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The Role of Visual Perception in Spoken Responses

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How subjects voice responses to flashed visual symbols was investigated at successive stages of the information processing. The representation exits from V1 mainly by 120–140, mean 130ms; cortical motor output to voice onset has a mean delay of 85ms. The latencies of voicing only a noise, blurting versus perceiving before responding correctly yield mean delays for perception (85ms) and for spatio-temporal motor coding of digits (45ms), with a mean total delay of 345ms. Prefrontal cortex and Intralaminar N. also contribute to perception.

K e y w o r d s: visual perception, occipito-frontal flow, Broca excitability, TMS mapping

1. Introduction

When a subject is required to identify and respond correctly to a randomly selected member of visually presented symbols, introspection may suggest that consciously perceiving the symbol precedes and determines the response. However, the unreliability of introspection in linking a conscious explanation to a motor response in commonplace; for example, a limb may be withdrawn from a source of injury and pain is felt, but after spinal cord trauma, the withdrawal occurs without felt pain. A definitive answer to the role of somatosensory perception as a possible mediator of behavioral responses seemed provided by careful parametric observations on the surgically exposed, human postcentral gyrus [1]. When stimulation with 100 Hz

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pulses, the train length had to last at least 0.3s before the patient later reported a projected sensation on the contralateral limb. However, reaction time to somatic stimulation in an alert human is less than one- half the minimum train length necessary at somatosensory cortex. Therefore, the response to the somatic stimulation was determined unconsciously; the later consciousness of the stimulus was retroactively attributed to have caused the motor response. The impact of these findings spread beyond neurophysiology [2, 3].

The redundancy of repetitive stimulation of cerebral cortex in eliciting a projected sensation was first demonstrated in the visual system. Single pulse transcranial magnetic stimulation (sTMS) over the occipital lobe elicited phosphenes [4]. The actual cortical (and subcortical) area stimulated was uncertain because of the large diameter (12.5cm, o.d.) of the magnetic coil (MC). The narrower the width of the coil, the greater the difficulty in eliciting phosphenes with the MC focally applied over V1 [5]. More relevant to the somesthetic observations is that sTMS of parietal lobe fails to elicit a projected sensation, confirming [1]. However, sTMS over motor cortex elicits a projected sense of movement of fingers in ischemically paralysed and somesthetically insensitive hand [6,7] and paresthesias in about 30% of subjects [8]; the role of frontal projections to the thalamic Intralaminar N in somatosensory responses was emphasized.

In the visual studies, we analyze transmission from visual stimulation through visual cortex to speech expressive cortex to voice towards explaining how subjects say correctly what is flashed before their eyes. The plan is to: (a) Time the output from V1 following a flashed symbol before the eye; (b) Time the output from language "eloquent", i.e. expressive cortex to voice; (c) After subtracting (a) and (b) from the overall latency of the voiced response, fractionate the intervening time available for possible perception of the visual symbol and motor coding of articulatory muscles (Fig. 1).

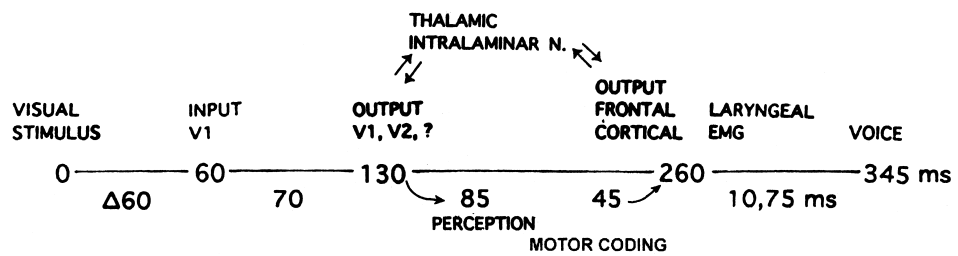

Fig. 1. Timing the flow of information from visual stimulus to voice onset. The upper row of numbers show cumulative group means; the numbers below show delays between functional steps in the overall process. The possibility of some overlap between perception and motor coding is not excluded, nor is to and fro communication between decision nodes excluded. (See text for further details). (Modified from Fig. 11, Amassian et al. [21])

2. The Timing from Visual Stimulation to V1 Output

The timing of transmission through V1 of the representation of a flashed language or arithmetic symbol was initially based on a sTMS pulse delivered over the presumed foveal cortical representation of the visual stimulus. Optimal suppression occurred when the mid- point of either the inferior margin of circular coil (9 cm o.d) or of the midpoint of the junction region of a figure 8 coil (7 x 14 cm) was situated about 2 cm above the inion. The coils initially used were made by the Caldwell Corp. (Kennewick, WA) and elicited a damped polyphasic electric field with two major components. Initially, a horizontal trigram of 3 randomized alphabetic letters each

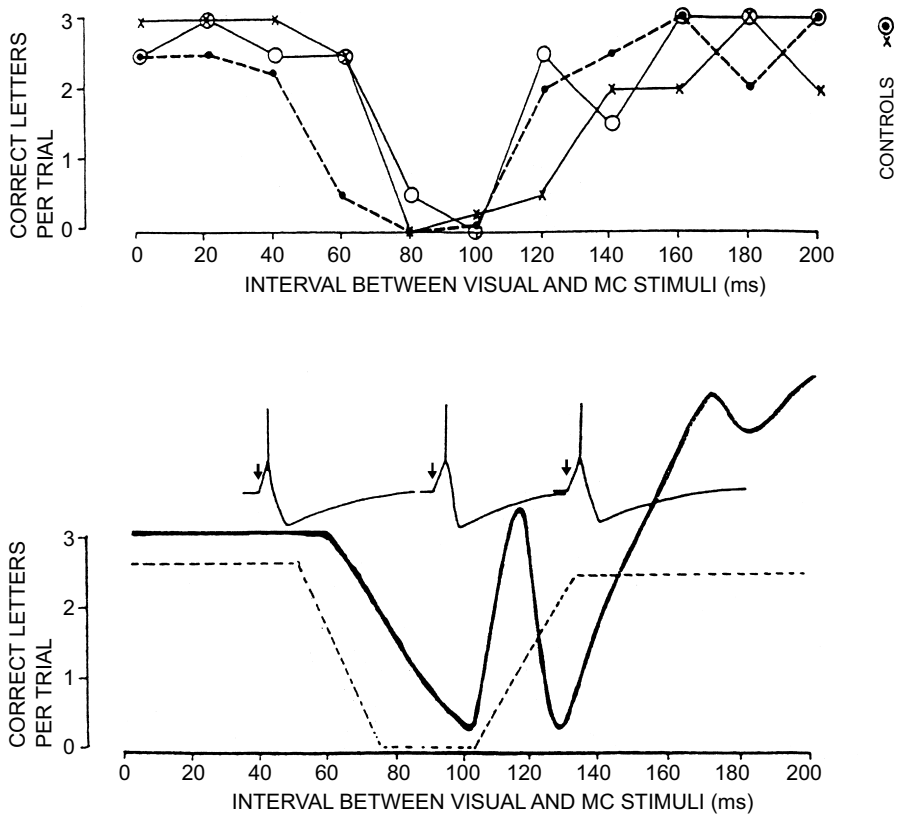

Fig. 2. Timing of visual suppression in 3 subjects (above) and proposed mechanism of suppression by sTMS induced IPSP (below). Above: The proportion of 3 flashed, dark letters on a white background that were correctly reported is plotted as a function of the delay for the sTMS pulse. (One subject exhibits depression 20ms earlier than the others). Below: Diagram illustrates the proposed mechanism of visual suppression at 80–100ms. The 'W' type of visual evoked potential solid line is combined with the suppression timing (dotted line) and diagrams of 3 early excitatory potential followed by 3 IPSPs elicited by sTMS at different delays relative to the visual evoked potentials. (Reproduced from Fig. 2 in Amassian et al. [9]

subtending less than 1 degree of visual angle were flashed for 2 ms. The luminance was adjusted such that further diminution would result in failure to identify all symbols flashed (Fig. 2). The general finding was that optimal suppression of perception could be elicited when the sTMS was timed approximately 80–100 ms after the visual stimulus. Shifting the coil to the right leads to greater suppression of the left most character and vice versa, i.e. the topography of the V1 representation was confirmed [9] with additional precision [10].

The neural elements directly excited by a sTMS pulse are most likely myelinated axons, especially where they bend out of the induced electric field [11]. At a bend, the exciting function is not the derivative of the electric field as with a linear axon, but the electric field [12]. Given that the optimal position of the 9 cm coil is centered on the midline rather than 4 cm lateral where a derivative of the field would be located [13], it is likely that excitation occurs at the bend in geniculocalcarine axons entering superiorly and inferiorly calcarine cortex; this was confirmed by demonstrating optimal suppression with a latero- medial induced electric field [14].

The 80–100 ms timing of optimal suppression occurs a little after the onset of the visual potential in V1 at 60–70 ms, depending *n* the luminance of the flashed stimulus. Although intracellular recordings are lacking of the effects of a TMS pulse on visual cortex, they may be deduced from an intracellular study of the effects of an electrical pulse delivered locally in cat motor cortex. Typically, a sequence of direct pyramidal tract (PT) or uninvaded cell discharge may occur and a brief EPSP with or without transynaptic discharge, terminated by a prolonged IPSP lasting tens of

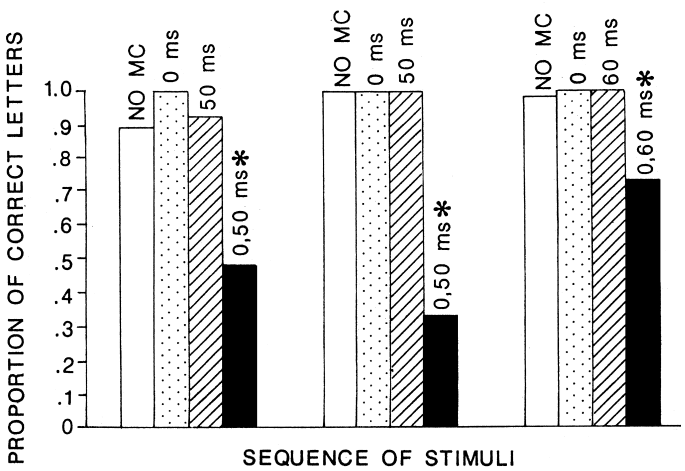

Fig. 3. The effect of two early TMS pulses on visual suppression. In each of 3 subjects, sTMS at 0 or at 50ms or 60ms delay from the visual stimulus did not diminish reporting of the trigram, but combined stimulation at 0 and 50 or 0 and 60ms led to significant depression, $p < 0.005$, 0.005 and 0.05, respectively. The efficacy of a conditioning pulse at 0 ms suggests a different explanation of the depression than an IPSP related to the evoked visual cortical potential (Reproduced from Fig.2 in Amassian et al. [23]).

ms [15]. The hyperpolarizing potential is enhanced by injecting depolarizing current i.e. it is an IPSP and is GABA mediated [16]. Most likely, the 80–100 ms phase of suppression is explained by the lag in development of the peak IPSP following the initiation of the visual evoked potential. Supporting evidence is provided by the delay in this phase of suppression when the evoked visual potential is delayed by optic neuritis [17].

Further studies revealed that TMS could suppress perception at other ISIs. For example, sTMS over the occiput elicits a blink from direct stimulation of the facial nerve [18], at the exit from the medulla [19, 20]. Not surprisingly, sTMS given before the visual stimulus suppresses perception as will extracranial electrical stimulation of the facial nerve [21]: The blink artifact should not be analogized with forward masking [22]. A true phase of TMS suppression was revealed by using two TMS pulses, which given individually were ineffective [23]. Thus an initial TMS at 0 or 10 ms after the visual stimulus followed by a second pulse at 60, 170, and 210 ms markedly prolonged the period of suppression, thereby revealing a continued component of the neural representation of the visual signal had survived (Fig. 4). The use of a large (12.5 cm o.d) round coil [24] or two (sandwich) coils [25, 26] revealed an early suppressive phase that peaked near 30 ms, and was then clearly reduced before the 80–100 ms phase.

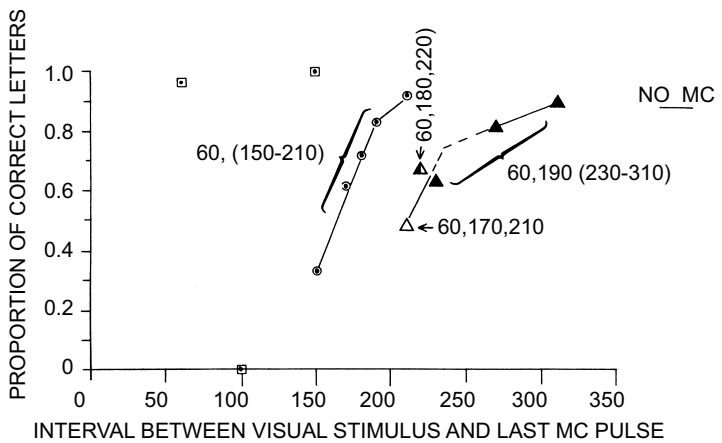

Fig. 4. The effect of repetitive TMS on visual suppression. The data are from the same subject. sTMS at 60ms or 150ms did not elicit visual suppression, but at 100ms, there was complete suppression. (square symbol). Combinations of 2 TMS pulses, e.g. at 60 + 150 ms led to suppression with near recovery at 60 + 210ms. Combinations of 60 + 170 + 210 led to further prolongation of suppression (open triangles). Finally, the combination of 60 + 190 + 230 (closed triangles) showed further prolongation of suppression with near recovery/ when the third pulse was at 310 ms. The findings imply discharge of visual cortical neurons to the flashed stimulus is prolonged provided the TMS pulse does not lead to major suppression at 80–100ms delay. Reproduced from Fig.4 in Amassian et al. [23]

The early 30 ms phase of suppression cannot be explained by an ISPS after the arrival of the evoked potential at 60–70ms. A possible subcortical site was supported by recordings from feline lateral geniculate body which revealed reduced firing rate following sTMS of visual cortex [27]. Alternatively, a different, faster visual system (e.g. magnocellular) may have transmitted the flashed visual signal [24]. Summarizing, the representation of the flashed symbol, used was probably transmitted by 130 ms.

3. Timing the Output from Eloquent Cortex to Voice

Penfield and Roberts [28] provided a major guide for TMS use in defining cortical area related to speech and articulation. Electrical stimulation of the human cortex that was surgically exposed for epilepsy surgery permitted a spatial restriction of the field activated and its identification not readily achievable with TMS. Furthermore, of crucial importance with TMS mapping, criteria were derived for differentiating dysphasia- related to cerebral dominance and dysarthria - of minimal value in identifying dominance. In particular, arrest of speech could be elicited by repetitive electrical stimulation of either left or right motor cortex. Dysphasic effects elicited from Broca's Area included slurring and repetition of words. However a complication of applying patient localization data to normal subjects was revealed in two patients where extirpations of Broca's Area was followed by their ability to talk the next day. Evidently, language expressive cortex had shifted, presumably to the right side. Plasticity of language comprehending cortex was also documented [29].

Mapping speech expressive cortex with sTMS permits explory of normal subjects, but suffers from the likelihood that facial and trigeminal motor axons are directly excited with effects on the voice. The amount of interference with voice depends on the phonemes uttered. Any effect with sTMS is magnified by using repetitive stimulation. Thus uttering "Whooo" is much more affected by sTMS than "Aaa" where repetitive stimulation leads to complete arrest of sounds (Fig. 5). Our tests of an early rTMS machine revealed speech arrest with stimulation of either left or right frontal lobes due to direct tetanization of cranial muscles.

Initially surface recordings were made with EEG electrodes from extrinsic laryngeal muscles including sternohyoid and later cricothyroid, a facial muscle (buccinator) and from expiratory muscles such as external oblique and rectus abdominis because of their importance in voice. Subsequently, the 8 electrode array used for implantation (Medtronics Corporations) proved superior for extrinsic laryngeal recording; because of its light weight, it could be taped to the neckand it permitted rapid testing of different electrode combinations. Recording from extrinsic laryngeal muscles has the advantages of ease of recording, very short peripheral conduction time (~ 2 ms) and absence of damage possibly occurring with wire electrode inserted into the intrinsic muscles. The voice was simultaneously recorded with the EMG.

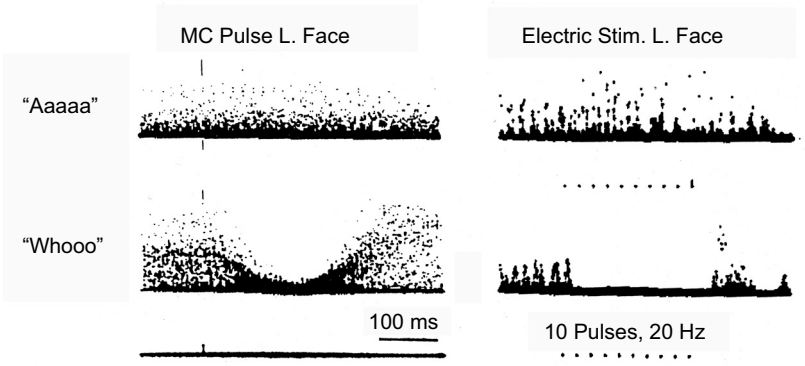

Fig. 5. The effect of sTMS and repetitive electrical stimulation of the face on different articulations. The incidence of the stimuli is indicated below. The voice is rectified. Reproduced from Fig. 1 from Ammassian et al. [39]

Routinely, sTMS was applied with background facilitation by the subject voicing; often 'W' was chosen because its multiple phonemes introduced the possibility of eliciting a change in their timing. The sTMS was triggered by the onset of the EMG after an adjustable delay (Fig. 6). The recordings were tested for contamination by activity of other neck muscles. The nearby sternomastoid clearly was activated by head turning whose effects were insignificant on the extrinsic laryngeal muscles. (However even the sternomastoid showed an increase in activity during speech). In mapping speech related frontal cortex with the edge of the round coil, we used a technique previously shown to elicit movement predominantly of a single digit

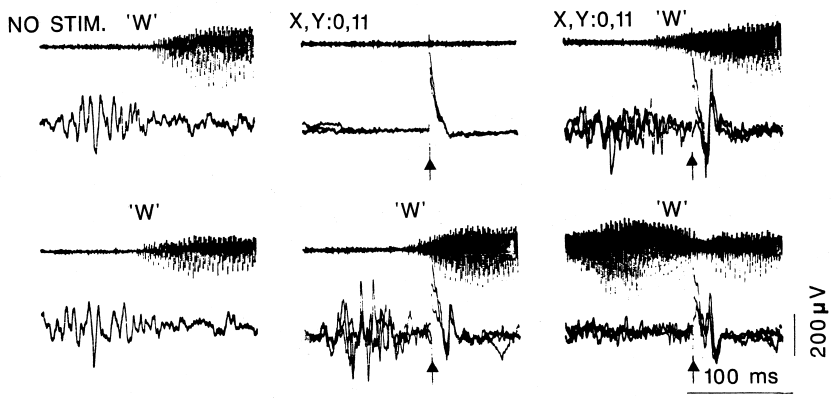

Fig. 6. Surface recording from laryngeal muscle during articulation and sTMS with and without articulation. Left column: Voice and initial EM6 during articulating 'W'. Sweep triggered by onset of EMG. Middle column: superimposed sweeps of EMG responses without facilitation by 'W' (above) and with facilitation (below). Right column: increasingly delayed sTMS- pulses reveals increased amplitude of response (above) and second positive component (below). Site of sTMS is X,Y,0,11 (grid in Fig.7)

[30]. Such focality of edge stimulation was used on frontal sites with the coil tilted antero- medially to minimize activation of temporalis and masseter muscles. The (X, Y) coordinates of the contact point of the coil edge was defined by a rectangular grid oriented such that (X, Y, O, O) was at the external auditory meatus; (Y, 1) level with the top of the zygoma and with the inferior orbital margin defined the tilt of the grid [31]. (Because of the medial curvature of the skull, T, 10 on the vertical grid would correspond to a point closer to the midline than on a two dimensional representation). Four sites of facilitated sTMS activation of laryngeal muscle were detected (Fig. 7) The shortest latencies of 6–8 ms were recorded at stimulation sites X, Y, 0, 9. Latencies of 13–20 ms and of 40ms were recorded at stimulation sites 3.5, 0.5 and 0.11. The shortest latency stimulation site 0.9 is from presumed motor cortex because increased strength of sTMS elicited arm movements. The longer latency responses (unlike those from motor cortex) were all accompanied by clearly prolonged voice: "Da–bul- you" became "Daaaa- bul- you", i.e. the interval between phonemes was prolonged, possibly equivalent to "slurring" [28]. The 3.5 site corresponds to Broca's Area and 0.5 to the foot of the precentral gyrus, which is cytoarchitecturally Area 6 [32]. The 0.11 site with medially directed magnetic flux most likely corresponds to the supplementary motor area (SMA). The combination of increased motor response

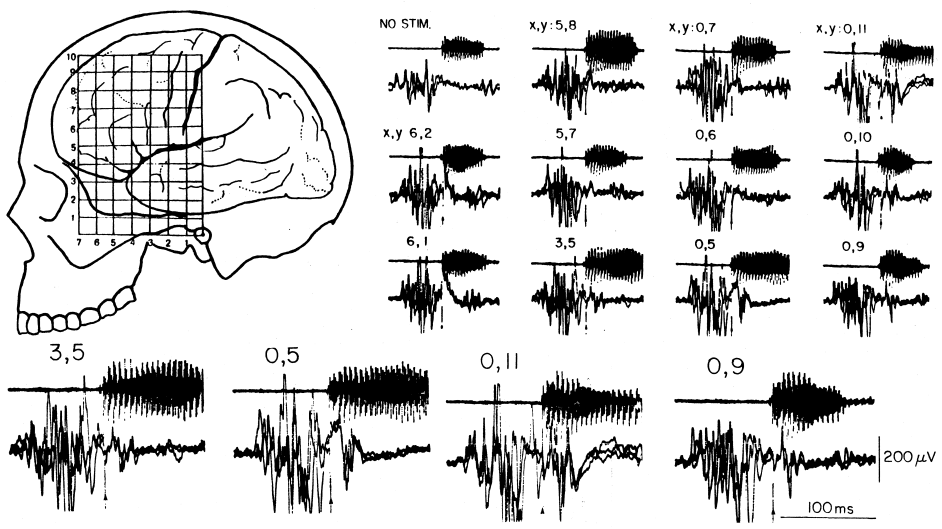

Fig. 7. Laryngeal CMAPs elicited by focal sTMS stimulation of different frontal sites in dominant hemisphere. Right: The superimposed sweeps are triggered by the onset of the EMG with articulation of 'W'. Voice record corresponds to initial phoneme. The incidence of the sTMS is similarly delayed for all traces. Left: the stimulation sites of the edge of the coil is referenced to the vertical X,Y grid. (See text for orientation of the grid). Below (amplification increased): stimulation site at 3.5; 0.5; 0.11; are associated with voice prolongation, unlike at 0.9 where increased sTMS intensity yielded contralateral arm movement and was probably over Area 4. (Modified from Fig. 9 in Amassian et al. [31])

latency and effect on timing between phonemes implies that the 3.5 and 0.5 and 0.11 stimulation sites are over higher order language motor areas; tentatively, they correspond to the sites on exposed cortex which when electrically stimulated cause dysphasia [28].

The spiky appearances of the higher order responses suggested that several functional components contribute to the waveform. This was confirmed by changing the delay between the trigger by the EMG onset of "W' and the sTMS pulse (Fig. 6); with increased delay, the separation of components became evident. The relationship between higher order and lower motor cortex was not explored. Stimulation of the inferior frontal gyrus (Broca's Area) of surgically exposed human cortex apparently yielded evoked potentials in orofacial cortex [33]. However it is unclear whether these represented orthodromic or antidromic potentials. Possibly, simultaneous stimulation with two sets of stimulating electrodes could resolve the problem; if no collision occurred then both orthodromic and antidromic connections exist. In the monkey, the homologue of Broca's Area did not project to the Area 4 [34].

The onset of voice is electronically timed. The subject should not be inspiring when visually stimulated because the latency is then significantly delayed, e.g. by more than 50 ms. Summarizing, the delay from conducted cortical motor output to laryngeal EMG (~10 ms) plus delay of onset of voice (~75ms) equals ~85 ms.

4. Fractioning the Delay between V1 Output and Cortical Motor Output

So far, the delays from flashed symbol to the onset of correct, voiced response (345 ms) include estimated output delay from V1 (130 ms) plus motor cortical output to voice onset (85 ms), equaling 215 ms (Fig. 1). After subtracting 215 ms from 345 ms, 130 ms remains that includes the time cost of producing specific spatio- temporal patterns of cortical motor output that: (a) activate specific articulatory muscles relevant for each phoneme and (b) time the muscle activations in sequencing the phonemes. Is any portion of the 130 ms plausibly available for perception? Figure 8 illustrates data from one member of the group of 4 subjects. The latency when attempting to perceive and then saying what was flashed was 362 +/– 31ms. By contrast, when blurting out the number, it was usually correct only by chance. The incorrect blurted responses had a latency of 268 +/– 48ms. Still earlier responses of 202 +/– 20ms were recorded when the subject made a noise 'ugh'. The difference between latencies of blurted and noise response was 268 – 202 ms = 66 ms (group mean 45 ms) available for motor programming for a digit (1–9). The additional delay when the subject tried to perceive the stimulus was 362 – 268 ms = 95 ms (group mean 85 ms). The ratio of incidences of blurting incorrectly to the longer latency correctly blurting varied among this group and others; one subject tested did not blurt incorrectly. The latency overlap of blurting correctly and perceiving most likely reflects the difficulty

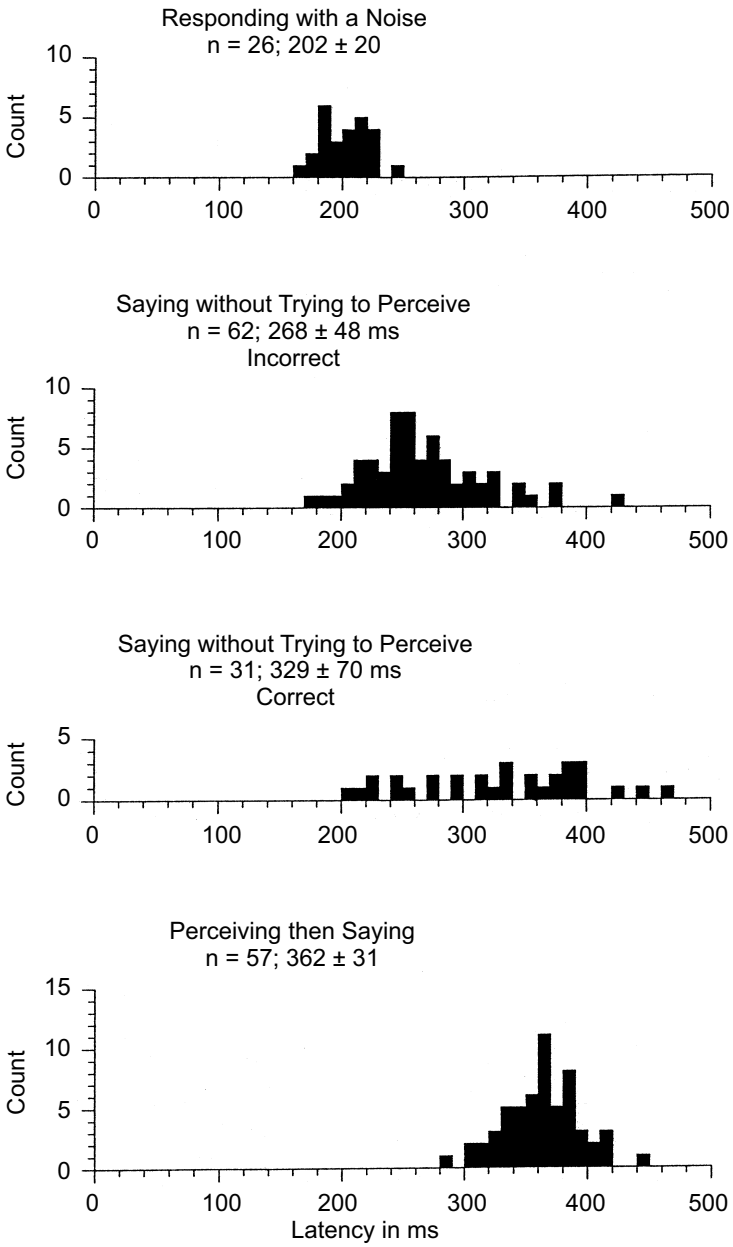

Fig. 8. Distribution of latencies of vocalization by the same subject performing different tasks. The visual stimulus was a flashed numeral 1–9. The different tasks in separate trials were: (a) to make a noise, (b) to blurt out the response, i.e. without trying to perceive it and (c) to perceive it and say it. All but one subject gave blurted both incorrect and correct responses; the correct "blurted" responses overlapped in latency those perceived which were virtually without error. The distribution of latencies from a different subject is shown in [21]; the ratio of blurted incorrect to correct responses in significantly lower than in the above. Reproduced from Fig. 2 in Ammasian et al. [40]

of an alert subject in suspending perception of the flashed symbol. The possibility of preprogramming a digit was tested by requiring the subject to blurt out the same digit regardless of what was flashed; such response added only 6 +/– 5.5 ms to the latency of "noise responses" implying it was preprogrammed.

The group mean delay of 85 ms for perceiving the digit may be compared with the mean delay of 88ms for adding, or 98 ms for subtracting two digits, excluding the delay for identifying two digits [35]. Addition and subtraction are introspectively examples of conscious activities, unlike the far more complex calculus that operates at the unconscious level in tracking and hitting a moving ball. Summarizing, the group mean delay of 130ms between V1 output and cortical motor output to voice onset is divided between perceptual delay (85 ms) and motor coding (45 ms), Fig.1, with some possible overlap.

5. Possible Neural Substrate for Perceiving and Reporting the Flashed Symbol

The neural substrate for reporting the flashed symbol clearly includes the transfer of information from occipital to frontal cortex; what other cortical activities may be involved? An important PET study disclosed increased metabolic activity mainly in lateral occipital lobe and Broca's Area when the normal subject read and spoke the response. Remarkably, Wernicke's Area showed no increase in activity, unless the task was more complicated [36]. In agreement, with the PET study, the amplitude of facial and laryngeal muscles response is clearly increased over control value 140 ms after visual stimulation and commences earlier at 120 ms (Fig. 9). Even a direct projection would involve conduction over myelinated axons presumably comparable to those of the corpus callosum with delays of 8–12 ms [37]. In conclusion, before the 130 ms assigned to V1, output begins signaling the representation of the symbol.

Evidence of increased complexity of the pathway from occipital to frontal cortex is provided by the finding of increase delay of 60 ms in facilitation of Broca's Area if a further condition is imposed; for example, if only even digits are to be spoken (Fig. 10). The increased latency (240 ms) compared with when all digits are spoken (180 ms) could involve increased activity in Wernicke's Area combined with preprogramming of a gate in Broca's Area, which excluded direct access from the occipital lobe.

It seems obvious that to perform swiftly in the visual tests described, the subject has to be both conscious and attentive. In metabolic studies, these activities may be subtracted in the final output. However, a sudden ischemic stroke of the middle cerebral artery may result in temporary loss of tonic facilitation of spinal stretch reflexes; by analogy, a tonic influence of Wernicke's Area on Broca's Area is subtracted, but may coexist with its dynamic processing of occipital output accompanying more complex linguistic tasks and increased metabolism. More generally related to the perceptual problem is the cortical- thulamo- cortical traffic with particular emphasis

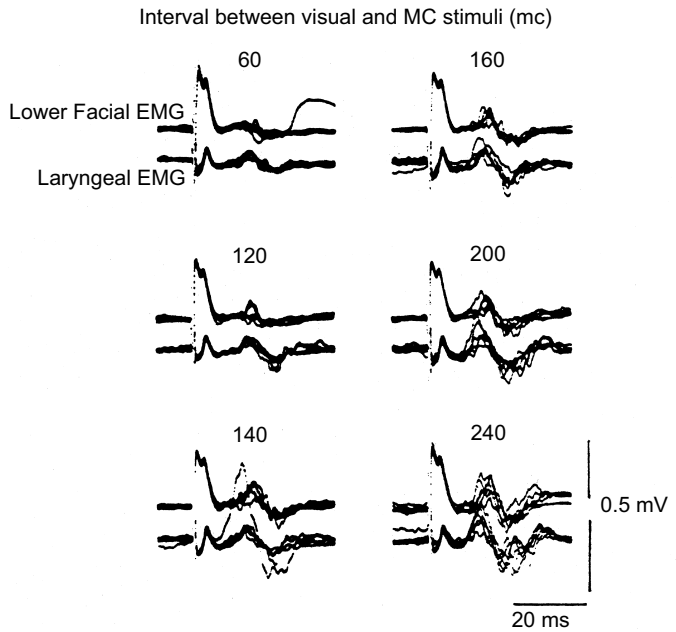

Fig. 9. Testing excitability of higher level, language cortex following visual stimulation. The sTMS pulse is delivered over presumed Broca's area. The facial EMG is from buccinator muscle. The control response is defined at an sTMS delay of 60ms after visual stimulation, i.e. before relay from V1. Both facial and laryngeal responses are increased at 140ms and later sTMS delays; a small increase commences at 120ms (modified from Fig. 11 in Amassian et. al. [21])

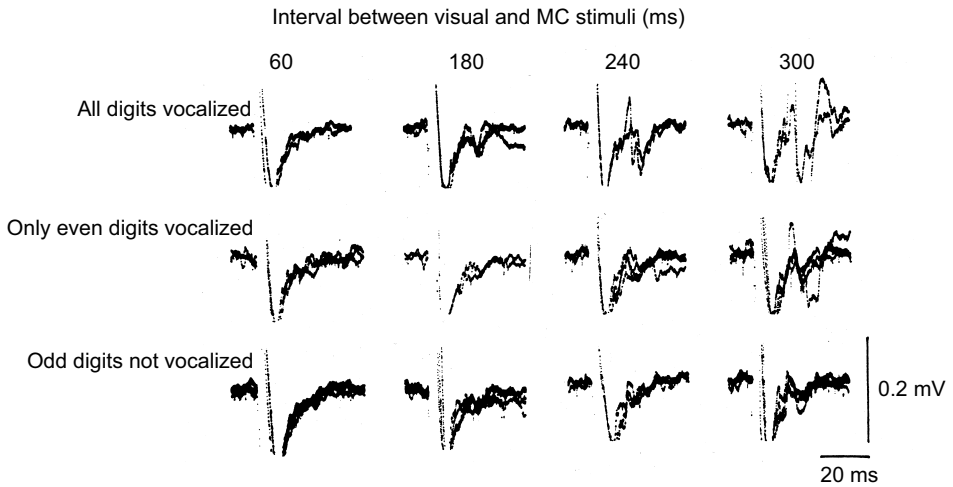

Fig. 10. The effect on excitability of higher level language cortex of vocalizing only selected digits of those flashed. Superimposed traces of laryngeal EMGs. When all digits were vocalized, sTMS at 180ms after the visual stimulus showed a response increase. With vocalization only of even digits, facilitation was postponed until a delay of 240 ms

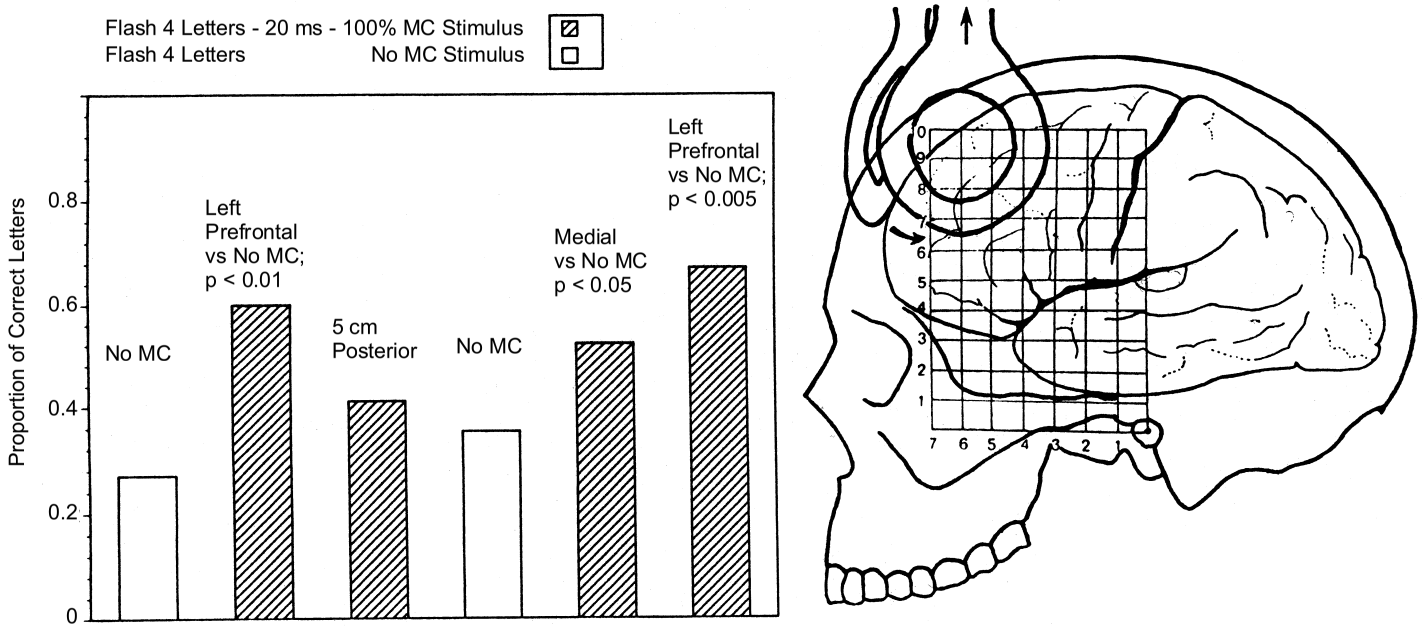

Fig. 11. The effect on the reporting of 4 flashed letters of changing the site of sTMS over anterior frontal cortex. At the right: the approximate positions of the 6 x 5.5cm coil are shown, which was shifted between 3 positions, indicated by arrows. Because of the curvature of the skull, the two dimensional representation of the vertical grid distorts the proximity of the medial border of the grid to the midline. At the left: The proportion of correctly reported letters is shown for each site of sTMS and without sTMS. Any increase in letters reported over control value is indicated for each site. Reproduced from Fig. 3, Amassian et al. [5]

on the thalamic intralaminar nuclei and their relationship to frontal lobe. For example, Figure 11 illustrates that the reporting of a flashed quadrigram is improved by prefrontal sTMS[(5]. Whatever specific attentive functions the anterior frontal cortex has for a particular sense such as vision [38] it may also have a broader function in sensibility in opening a thalamic gate thereby facilitating cortex-thalamo-cortical relationships that subserve conscious perception of additional modalities [5].

6. Conclusion

The flow of information from a flashed visual symbol to the spoken response was timed at significant stages such as calcarine cortex and Broca's Area with single pulse TMS. The two effects of TMS used in the timing analysis were first, the inhibiting effect on visual processing by the induced IPSP (eg in VI); secondly, the later excitatory effect anteriorly of the transmitted visual representation was measured by the changes in laryngeal EMGs and recorded voice elicited by test TMS pulses of Broca's Area. When combined with appropriate verbal tasks, the overall latency of the verbal response (eg. average 345 ms latency) could be fractionated into components related specifically to perception (eg 85 ms) of the flashed symbol and to the spatio- temporal coding of articulatory muscles (eg 45 ms) in initiating the voiced response. By contrast, making an invariant verbal response to different flashed symbols occurred with a latency of a few milliseconds later than uttering a noise, implying that the spatio- temporal coding was then preprogrammed [21].

The enhancement of visual perception by sTMS of prefrontal cortex [5] and the frontal projections to the intralaminar N. served to emphasize that cortic- thalamic areas outside the classical visual and motor areas can subserve the conscious spoken response.

References

1. Libet B., Alberts W.W., Wright EW., Levin G., Feinstein B:. Production of threshold levels of conscious sensation by electrical stimulation of human somatosensory cortex. J. Neurophysiol. 1964, 27, 546–578.
2. Dennett D.C.: Consciousness explained, Little: Brown and Co. New York 1991.
3. Penrose R.: The emperor's new mind Oxford University Press, New York 1989.
4. Barker A.T., Freeston I.L., Jalinous R., Merton P.A., Morton H.B.: Magnetic stimulation of the human brain. J. Physiol. (Lond) 1985, 369, 3P.
5. Amassian V., Zoltan M., Sagliocco L., Hassan N., Maccabee P., Craccoo J.B., Cracco R.Q., Bodis-Wollner: Perception of phosphenes and flashed alphabetic characters is enhanced by single-pulse transcranial magnetic stimulation of anterior frontal lobe: The thalamic gate hypothesis. Perception 2008, 37, 375–388.
6. Amassian V.E., Cracco R.Q., Maccabee P.J.: A sense of movement elicited in paralyzed distal arm by focal magnetic coil stimulation of human motor cortex. Brain Research 1989, 479, 355–360.

7. Gandevia S.C., Killian K., McKenzie D.K., Crawford M., Allen G.M., Gorman R.B., Hales J.P.: Respiratory sensations, cardiovascular control, kinaesthesia and transcranial stimulation during paralysis in humans. J. Physiol. 1993, 470, 85–107.
8. Amassian V.E., Somasundaram M., Rothwell J.C., Britton T., Cracco J.B., Cracco R.Q., Maccabbe P.J., Day B.L.: Parethesias are elicited by single pulse, magnetic coil stimulation of motor cortex in susceptible humans. Brain 1991, 114, 2505–2520.
9. Amassian V.E., Cracco R.Q., Maccabbe P.J., Cracco J.B., Rudell A., Eberle L.: Suppression of visual perception by magnetic coil stimulation of human occipital cortex. Electroenceph. Clin. Neurophysiol. 1989, 74, 458–462.
10. Kamitami Y., Shimojo S.: Manifestation of scotomas created by transcranial magnetic stimulation of human visual cortex. Nat. Neurosci. 1999, 2, 767–771.
11. Amassian V.E., Eberle L., Maccabee P.J., Cracco R.Q.: Modeling magnetic coil excitation of human cerebral cortex with a peripheral nerve immersed in a brain-shaped volume conductor: The significance of fiber bending in excitation. Electroenceph. Clin. Neurophysiol. 1992, 85, 291–301.
12. Maccabee P.J., Amassian V.E., Eberle L.P., Cracco R.Q.: Magnetic coil stimulation of straight and bent amphibian and mammalian peripheral nerve in-vitro: Locus of excitation. J. Physiol. (Lond) 1993, 460, 201–219.
13. Maccabee P.J., Eberle L., Amassian V.E., Cracco R.Q., Rudell A., Jayachandra M.: Spatial distribution of the electric field induced in volume by round and figure '8' magnetic coils: relevance to activation of sensory nerve. Electroenceph. Clin. Neurophysiol. 1990, 76, 131–141.
14. Amassian V.E., Maccabee P.J., Cracco R.Q., Cracco J.B., Somasundaram M., Rothwell J.C, Eberle L., Henry K., Rudell A.P.: The polarity of the induced electric field influences magnetic coil inhibition of human visual cortex: implications for the site of excitation. Electroenceph. Clin. Neurophysiol. 1994, 93, 21–26.
15. Rosenthal J., Waller H.J., Amassian V.E.: An analysis of the activation of motor cortical neurons by surface stimulation. J. Neurophysiol. 1967, 30, 844–858.
16. Krynjevic K., Randic M., Straughan D.W.: Nature of a cortical inhibitory process. J. Physiol. (Lond) 1966, 184, 49–77.
17. Masur H., Papke K., Oberwittler C.: Suppression of visual perception by transcranial magnetic stimulation- experimental findings in healthy subjects and patients with optic neuritis. Electroenceph. Clin. Neurophysiol. 1993, 86, 259–267.
18. Murray N.M.F., Hess C.W., Mills R.R., Schriefer T., Smith S.J.M.: Proximal facial nerve conduction using magnetic stimulation. Electroenceph. Clin. Neurophsiol., 1987, 66, S71.
19. Maccabee P.J., Amassian V.E., Cracco R.Q., Cracco J.B., Anziska B.J.: Intracranial stimulation of facial nerve in humans with the magnetic coil. Electroenceph. Clin. Neurophysiol. 1998, 70, 350–354.
20. Liscic R.M., Morota N., Deletis V.: Intramedullary stimulation of the facial and hypoglossal nerves: Estimation of the stimulated site. Crotian Med. J. 2000, 41 (4), 384–388.
21. Amassian V.E., Cracco R.Q., Maccabee P.J., Cracco J.B., Rudell A.P., Eberle L.: Transcranial magnetic stimulation in the study of the visual pathway. J. Clin. Neurophysiol., 1998, 15, 288–304.
22. Breitmeyer B.G., RoT., Ogmen H.: A comparison of masking by visual transcranial magnetic stimulation: implications for the study of conscious and unconscious visual processing. Consciousness and Cognition 2004, 13, 829–843.
23. Amassian V.E., Maccabee P.J., Cracco R.Q., Cracco J.B., Rudell A.P., Eberle L.: Measurement of information processing delays in human visual cortex with repetitive magnetic coil stimulation. Brain Research 1993, 605, 317–321.
24. Paulus W., Korinth S., Wischet S., Tergau F.: Diffrential inhibition of chromatic and achromatic perception by transcranial magnetic stimulation of the human visual cortex. NeuroReport 1999, 10, 1, 248.
25. Corthout E., Utti B., Walsh V., Hallett M., Cowey A.: Timing of activity in early visual cortex as revealed by transcranial magnetic stimulation. NeuroReport 1999, 10, 2631–3634.

26. Corthout E., Hallett M., Cowey A.: Early visual cortical processing suggested by transcranial magnetic stimulation. NueroReport 2002, 13, 1163–1166.
27. Moliadze V., Zhao Y., Eysel U., Funke K.: Effect of transcranial magnetic stimulation on single-unit activity in the cat primary visual cortex. Physiology 2003, 555, 665–679.
28. Penfield W., Roberts L.: Speech and brain mechanisms. Princeton University Press, Princeton 1959.
29. Ojemann G., Mateer C.: Human language cortex: localization of memory, syntax and sequential motor- phoneme identification systems. Science 1979, 205, 1401–1403.
30. Amassian V.E., Maccabee P.J., Cracco R.Q., Cracco J.: Basic mechanisms of magnetic coil excitation of nervous systems in humans and monkeys: Applications in focal stimulation of different cortical areas in humans. In: "Magnetic Stimulation in Clinical Neurophysiology" S. Chokroverty (Ed.), Butterworth, Stoneham 1990 73–111.
31. Amassian V.E., Cracco R.Q., Maccabee P.J., Cracco J.B., Henry K.: Somepositive effects of transcranial magnetic stimulation. In: Advances in Nerology: 67, Negative Motor Phenomena, Ed. S. Fahn, M. Hallett, H.O. Luders, C.D. Marsden, Raven Press, New York 1995, 79–106.
32. Campbell A.W.: Histological studies on the localization of cerebral function. Cambridge University Press, Cambridge 1905.
33. Greenlee J.D., Oya H., Kawasaki H., Volko L.O., Kaufman O.P., Kovach C., Howard M.A., Brugge J.F.: A functional connection between inferior frontal gyrus and orofacial motor cortex in human, J. Neurophysiol. 2004, 92, 1158–1164.
34. Petrides M., In Broca's Region, Ed. Grodzinsky Y., K. Amunts., Oxford University Press, Oxford 2006, 3–46.
35. Amassian V.E., Cracco R.Q., Maccabee P.J., Cracco J.B., Eberle L., Rudell A.: The time cost of mental arithmetic and its relationship to conscious awareness. J. Physiol. 1993, 467, 97P.
36. Amassian V.E., Cracco R.Q., Maccabee P.J., Cracco J.B., Eberle L., Rudell A.: The time cost of mental arithmetic and its relationship to conscious awareness. J. Physiol. 1993, 467, 97P.
37. Cracco R.Q., Amassian V.E., Maccabee P.J., Cracco J.B.: Comparison of human transcallosal responses evoked by magnetic coil and electrical stimulation. Electroenceph. Clin. Neurophysiol. 1989, 74, 417–424.
38. Ruff C.C., Blackenburg F., Bjoertomt O., Bestmann S., Freeman E., Haynes J.D., Rees G., Josephs O., Deichmann R., Driver J.: Concurrent TMS-fMRI and psychophysics reveal frontal influences on human retinotopic visual cortex. Curr. Biol. 2006, 8, 16, 1479–88. Comment in: Curr Biol. 2006, 16, R 581–583.
39. Amassian V.E., Cracco R.Q., Maccabee P.J., Vergara M., Hassan N.: Phonetic aids in differentiating levels of human speech interference by magnetic stimulation. J. Physiol. 1996, 497, P 34P.
40. Amassian V.E., Rudell A.P., Cracco RQ.: The timing of human visual perception: estimates based on language vocalization and the recognition potential pp. 223–230 in: Advances in Clinical Neurophysiology, Eds. R.C. Reisin, M.R. Nuwer, M. Hallet, C. Medina. Sppl. Clin. Neurophysiology 2002, 54.