"CONTINGENT NEGATIVE VARIATION" AS A CONTROL SIGNAL OF CEREBRAL ORIGIN

J. Lokar, T. S. Prevec, and J. K. Trontelj

Summary

Contingent negative variation (CNV) is described as an electroencephalographic potential which is generated by the frontal cortex during the time interval between a conditioning and an imperative stimulus, provided that the latter has a definite meaning for the subject.

The purpose of the work was to determine whether CNV can be obtained through a pair of sensory stimuli which are not followed by motor action.

The experiments in hemiplegic patients have shown that CNV appears with approximately equal amplitude, whether they carry out the required movement with the healthy hand or unsuccessfully try to perform it with the paralysed hand. CNV was detected in a tetraplegic patient who was completely unable to perform any movement with his limbs.

The possibility of employing CNV as a control signal of cerebral origin independent of motor action is discussed.

Contingent negative variation (CNV) is an electroencephalographical phenomenon, first described by Grey Walter [1, 2, 3, 4].

CNV is a slow potential shift, negative in polarity and maximal at vertex (with mastoid reference). It is generated in the front al cortex and develops during the time interval between a conditional stimulus and the imperative ("unconditional") stimulus when a response is required to the imperative stimulus or when the second stimulus involves the subject's interest.

CNV develops during the period after the first stimulus when the subject expects the second stimulus announced by the first one (Fig. 1).

Measurements with intracerebral [5] and epidural [6] electrodes have confirmed the cerebral origin of CNV, which proved to be independent of respiration, heart beat, eye movements, etc. It has been detected in adults and in children [7], and also in primates [8], [9].

The amplitude of CNV depends on expectancy [1, 2, 3, 4], motivation [10], concentration and readiness [11], the motor action demanded [12], and on some other psychophysiological mechanisms and psychopathological conditions [13].

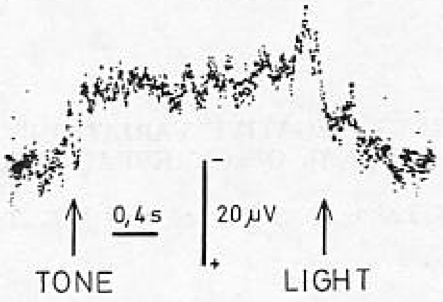

Fig. 1. Contingent negative variation (CNV). In this and subsequent recordings, upward deflection indicates negativity under the active electrode.

CNV has been reported to appear even when the interval was prolonged to 20 seconds [3], while most authors were unable to detect it with intervals exceeding 4 seconds [14]. There appears to exist large individual variation in the length of the interval at which CNV becomes undetectable (Fig. 2).

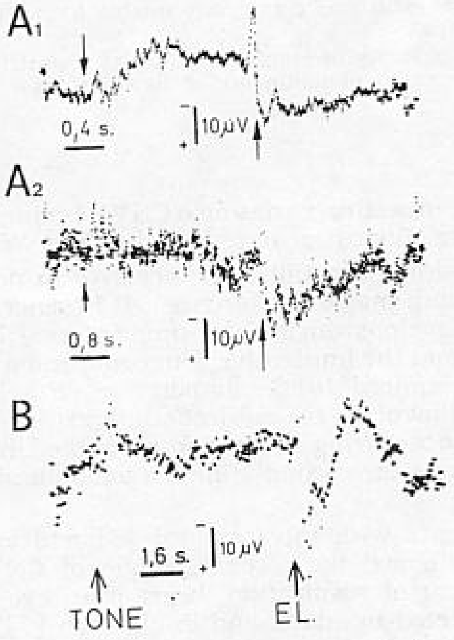

Fig. 2. In subject A, CNV could be detected with the interstimulus interval of 2 seconds (A—1), but not with the interval of 4 seconds (A—2). In subject B, however, CNV was still obtainable at 8 seconds' interval.

Motor action is not indispensable for the generation of CNV, if the second (i. e. imperative) stimulus is a task involving a short thinking process rather than a simple sensory stimulus [15].

The experiments described in this paper were designed to determine whether or not CNV can be obtained through a pair of simple sensory stimuli without being followed by a motor action.

The general plan of the experiments is given in Figure 3. The pairs of stimuli (S_1—S_2) were delivered in a random sequence. The interval between both stimuli (which were electrical, visual, auditory, or combined) is the "expectancy period". Because of the low amplitude ratio between CNV detected by silver disc electrodes from the scalp and the "noise" of random EEG, the method of cross-correlation on a computer of average transients was used. The delay between start of computer analysis and the signal (S_1) has been interpolated in order to obtain the initial zero level of the recording. The crucial component of the set was the amplifier which had to comply with rigid requirements imposed by the nature of the detected response. The problem of drifting due to electrode polarization and other DC artifacts had to be compensated for by "automatic zero" adjustment, because the lower frequency limit was as low as 0.14 Hz.

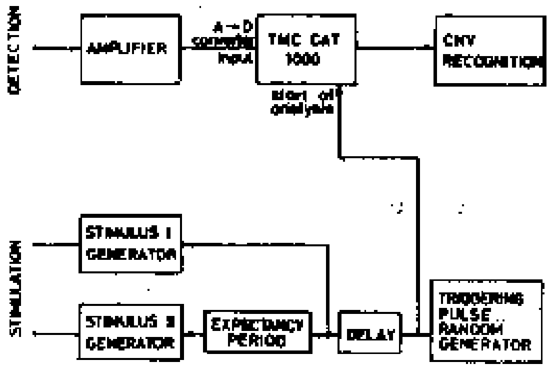

Fig. 3. Experimental arrangement for the detection of CNV.

Our results have shown that a trained subject can generate CNV without any motor action, although both stimuli are sensory (Fig. 4).

Such a pair of stimuli applied at the same interval can generate merely nonspecific somatosensory potentials, if they have no psychological meaning for the subject (Fig. 4 A).

When, however, the first stimulus is given the meaning of a conditioning and the second one of an imperative stimulus which must be followed by a motor action, the subject generates CNV (Fig. 4 B).

However, the subject can learn to interpret the stimuli as conditioning and imperative, respectively, and generate CNV, without initiating any motor action (Fig. 4 C).

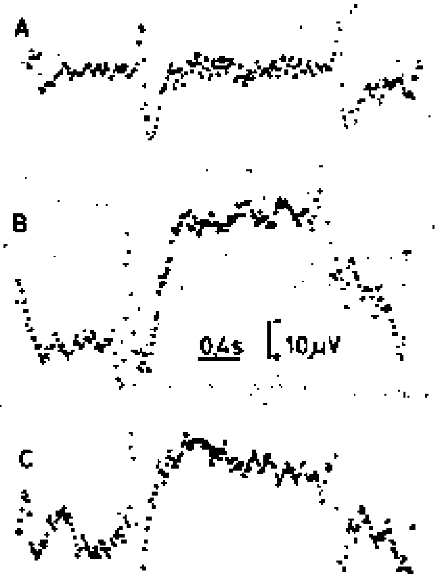

Fig. 4. When the subject is unattentative to the stimuli, no CNV is generated. The recording only shows sensory evoked responses (A). CNV appears when a motor (B) or mental (C) action had to be started after the second stimulus of the pairs.

Our experiences suggest that a hemiplegic patient will generate CNV both when told to respond to sensory stimuli with a movement of the healthy and of the affected side, although in the latter case he is unable to do so (Fig. 5).

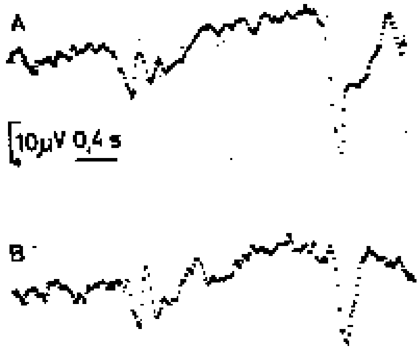

Fig. 5. CNV's generated by a hemiplegic patient. A: when the response required was a movement of the uninvolved hand. B: when it was an attempt to move the plegic hand (wihout there occurring any actual movement).

A tetraplegic patient, who was unable to do any movement with his limbs, could generate CNV, although both stimuli were simple sensory, e.g. light flashes (Fig. 6). The requirement is that the two stimuli have a definite meaning for the patient: that the first stimulus announces the second one which tells to perform a movement, although he is unable to do so.

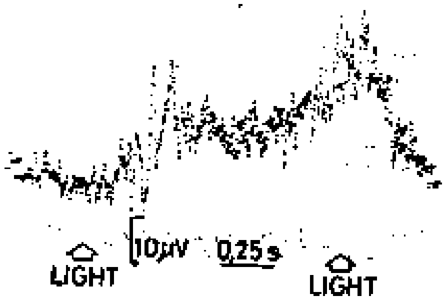

Fig. 6. CNV generated by a tetraplegic patient who was unable to perform any movement with his limbs.

After some conditioning a tetraplegic patient, as well as any other subject, can learn to choose deliberately whether or not to respond with CNV to the stimuli. It is this feature of CNV which offers the possibility of using it as a controlling signal. The prominent characteristic of this signal is that it is completely independent of any motor activity. Thus it could be, for instance, of immense value for communication with a patient completely curarized in the course of the treatment for tetanus.

The question asked by a control engineer will undoubtedly be how many degrees of freedom can be obtained from CNV, and what can be the amount of information per unit of time.

To answer these questions, three stimuli were applied and the subject was asked to generate CNV either in the interval between stimulus I and stimulus II, or between stimulus II and stimulus III, or else between stimulus I and stimulus III. This gave a logical signal with three degrees of freedom; with four stimuli we should already have six degrees of freedom. This considerably increases the amount of information per time unit, although the generation of CNV is a relatively slow process.

In our last experiments, a tetraplegic patient has learned to operate a switch by means of CNV. This was accomplished by automatic recognition of CNV from the averaging computer (Fig. 7). Recognition, which was on-line, was based on comparison of integrals of individual sections of the summated EEG. In this way the artifactual peaks were eliminated and recognition was made reliable.

It may be concluded from these results that the use of CNV as a control signal is technically possible and may be of great practical value in certain special cases.

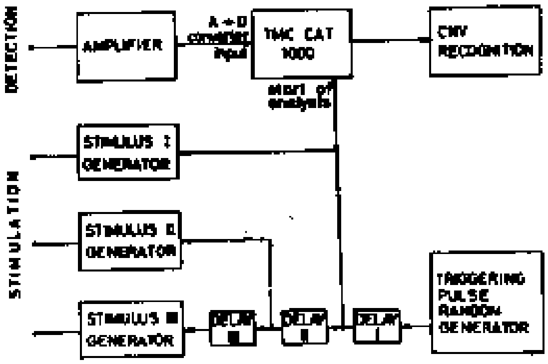

Fig. 7. Arrangement for the recognition of CNV when used as a controlling signal.

REFERENCES

1. Walter, W. G., Cooper, R., Aldridge, V. J., McCallum, W. C., Winter, A. L., "Contingent Negative Variation: An Electric Sign of Sensory-Motor Association and Expectancy in the Human Brain". *Nature, 203:* 380, London, 1964.
2. Walter, W. G., "The Convergence and Interaction of Visual, Auditory and Tactile Responses in Human Nonspecific Cortex", *Ann, N. Y. Acad. Sci., 112:* 320—361, 1964.
3. Walter, W. G., Cooper, R., Aldridge, V. J., Cohen, J., "L'origine et la signification de l'onde d'expectative", *Rev. Neurol., 111:* 257—273, 1964.
4. Walter, W. G., "Slow Potential Waves in the Human Brain Associated with Expectancy, Attention and Decision", *Arch. Psychiat. Nervenkr., 206:* 309—322, 1964.
5. Walter, W. G., Cooper, R., Crow, H. J., McCallum, W. C., Warren, W. J., Aldridge, V. J., Storm van Leeuwen, W., Kamp, A., "Contingent Negative Variation and Evoked Responses Recorded by Radio-Telemetry in Free-Ranging Subjects", *Electroenceph. clin. Neurophysiol., 23:* 197—206, 1967.
6. Low, M. D., Borda, P. R., Frost, D. J., Kellaway, P., "Surface-Negative, Slow-Potential Shift Associated with Conditioning in Man", *Neurology, 16:* 771—782, 1966.
7. Cohen, J., Offner,F., Palmer, C. W., "Development of the Contingent Negative Variation in Children, *Electroenceph. clin. Neurophysiol., 23:* 779, 1967.
8. Low, M. D., Borda, R. P. Frost, J. D., Kellaway, P., "The Contingent Negative Variation in Sub-Human Primates", *Physiologist, 8:* 223, 1965.
9. Low, M. D., Borda, R. P., Kellaway, P., "Contingent Negative Variations" in Rhesus Monkeys: An EEG Sign of a Specific Mental Process", *Percept mot. Skills, 22:* 443—446, 1966.

10. Irwin, A. D., Knott, R. J., McAdam, W. D., Rebert, C. S., "Motivational Determinates of the 'Contingent Negative Variation'," *Electroenceph. clin. Neurophysiol., 21:* 538—543, 1966.
11. Low, D. M., Coast, C. A., Retting, M. G., McSherry, J. W., "Anxiety, Attentiveness-Alertness: A Phenomenological Study of the CNV. *Neuropsychologia, 5:* 379—384, 1967.
12. Low, D. M., McSherry, J. W., "Further Observations of Psychological Factors Involved in CNV Genesis", *Electroenceph. clin. Neurophysiol., 25:* 203—207, 1968.
13. McCallum. W. C., Walter, W. G., "The Effects of Attention and Distraction on Contingent Negative Variation in Normal and Neurotic Subjects", *Electroenceph. clin. Neurophysiol., 25:* 319—329, 1968.
14. McAdam, D. W., Irwin, A. D., Rebert, S. C., Knott, J. R.,: Conative Control of the Contingent Negative Variation. *Electroenceph. clin. Neurophysiol.,* 1966, *21:* 194—195.
15. Cohen, J., Walter, W. G., "The Interaction of Responses in the Brain to Semantic Stimuli," *Psychophysiology, 2:* 187—196, 1966.
16. Lokar, J., "Recording of CNV", Meting of the Croatian Society of Electroencephalography and Clinical Neurophysiology, Zagreb, 1969 (unpublished).