IPS left: $X = -34$, $Y = -62$, $Z = 50$; right: $X = 38$, $Y = -65$, $Z = 48$; *vs* OCC $X = 1$, $Y = -98$, $Z = 18$	Functional and Brainsight™	Right AG/adjacent posterior part of the IPS	Mental number bisection	Reduction of pseudoneglect

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