Electroencephalography and clinical Neurophysiology, 1983, 56: 367–372
Elsevier Scientific Publishers Ireland, Ltd.

PREPARATION- OR INTENTION-TO-ACT, IN RELATION TO PRE-EVENT POTENTIALS RECORDED AT THE VERTEX [1]

BENJAMIN LIBET *, ELWOOD W. WRIGHT, Jr. ** and CURTIS A. GLEASON **

** Department of Physiology, University of California, San Francisco, Calif. 94143, and ** Neurological Institute, Department of Neuroscience, Mount Zion Hospital and Medical Center, San Francisco, Calif. 94115 (U.S.A.)*

(Accepted for publication: April 28, 1983)

A slow negative shift in potential, recordable extracranially, appears during the second or so preceding a signal to which a subject is supposed to respond. The 'contingent negative variation' (CNV) was the first discovered example of this (Walter et al. 1964). Similar pre-event potentials were found in a variety of delayed reaction paradigms, in both man (Low et al. 1966a; Donchin et al. 1971, 1972; Kutas and Donchin 1980; Rohrbaugh et al. 1980; Sanquist et al. 1981; Libet et al. 1982) and monkeys (Low et al. 1966b; Rebert 1972; Rosen and Stamm 1972). Several classes of processes may be reflected in these pre-event potentials: (1) a non-motor process; suggestions for this have included expectancy or anticipation (Walter et al., 1964), or an orienting or possibly more 'general response to salient or novel stimuli' (see Rohrbaugh and Gaillard, 1983) which may involve a shift in attentive or arousal state (Desmedt 1981) and leads to some behavioral/mental response (Donchin et al. 1971, 1972); (2) a general cerebral motor process, as represented in the readinesspotential (RP), that leads to the response (e.g., Rohrbaugh et al. 1980; Sanquist et al. 1981); (3) a combination of (1) and (2) (see Kutas and Donchin 1980; Rohrbaugh and Gaillard 1983); (4) a conative process of preparing or intending to act, independent of any actual movement (e.g., Low et al. 1966a; Libet et al. 1982). The present work helps to distinguish more definitively among these alternatives for the case of vertex-recorded potentials. The same human subject was tested with closely related procedures all of which developed mental sets of strong expectancy, orientation and attentiveness but differed in whether motor or non-motor responses were required. The study utilizes the subjects' introspective reports, in conjunction with the behavioral tasks, to define the mental sets in question.

Methods

Recording and other procedures are fully described in Libet et al. (1982); only a reduced description of features essential to understanding the present text is presented. The EEG was recorded monopolarly at the vertex, referred to linked mastoid electrodes, utilizing a DC system. Storage of each 2 sec period, for averaging of 40 trials, began 1.4 sec before a trigger signal for 'zero-time.' This trigger was either the electromyogram (EMG), recorded over the appropriate forearm muscle in the case of motor trials, or the stimulator synch pulse in sensory non-motor trials. In each 2–3 h session at least one motor and one sensory series of 40 trials were studied, after some training runs. Each trial began with a warning tone at which the subject was to relax, fix his gaze on a point on the 5 inch screen of a cathode ray oscilloscope (CRO) about 2 m away and not blink until after the trial. (Absence of eye movements and blinking was monitored visually. The identical procedure had been found to obviate any significant contribution from ocular potentials with EOG recordings; see Libet et al. 1982. In any case, ocular functions were the same for all series and

[1] This work was supported in part by the Research Support Program of the Mount Zion Hospital and Medical Center, San Francisco.

could not account for systematic differences among recorded vertex potentials.) Within 1–2 sec the operator initiated continuous circular clockwise revolutions of the CRO spot of light, each starting at '12 o'clock' and completed in 2.56 sec, rather than in the conventional 60 sec.

For 'pre-set motor series' (M), the subject was to observe the spot reaching a pre-arranged time at which he would suddenly and sharply flex the fingers of the right hand (see Libet et al. 1982), similar to the acts used in studying readiness potentials (RP). For each successive block of 10 trials, the pre-set 'clock-time' to act was '70 sec,' '80 sec,' '100 sec' and '50 sec.' Subjects were encouraged 'to hit the moving spot as it crossed the pre-set time position.' Their EMG trigger times were recorded and, in most trials for all subjects, these were within 1–2 'sec' (actually about 50–100 msec) of the pre-set time. For both 'M-veto' and 'pre-set sensory' (S) series, procedures and pre-set times were the same as in M series, except that no motor act was produced by the subject. In M-veto series subject vetoed his intention to act just prior to the pre-set time for action (see fuller description in Results), while in S series delivery of a task-related stimulus to the back of the right hand at the pre-set time replaced the requirement to move. The stimulus was a single pulse at about 10–20% above threshold; it was weak enough to be missed unless the subject was properly attentive to it at the pre-set time of delivery, but strong enough to be perceived without equivocation when attending to it. In a small percentage of trials (5–8 of the 40) selected at random, the stimulus was omitted at the pre-set time. Subjects' task was to recognize any such omissions and, when later asked, to report their totals. All subjects were close to 100% accurate in the stimulus task; a relatively large P300 potential (Figs. 1 and 2) further attested to the suitability of attentive state and response.

The 5 subjects (2 males, 3 females) were students in their 20's. Four subjects (BD, SS, SB, GL) were familiar with the general procedures from related previous studies (see Libet et al. 1982, 1983), but none were aware of the experimental design or hypotheses in the earlier or present studies. BD and SS were studied in 3 sessions each, SB in 2, GL and AH in 1 each.

Results

Pre-set motor (M) series

All subjects exhibited a ramp-like slow negative shift preceding EMG-0 time by > 1.4 sec (M in Figs. 1 and 2). Such pre-event potentials resemble those reported when forewarned time to act is signaled by a discrete stimulus (e.g., Low et al. 1966a,b; Donchin et al. 1971, 1972; Kutas and Donchin 1980; Rohrbaugh et al. 1980; Sanquist et al. 1981), instead of by the monitoring of 'clock-time' by our subjects. They also resemble the RPs that precede either self-paced movements (e.g., Kornhuber and Deecke 1965; Vaughan et al. 1968; Deecke et al. 1976) or those freely self-initiated movements that involve mental pre-planning (Libet et al. 1982).

M-veto series

For each of the 40 events in these series, the subject was instructed (a) to adopt the same mental set as in M series, of preparing to move at the

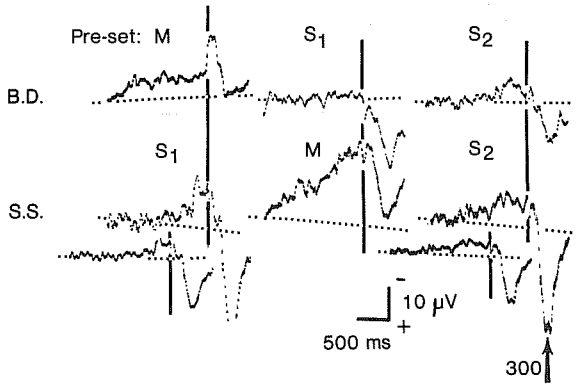

Fig. 1. Pre- and post-event potentials in pre-set motor (M) and pre-set sensory (S) series, carried out for subjects BD and SS in July, 1980 (cf. Fig. 2). (The 'P300' wave after the stimulus was so large in the S-series for SS that additional tracings at one half the gain, but same time-base, are shown as inserts, each with a separate 0-time vertical line.) *In both Figs. 1 and 2*: each tracing is average of vertex potentials in 40 trials, presented in the actual sequence of performance in a given session for that subject. (S_1 and S_2 refer to the first and second of the S series in the session.) The solid vertical line through each column represents '0-time,' given by the EMG for M series and by an externally supplied trigger pulse in M-veto and S series; '0-time' coincided with pre-set time for each event (see text). The dashed horizontal line in each tracing is estimated DC baseline.

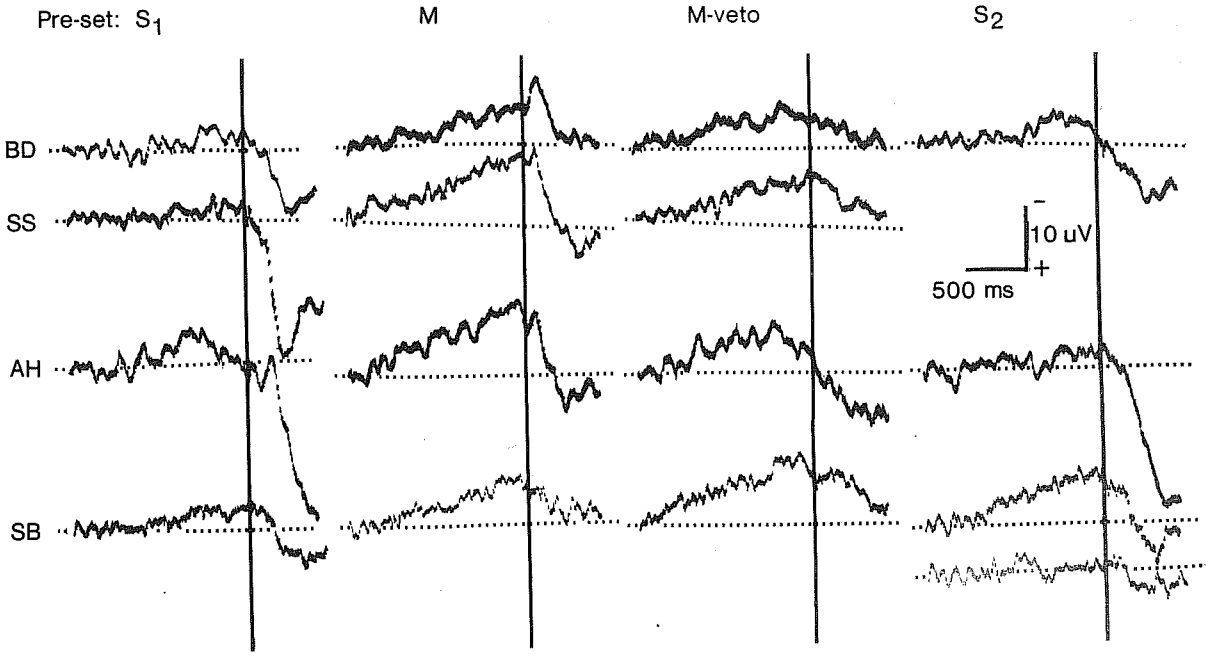

Fig. 2. Pre-event vertex potentials in S, M and M-veto series (see text), in 1 session for each of 4 subjects (in spring of 1982). Subjects BD and SS were same as in Fig. 1. In M-veto series there were no actual motor acts (as in S series), but there was preparation/intention to act before each pre-set time (as in M series). For subject SB, the tracing below S_2 represents a final (S_3) series of pre-set skin stimuli for which the subject was told to ignore the previous instruction to attend to any omitted stimuli, as there would be no omissions of stimuli. (The relatively flat tracing indicates that potential shift in his previous (S_2) series was related to something in his psychological set.)

designated pre-set time, but (b) 'to veto' this intention when the revolving CRO spot arrived within about '2.5–5 sec' (actually about 100–200 msec) before pre-set time. The absence of any observable motor activation was confirmed by monitoring the EMG at sufficiently high gain. The computer trigger for pre-set 0-times, in the absence of an EMG, was supplied by an operator in another room. In spite of the strangeness of this request, every subject reported experiencing varying degrees of preparation and intention before vetoing the action. A few subjects reported that the urge to move extended to some additional parts, like the left hand or a leg, but no actual movements of these were observed or experienced. Each subject in fact did produce a ramp-like pre-potential in one or more such series (Fig. 2, M-veto). Amplitude was usually though not always (SB, Fig. 2) smaller than for M in the same subject. Also, while 'pre-set RPs' in M series typically rise until close to 0-time (see also Libet et al. 1982), in M-veto series they tend to reverse direction within some 150–250 msec before 0-time; this suggests that the negative rise terminates at about the presumed time for reversing the intention to act.

Pre-set stimulus (S) series

Each S series could be directly compared with an M series performed in succession by the same subject in each session. For making task-related reports, the subject was instructed simply to remember the occurrences of stimulus omissions, but not to think about making a motor report about them until requested by the observer; this was to minimize the possibility that any preparation to move might begin before pre-set 0-time and thus induce its own pre-event potential, as in the M and M-veto series. The subjects reported an experience of moderate to strong expectancy or anticipation as the revolving CRO spot approached the pre-set

time for the stimulus. In each session they were asked to compare the subjective intensities of their expectancies for events in S vs. M series after these were performed in sequence. They reported that their expectancies in S events were roughly comparable to those in their M series. That is, the S expectancies were reported to be equal to, somewhat greater or somewhat less than M expectancies, in roughly similar proportions, and even by the same subject in different sessions.

Pre-event potentials in S series ranged from being almost 0 (i.e., flat DC, Fig. 1, BD-S_1; Fig. 2, SS, AH-S_2) to exhibiting some negative shifts that were much smaller and briefer than and lacking the ramp-like form of those in M series (Fig. 1, BD-S_2, SS-S_1 and S_2; Fig. 2, BD-S_2, AH-S_1, SB-S_1; the one exception was exhibited by subject SB for S_2). Such variations between 0 and some small negative shift could be exhibited by each subject, in different S series even within the same session. The presence or absence of small pre-event potentials in different S series did not correlate with the reported intensities of expectancy. In some S series with essentially 0 pre-event potential, experiences of expectancy were reported to be as great or greater than in M series.

Comparing all 3 types of series, a prominent and consistent pre-event slow negative shift appeared only in M or M-veto series, but was absent or relatively small and brief in S series. This relationship appears definitive, even though statistically quantitative values cannot be derived. In addition to the striking qualitative differences between S vs. M or M-veto series in the present total of 10 sessions on 5 subjects, the nature and range of pre-event potentials under related conditions, in many previous sessions with 4 of these subjects (see Libet et al. 1982), helped establish the reliability of the presently reported ones.

Discussion

The results lead to the conclusion that those non-motor processes common to all present series (M, M-veto, and S) appeared to be not sufficient to produce the vertex-recorded pre-event potential. The cerebral processes additionally present in M and M-veto series, those for preparation or intention to perform a motor act even if not consummated in a movement, appeared to provide the factor necessary for the appearance of most if not all of the pre-event potential recorded under our conditions.

The present findings are in accord with those in studies of CNV utilizing intervals of 3–4 sec rather than 1–1.5 sec, between the warning (S_1) and the imperative (S_2) stimuli. The late or terminal phase of such CNVs resembles RPs, in topographical distribution and form (see Rohrbaugh and Gaillard 1983). The early 'O' wave in such CNVs is largest at the midline frontal (F_2) electrode, a site not studied here. Also, the early phase appears to terminate within a second or two after the warning stimulus. This could account for its apparent absence during the averaged 1.4 sec intervals preceding our task-related S event; any general type of orienting potential in our paradigm could have appeared some seconds earlier, when the revolution of the CRO spot was begun. Our evidence does not exclude the possibility that a non-motor 'O' type component may contribute to a vertex-recorded CNV when the interval between S_1 and S_2 is only 1–1.5 sec, but it argues against even such CNVs consisting solely of such a non-motor process. Recent evidence (Libet et al. 1982) supports a related view that the more completely endogenous RPs in self-initiated 'spontaneous' voluntary movements represent preparation/intention for moving, not some non-motor process.

An absence of pre-event potential when task-related stimuli were delivered, at regular intervals known to the subject, had already been reported by Desmedt and Debecker (1979); but their subjects did not continuously monitor approaching time for the stimulus and the issue of expectancy/anticipation was not raised by that study. The pre-set S event in our study produced either no pre-event SP or a small brief one. Perhaps even the latter would be absent if it were possible to eliminate any tendency, conscious or unconscious, for the subject to prepare or intend to make a motor response even though the latter was not requested. This is in part supported by the findings that subjects produced both an essentially zero pre-event potential and a small, brief pre-event

SP in different pre-set S series performed in the same experimental session, without correlative changes in expectancy or attention. On such a view, any small SPs in S series might represent 'covert RPs' related to those in M-veto series. It also suggests that in evaluating reports that some CNV can appear even when an immediate motor response is not requested (see Donchin et al. 1971, 1972; but compare Desmedt and Debecker 1979), it is clearly important to consider possible RP contributions from covert preparation or intention to produce an unrealized motor response.

Of especial interest is our finding that a developing preparation or intention to move can clearly be accompanied by a substantial 'RP' even when the subject knows he will eventually veto the intention to act, and when in fact he does not activate the muscle. Such a 'covert RP' might be a general feature of non-consummated urges or intentions to act (Libet et al. 1982). Mental performance of imaginary movements has been found to be associated with an increase of blood flow in mesial supplementary motor cortex (Lassen et al. 1978). Such evidence could not establish whether the increased neural actions coincided with the preparational phase just before each imagined act, as could be done for the present covert RPs preceding vetoed actions. But it is in accord with other evidence that supplementary motor area may be a generator of vertex-recorded RPs (Deecke and Kornhuber 1978; Eccles 1982; Libet et al. 1982).

Summary

Pre-event potentials were compared in the same subject, for 3 types of forewarned events, in which the foreperiod for orienting or attention began several seconds before the event. All of these trials involved similar non-motor components (expectancy, attentiveness, general orienting to a salient stimulus) but differed in whether motor or non-motor responses were required. A prominent and consistent slow negative shift preceded the pre-set time for a motor response, even when the subject 'vetoed' his intention to act shortly before the pre-set time. Pre-event potentials were absent, or small and brief, when the event was a task-related skin stimulus not involving preparation to move. The findings selectively support the view that mental preparation/intention to act is a necessary and perhaps dominant process associated with the vertex-recorded pre-event, slow negative potential. They also show that such a pre-event potential can appear even when the subject knows he is going to veto his developing intention to act and does not actually move.

Résumé

Mise en relation de la préparation ou de l'intention d'effectuer un acte avec les potentiels précédant l'événement recueillis au vertex

Les potentiels précédant l'événement ont été comparés chez le même sujet pour 3 types d'événements avec avertissement préalable, dans lesquels cette période préalable d'orientation ou d'attention commençait plusieurs secondes avant l'événement. Tous ces essais comportaient les mêmes composantes non motrices (attente, attention, orientation générale à un stimulus brusque) mais différaient en ce qu'une réponse motrice était ou non, demandée. Une variation négative lente, importante et stable, apparaissait avant le moment fixé pour la réponse motrice, même lorsque le sujet décidait de ne pas agir peu de temps avant ce moment. Les potentiels précédant l'événement étaient absents, ou petits et brefs lorsque l'événement était un stimulus tactile lié à la tâche, n'impliquant pas de préparation au mouvement. Ces données confirment l'idée selon laquelle la préparation mentale d'un acte ou l'intention d'agir est un processus nécessaire et probablement dominant associé au potentiel négatif lent précédant l'événement qui est enregistré au vertex. Elles montrent également qu'un potentiel négatif pré-événement peut apparaître même quand le sujet sait qu'il s'interdira l'intention d'agir et qu'il ne développera pas de mouvement.

We thank Drs. Enoch Callaway and Alan Gevins for their helpful criticism of the manuscript.

References

Deecke, L. and Kornhuber, H.H. An electrical sign of participation of the mesial "supplementary" motor cortex in human voluntary finger movement. Brain Res., 1978, 159: 473–476.

Deecke, L., Grözinger, B. and Kornhuber, H.H. Voluntary finger movement in man: cerebral potentials and theory. Biol. Cybernet., 1976, 23: 99–119.

Desmedt, J.E. Scalp-recorded cerebral event-related potentials in man as point of entry into the analysis of cognitive processing. In: F.O. Schmitt, F.G. Worden, G. Adelman and S.D. Dennis (Eds.), The Organization of the Cerebral Cortex. M.I.T. Press, Cambridge, Mass., 1981: 441–473.

Desmedt, J.E. and Debecker, J. Slow potential shifts and decision P350 interactions in tasks with random sequences of near threshold clicks and finger stimuli delivered at regular intervals. Electroenceph. clin. Neurophysiol., 1979, 47: 671–679.

Donchin, E., Otto, D., Gerbrandt, L.K. and Pribram, K.H. While a monkey waits; electrocortical events recorded during the foreperiod of a reaction time study. Electroenceph. clin. Neurophysiol., 1971, 31: 115–127.

Donchin, E., Gerbrandt, L.K., Leifer, L. and Tucker, L. Is the contingent negative variation contingent on a motor response? Psychophysiology, 1972, 9: 178–188.

Eccles, J.C. The initiation of voluntary movements by the supplementary motor area. Arch. Psychiat. Nervenkr., 1982, 231: 423–441.

Kornhuber, H.H. and Deecke, L. Hirnpotentialänderungen bei Willkürbewegungen und passiven Bewegungen des Menschen: Bereitschaftspotential und reafferente Potentiale. Pflügers Arch. ges. Physiol., 1965, 284: 1–17.

Kutas, M. and Donchin, E. Preparation to respond as manifested by movement-related brain potentials. Brain Res., 1980, 202: 95–115.

Lassen, N.A., Ingvar, D.H. and Skonhøj, E. Brain function and blood flow. Scient. Amer., 1978, 239: 62–71.

Libet, B., Wright, Jr., E.W. and Gleason, C.A. Readiness potentials preceding unrestricted "spontaneous" vs. preplanned voluntary acts. Electroenceph. clin. Neurophysiol., 1982, 54: 322–335.

Libet, B., Gleason, C.A., Wright, E.W. and Pearl, D.K. Time of conscious intention to act in relation to onset of cerebral activities (readiness-potential); the unconscious initiation of a freely voluntary act. Brain, 1983, 106: 623–642.

Low, M.D., Borda, R.P. and Kellaway, P. "Contingent negative variation" in rhesus monkeys: an EEG sign of a specific mental process. Percept. Motor Skills, 1966a, 22: 443–446.

Low, M.D., Borda, R.P., Frost, Jr. J.D. and Kellaway, P. Surface-negative, slow-potential shift associated with conditioning in man. Neurology (Minneap.), 1966b, 16: 771–781.

Rebert, C.S. Cortical and subcortical slow potentials in the monkey's brain during a preparatory interval. Electroenceph. clin. Neurophysiol., 1972, 33: 389–402.

Rohrbaugh, J.W. and Gaillard, A.W.K. Sensory and motor aspects of the contingent negative variation. In: A.W.K. Gaillard and W. Ritter (Eds.), Tutorials in ERP Research: Endogenous Components. North-Holland Publishing Company, Amsterdam, 1983: 269–310.

Rohrbaugh, J.W., Syndulko, K., Sanquist, T.F. and Lindsley, D.B. Synthesis of the contingent negative variation brain potential from noncontingent stimulus and motor elements. Science, 1980, 208: 1165–1168.

Rosen, S.C. and Stamm, J.S. Cortical steady potential shifts during delayed response performance by monkeys. Electroenceph. clin. Neurophysiol., 1972, 33: 389–402.

Sanquist, T.F., Beatty, J.T. and Lindsley, D.B. Slow potential shifts of human brain during forewarned reaction. Electroenceph. clin. Neurophysiol., 1981, 51: 639–649.

Vaughan, Jr., H.G., Costa, L.D. and Ritter, W. Topography of the human motor potential. Electroenceph. clin. Neurophysiol., 1968, 25: 1–10.

Walter, W.G., Cooper, R., Aldridge, V.J., McCallum, W.C. and Winter, A.L. Contingent negative variation: an electrical sign of sensorimotor association and expectancy in the human brain. Nature (Lond.), 1964, 203: 380–384.