*Physiol. Res. 41: 391–396, 1993*

# Asymmetry of Hemispheric EEG Slow-potentials During One-Dimensional Tracking

M. INDRA, Z. BOHDANECKÝ

*Institute of Physiology, Academy of Sciences of the Czech Republic, Prague*

*Received February 24, 1993*
*Accepted June 18, 1993*

## Summary

Hemispheric EEG slow-potential asymmetry (SPA) during a one-dimensional horizontal tracking task was recorded over $O_1$, $O_2$, $C_3$ and $C_4$ electrode positions. The time instants of tracking error occurrences (OUT events) and their corrections (IN events) were used as synchronization events in selected EEG epochs. The central values (medians) of amplitudes in the averaged 500 ms EEG epochs were used for SPA description. Significant negative correlations between medians calculated for the time epochs prior to and after the events were found indicating a specific influence of these events on SPA. Prior IN events the left hemisphere (represented by $O_1$ and $C_3$ positions only) was more negative than the right one, while it was significantly more positive after the same type of events. An opposite relationship was suggested for OUT events.

## Key words

EEG slow-potentials – Hemispheric asymmetry – Tracking

## Introduction

Two basic types of cortical slow potentials (SP) preceding the beginning of movement (finger flection or button pressing) have been distinguished in the literature. The first one is represented by the contingent negative variation (CNV) in simple reaction tasks (Walter *et al.* 1964) and the other one labelled Bereitschafts or readiness potential (BP, RP) is recorded before self-paced voluntary movements (Kornhuber and Deecke 1965).

The CNV appears in the EEG record during the period preceding a simple reaction task (RT) paradigm with the largest amplitudes at the vertex. The late wave of CNV (at the end of the preparatory period) reflecting an anticipation process moreover exhibits hemispheric asymmetry with larger amplitudes on the contralateral hemisphere to the side of movement (Callaway 1975).

The BP has more components, particularly in its late phases. It begins as a negative potential symmetrically 1000–1500 ms before the onset of voluntary movement. Its negativity then increases more rapidly during approximately 400 ms, especially contralaterally to the moving limb (the contralateral preponderance of negativity). Reaching its maximal amplitude 80–100 ms prior to the onset of movement the readiness potential value is often transformed into a positive deflection (premotion positivity) followed by the motor potential over the hand area in the motor cortex (Deecke *et al.* 1969, Deecke 1987, Tarrka and Hallett 1990).

Hemispheric asymmetry in cortical SP reflecting their laterality has also been demonstrated recently under different experimental conditions of motor preparation or anticipation by Damen and Brunia (1987) and by Rockstroh *et al.* (1990).

Our previous experiments suggested that similar SPs could also be detected during simple continuous one-dimensional hand tracking (i.e. aimed movement), namely in connection with tracking errors or their corrections (Indra *et al.* 1989).

The aim of the present study was to test the relationship between different experimental tracking conditions and the expected SPA. It was anticipated that the asymmetry should reflect the phase of tracking task with respect to the time of tracking errors and their corrections. In other words, the goal of the study was to detect any possible relationship between the different phases of tracking execution in right-handed subjects and parallel changes in the left pre-motor or motor areas. The effort of the subject expressing either the intensity and intention to return the light spot back within the target limits or their time course only could be assessed from the magnitude of the expected change in the left hemisphere.

## Methods

*Procedure*

Seven right handed healthy subjects (4 men, 3 women) 19–22 years old and completely naive as regards their tracking skill, volunteered for the experiment. All subjects were right handed as was proved by the Edinburgh Handedness Inventory (Oldfield 1971), all of them had normal or corrected to normal vision. They sat comfortably in a semi-dark chamber 120 cm in front of a CRT monitor on which the tracking tasks were presented. The experiment consisted of eight 3 min tasks during which the target, represented by two 1 cm vertical lines moved horizontally across the 10 cm wide CRT screen (Fig. 1). The control lever with one degree of freedom was situated in front of the subject near his/her right hand. Its movement was accompanied by horizontal movement of a light-spot on the screen. During the tracking tasks the subjects had to keep the light-spot within the given target limits.

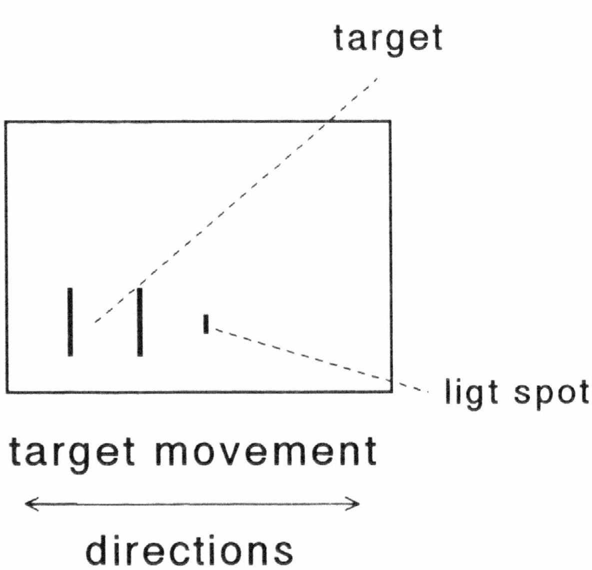


**Fig. 1**
The task presentation on the CRT screen. Moving target is represented by two vertical lines on the left side and the light spot controlled by the joystick in the middle of the screen.

Two algorithms controlling the target movement were adopted: (1) the interrupted tracking task (IT), when the target moved only when the light-spot was situated inside the target and did not move when it occurred outside; (2) the continuous tracking (CT) when the target moved independently of the light-spot position with respect to the target. The speed of target movement was either 4 or 6 cm/s and it was kept constant during the trial. The width of the target was either 10 or 20 mm.

At the beginning of each session the target was always presented on the left side, and the light-spot was positioned in the centre of the screen. The subject had to move the light-spot towards the target and when he reached its centre, the target started its pre-programmed periodical movement from the left side to the right and *vice versa.*

Tracking error (OUT event) was scored whenever the subject failed to keep the light-spot within the given target boundaries. The return into the middle of the target was evaluated as an error correction (IN event). The subjects were asked to make this correction immediately after the moment, when they realized their error. No special time measurement between error commission and correction was therefore possible. As two basic types of tracking tasks were run, four fundamental types of IN and/or OUT events in our experiments labelled as INI/OUTI – for the IT and INC/OUTC – for the CT could be distinguished.

*EEG data acquisition*

EEG was recorded during the series of 8 tracking tasks from $O_1$, $O_2$ and $C_3$, $C_4$ positions monopolarly by means of non-polarizing Ag/AgCl electrodes. Linked ear lobe electrodes served as a common reference. Amplification and filtration (3 dB down at 30 Hz) was achieved by means of a four channel MIKI 1623E DC amplifier. Its output signal and the synchronizing pulses corresponding to the OUTs/INs were digitized at the rate of 128 samples/s and recorded using amplitude-pulse-width modulation on a tape recorder. Target control, tracking error detection as well as off-line EEG processing (time epochs selection and averaging) were performed by means of a TESLA PP04 computer (PDP 11/34 type). For final statistical evaluation a commercial statistical package STATGRAPHICS implemented on a standard PC AT was used.

*Slow potentials evaluation*

An averaging procedure was adopted to emphasize SPs related to OUT and IN events for each subject, tracking task and electrode, respectively. Using a specially developed program, two different groups of one second epochs (with no EOG or other artifacts) were selected for each trial in the EEG recordings. In the chosen epochs, either an OUT (for OUT epochs) or IN event (for IN epochs) were placed in their centre (i.e. 500 ms before and after the selected event), averaging being mutually time locked (Fig. 2). Usually 20–30 epochs were chosen for averaging, in dependence on the number of rejected epochs.

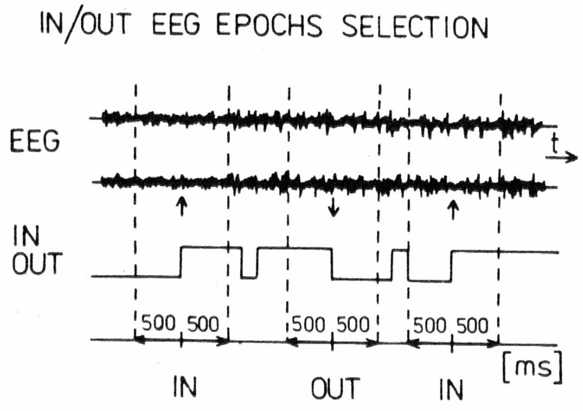


**Fig. 2**
The IN and OUT EEG epochs selection. Either only one IN event (the moment of tracking error correction) is located in the middle of the IN epoch or OUT event (the moment of tracking error occurrence) in the middle of the OUT epoch chosen. Two IN and one OUT epochs were selected as an example.

The symmetrical SP calculated over the occipital ($O_1$, $O_2$) and central ($C_3$, $C_4$) areas were compared, the former location being important for SP related to perceiving the visual stimuli, the latter one for those related to motor control. To assess the hemispheric SP differences (SPD), the arithmetical subtractions ("left minus right hemisphere" at symmetrical electrode positions) of corresponding averaged EEG epochs were performed.

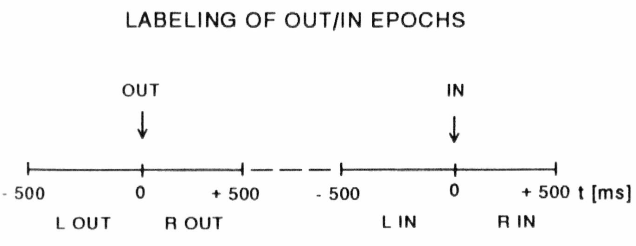


**Fig. 3**
500 ms time epochs preceding and following the OUT (IN) events labelled as LOUT (LIN) and ROUT (RIN).

The median values of SPD were calculated over the 500 ms time intervals before and after the OUT or IN events (from −500 ms to 0 ms and from 0 ms to +500 ms, respectively). The time epochs preceding and following the OUT (IN) event were labelled as LOUT (LIN) and ROUT (RIN), respectively (Fig. 3). The median was chosen as a more appropriate measure than the mean for these comparisons, as the amplitude fluctuations of EEG were expected not to be normally distributed.

Statistical evaluation was made separately for CT and IT tasks. The multi-factor ANOVA (STATGRAPHICS) was adopted to find differences in the following factors of SPD medians: subject (1−7), task (1−4), event (OUT,IN), electrode pair (O, C) and time epoch (L, R). The correlation analysis of SPD medians was run to test the mutual dependence among LOUT, ROUT, LIN and RIN epochs. The paired t-test was used finally to test the difference between prior and post event epochs.

## Results

*Slow potential laterality*

As neither subjects nor various tracking conditions (target speed, target width) produced significantly different SPD medians, data covering all tasks were pooled into two groups only (the IT and CT data files) each with eight variables including all combinations of event x electrode pair x time epoch factors.

(a) Correlation analysis of SPD medians of the LOUT, ROUT, LIN and RIN epochs showed significant negative correlations between prior and corresponding post event epochs in all cases for each of the electrode pairs. No other significant correlations were found in the remaining situations. This finding means that the SPD values were changed by both types of events. The results are presented in detail in Table 1. Joined data of both electrode pairs yielded a similar effect.

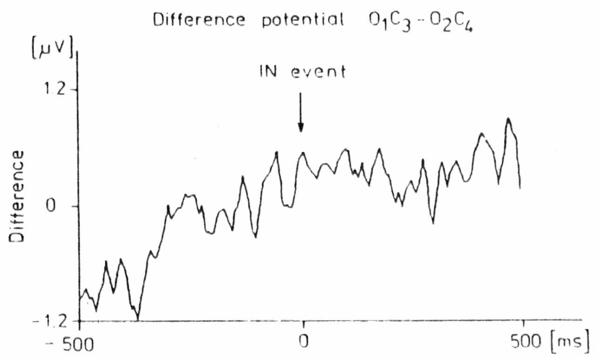


**Fig. 4**
The averaged difference potential (SPD) calculated from all subjects and continuous tracking tasks (CT) during the IN epoch.

**Table 1**
Correlation coefficients and significance levels for CT and IT tasks (sample size = 28). *** $p<0.001$

Task: CT

| | Electrode Pair: $O_{12}$ | | | | Electrode Pair: $C_{34}$ | | | |
|---|---|---|---|---|---|---|---|---|
| | LOUT | ROUT | LIN | RIN | LOUT | ROUT | LIN | RIN |
| LOUT | **1.000** *** | **–.972** *** | .257 | –.114 | **1.000** *** | **–.959** *** | –.192 | .296 |
| ROUT | **–.927** *** | **1.000** *** | –.058 | –.047 | **–.959** *** | **1.000** *** | .125 | –.216 |
| LIN | .257 | –.058 | **1.000** *** | **–.938** *** | –.199 | .125 | **1.000** *** | **–.950** *** |
| RIN | –.114 | –.048 | **–.938** *** | **1.000** *** | .296 | –.216 | **–.950** *** | **1.000** *** |

Task: IT

| | Electrode Pair: $O_{12}$ | | | | Electrode Pair: $C_{34}$ | | | |
|---|---|---|---|---|---|---|---|---|
| | LOUT | ROUT | LIN | RIN | LOUT | ROUT | LIN | RIN |
| LOUT | **1.000** *** | **–.965** *** | –.060 | .025 | **1.000** *** | **–.983** *** | .154 | –.256 |
| ROUT | **–.965** *** | **1.000** *** | –.074 | –.043 | **–.983** *** | **1.000** *** | –.150 | .238 |
| LIN | –.060 | .074 | **1.000** *** | **–.972** *** | .153 | –.150 | **1.000** *** | **–.898** *** |
| RIN | .025 | –.042 | **–.972** *** | **1.000** *** | –.256 | .238 | **–.898** *** | **1.000** *** |

(b) It followed from the paired t-test of corresponding SPD medians that only IN events in CT tasks were accompanied by significant SPD changes (Fig. 4). The SPD medians calculated for both joined electrode pairs over the 500 ms time epochs before IN events were significantly lower than those calculated for corresponding 500 ms epochs after IN events ($-0.5\,\mu V$, $+0.4\,\mu V$, respectively and $t_{55} = -2.04$, $p<0.05$). The main contribution to this result came from the central ($C_3-C_4$) position ($-0.6\,\mu V$, $+0.6\,\mu V$, respectively and $t_{27} = -2.606$, $p<0.05$). This shows that when greater effort is expected before the IN events for error correction, some parts of the left hemisphere (represented by electrode localizations $O_1$, $C_3$ only) were more negative with respect to the right one. On the contrary, the right hemisphere after the IN event was more negative with respect to that on the left.

The SP changes accompanying OUT events in CT tasks suggested a weak mirror-like effect of the results described above, with no statistical significance at all ($+0.1\,\mu V$, $-0.2\,\mu V$, respectively).

No significant differences were, however, found either in the IN or OUT epochs during the IT task completition.

## Discussion

The aim of this study was to verify the hypothesis that the relationship between different tracking conditions (CT, IT, slow/fast tasks with a wide/narrow target) and expected hemispheric asymmetry, expressed in the terms of SPD medians, exists. This hypothesis suggested in particular that the hemispheric asymmetry should reflect the actual phase of tracking (OUT, IN epochs), as different levels of effort could be expected in the course of different phases of the tracking task (Kutas and Donchin 1974).

The results of correlation analysis of SPD medians suggested that the OUT and IN events could have some influence on hemispheric activation. The high negative correlations between prior and post event epochs could be caused by the fact that the lower SPDs before an event were followed by "complementary" higher SPDs after the same event and *vice versa*. Thus, the high negative correlation does not mean a " major direction" of SPD change after the OUT or IN event. If no effect of OUT and IN events occurred, then the SPD medians before and after these events should not differ significantly and corresponding correlations should, on the contrary, be highly positive.

Low correlation values presented in Table 1 suggest that the corresponding time epochs (ROUT x LIN and RIN x LOUT) are mutually independent. This result is not surprising, as the time intervals (gaps) between ROUT and LIN or RIN and LOUT epochs could be relatively large (lasting several seconds) and thus many different brain processes can take place during these epochs.

To specify the direction of SPD, the paired t-test was applied to their respective median values (before and after the events). The contralateral activation of the left hemisphere during the error correction epochs of CT tasks resulted in significantly more negative SPD medians prior to the IN events than immediately after them. The main contribution to this result came from central – motor area ($C_3-C_4$) electrodes. The effort required for performing the specifically aimed movement seems to be accompanied consequently by a contralaterally distributed negative SP resembling the late wave of CNV (expectation of the "hit result"). This finding about development of negativity resembles the recent results of Elbert *et al.* (1991), who described pronounced negativities over the left fronto-temporal region during processing of brief temporal intervals.

Although the contralateral activation of the left hemisphere could be expected (see e.g. Keller and Heckhausen 1990) at the moment after individual error recognition, the significance of this "mirror effect" for the OUT event was not confirmed by the paired t-test. Probably, the time interval of 500 ms only, when the SPs were registered, was too short for developing a sufficiently obvious change of the SP amplitude to be distinguished from the background EEG signal.

The IT tasks were not characterized by such differences at all, in spite of the subject's higher attention. His immediate reaction and higher level of effort, that characterize the principal features of this type of tasks, could also be expected to yield the higher SPD differences. The faster correcting movements in response to the OUT events with shorter error correction times and greater amount of movement artifacts could, however, be the reason of insufficient development of SPD in this situation.

Unlike the typical CNV experiments, it is difficult to distinguish the two types of responses of orientation and actual preparation (Brunia *et al.* 1985). The typical morphology of this potential change can be recorded using at least one-second duration of the tested foreperiod. The situation in our paradigm did not permit such a large foreperiod and, moreover, there exists a time uncertainty effect, presented to the subject at random. This specific condition cannot reflect the full development of the above phenomenon. However, it does reflect the execution level of motor responses required for error correction. In agreement with original Kornhuber's (1974) statement, it is restricted to the motor cortex contralateral to the movement. These results clearly indicate that the most dominant tracking events, from electrophysiological point of view, are the IN events in CT tasks, being accompanied by significant hemispheric asymmetry (Keller and Heckhausen 1990). Moreover, they support our original hypothesis that the cortical activation can also be measured by means of hemispheric slow potential asymmetry during continually aimed movements and not during quiet motionless periods before onset of the movement.

**Acknowledgment**
This study was sponsored in part by a special grant of the Hotel Forum Praha, a division of the Inter-Continental Hotel Corporation (0042-2-4190 111).

## References

BRUNIA C.H.M., HAAGH S.A.V.M., SHEIRS J.G.M.: Waiting to respond: electrophysiological measurements in man during preparation for a voluntary movement. In: *Motor Behavior Programming, Control and Acquisition*. H. HEURER, U. KLEINBECK, K.H. SCHMIDT (eds), Berlin, Springer Verlag, 1985, pp. 35–78.

CALLAWAY E.: *Brain Electrical Potentials and Individual Differences*. Grune and Stratton, New York, 1975.

DAMEN E.J.P., BRUNIA C.H.M.: Precentral potential shifts related to motor preparation and stimulus anticipation: a replication. Current trends in event-related potential research. *Electroenceph. Clin. Neurophysiol.* Suppl. **40:** 13–16, 1987.

DEECKE L.: Bereitschaftspotential as an indicator of movement preparation in supplementary motor area and motor cortex. In: *Motor Areas of the Cerebral Cortex.* Ciba Foundation Symposium 132. Wiley, New York, 1987, pp. 231–250.

DEECKE L., SCHEID P., KORNHUBER H.H.: Distribution of readiness potential, premotion positivity, and motor potential of the human cerebral cortex preceding voluntary finger movements. *Exp. Brain Res.* 7: 58–164, 1969.

ELBERT T., ULRICH R., ROCKSTROH B., LUTZENBERGER W.: The processing of temporal intervals reflected by CNV-like potentials. *Psychophysiology* **28:** 648–655, 1991.

INDRA M., BOHDANECKÝ Z., RADIL T.: The basic electrophysiological phenomena related to one-dimensional hand tracking. *Int. J. Psychophysiol.* **7:** 238–239, 1989.

KELLER I., HECKHAUSEN H.: Readiness potentials preceding spontaneous motor acts: voluntary vs. involuntary control. *Electroenceph. Clin. Neurophysiol.* **76:** 351–361, 1990.

KORNHUBER H.H.: Cerebral cortex, cerebellum and basal ganglia: an introduction to their motor functions. In: *The Neurosciences, Third Study Program,* F.O. SCHMITT, F.G. WORDEN (eds), MIT Press, Cambridge, 1974, pp. 276–280.

KORNHUBER H.H., DEECKE L.: Hirnpotentialänderungen bei Willkürbewegungen und passiven Bewegungen des Menschen: Bereitschaftspotential und reafferente Potentiale. *Pflügers Arch.* **284:** 1–17, 1965.

KUTAS M., DONCHIN E.: Studies of squeezing: handedness, responding hand, response force, and asymmetry of readiness potential. *Science* **186:** 545–547, 1974.

OLDFIELD R.C.: The assessment and analysis of handedness: the Edinburgh Inventory. *Neuropsychologia* **9:** 97–113, 1971.

ROCKSTROH B., ELBERT T., BIRBAUMER N., LUTZENBERGER W.: Biofeedback-produced hemispheric asymmetry of slow cortical potentials and its behavioral effects. *Int. J. Psychophysiol. 9:* 151–165, 1990.

TARRKA I.M., HALLETT M.: Cortical topography of premotor and motor potentials preceding self-paced, voluntary movement of dominant and non-dominant hands. *Electroenceph. Clin. Neurophysiol.* **75:** 36–43, 1990.

WALTER W.G., COOPER R., ALDRIDGE V.J., Mc CALLUM W.C., WITNER A.L.: Contingent negative variation: an electric sign of sensorimotor association and expectancy in the human brain. *Nature* **203:** 380–384, 1964.

---

**Reprint Requests**

Dr. M. Indra, Institute of Physiology, Academy of Sciences of the Czech Republic, 142 20 Prague 4, Vídeňská 1083, Czech Republic.