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CEREBRAL POTENTIALS PRECEDING UNILATERAL AND SIMULTANEOUS BILATERAL FINGER MOVEMENTS [1]

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Three different cerebral potentials preceding unilateral human voluntary movements have been demonstrated (Kornhuber and Deecke 1964, 1965; Deecke et al. 1969, 1976). Contrary to general expectations, the early activity preceding unilateral movements is not unilateral but bilateral from the beginning. A slowly rising negative potential, the Bereitschaftspotential (BP), starts with an average onset time of 800 msec in precentral and parietal regions of both sides and the midline. The second potential, the pre-motion positivity (PMP), is also bilateral and has its maximum over the parietal and precentral regions. The PMP starts with an onset time of 90—80 msec on the average. Only the last potential, the motor potential (MP), is unilateral preceding unilateral movements, and is restricted to the motor cortex contralateral to the movement.

Since the topography of these potentials is well known with unilateral movements, it was of interest to study their distribution preceding bilateral simultaneous finger movements. In an earlier study with bilateral movements (Shibasaki and Kato 1975), the topography of the 3 movement-related potentials cannot be determined, since only 2 electrodes were employed.

Method

Experiments were performed on 19 healthy right-handed subjects (13 males and 6 females aged from 19 to 31 years). Right-handedness was assessed by means of a questionnaire determining manual priority for writing, throwing, washing, grooming, hammering, using tools, etc. All of the 19 subjects had a

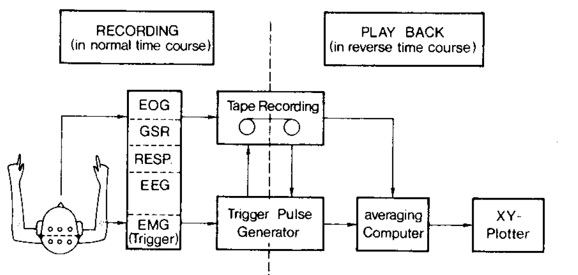

Fig. 1. Experimental arrangement. Recording: the subject's EEG, EOG, galvanic skin reflex, respiration and EMG are recorded. The first action potential in the EMG from flexor digitorum communis muscle (pars indicis) is used as the trigger pulse. This and a second pulse, delayed by 500 msec, are stored on tape, together with all data. The EEG is monitored, and the experimenter can edit the record with special pulses that cause either an accept or a reject condition during playback. Playback: data are analysed in the opposite time direction (reverse analysis). The second trigger pulse, if not marked by a reject editing pulse, starts the Biomac 1000 computer on averaging of the ensuing 2.56 sec of EEG record.

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score of 100% dexterity. Fig. 1 shows the experimental arrangement. The subjects lay comfortably in a sound-damped electrically shielded room and performed abrupt volar flexions of the right index finger in the case of unilateral movements, or simultaneous volar flexions of the right and left index fingers in the case of bilateral movements. This was performed by moving the trigger of a pistol. Prior to the experiment, the subject had been trained to achieve a sudden rapid movement out of complete muscular relaxation (silent EMG). The finger remained in the flexed position during the analysis time. Movements were self-paced at irregular intervals between 5 and 15 sec. Subjects fixed their gaze on a given point and avoided any other inadvertent movement such as eyeblinks, facial, masticatory, swallowing or other movements.

The EEG was recorded from left, mid and right precentral as well as left, mid and right parietal locations. The parietal and vertex leads were placed according to the international 10—20 system (Jasper 1958) and the lateral precentral leads were placed approximately 1 cm anterior to the traditional locations in order to overlie the hand area of the precentral gyrus. Hair surrounding the locations was glued to the skin by means of collodion, and Beckman adhesive electrodes were affixed to the collodion. In order to exclude possible side differences from the reference, both ear lobes were linked together to serve as the reference in monopolar recording. In addition, bipolar recording, left versus right precentral, was employed. The EEG was amplified on a Mingograph EEG machine using a time constant of 1.6 sec. The EMG was recorded from skin electrodes overlying the *flexor digitorum communis* muscle (*pars indicis*). The trigger pulse was generated from the very first muscle spike of the right *flexor indicis* (also in the case of bilateral movement), and a delayed pulse was executed by a quartz-operated trigger pulse generator exactly 500 msec later. The second trigger pulse served as the impulse to start the averaging computer on the reverse analysis run in the opposite time direction. Averaging was performed off-line using a Biomac 1000 Computer, averaging 2 channels simultaneously. Totals of 256—512 per kind of movement were averaged. Artefacts not eliminated by training were excluded from the averaging process by on-line editing (electrical marking and automatic rejection of artefact-contaminated movements). The analysis time was set from 2.0 sec before to 0.5 sec after movement onset, as determined by the EMG. Any systematic errors due to channel asymmetries were avoided by the systematic permutation of electrode positions and recording channels performed in a cyclic manner. Bilateral and unilateral movements were performed in blocks of $N = 128$, the sequence of which was varied in random order. It would have been ideal to include the investigation of left unilateral movements in the same experiment. But such long experiments would have exceeded the subjects' tolerance since the present experiments already lasted 4—5 h.

Amplitudes were measured at 3 points in time, (1) 150 msec prior to movement onset in the EMG (P150), (2) 75 msec prior to movement onset (P75), and (3) at movement onset itself (P0). These 3 amplitudes, measured with reference to a baseline established from the period 2.0—1.5 sec before movement onset, were selected in order to estimate the potential wave form within the final 150 msec prior to the first muscle activity. During this period, 3 potentials with different polarities and onset times are superimposed on each other, BP, PMP and MP (cf. Deecke et al. 1976). BP was measured as P150, i.e. prior to the period of superposition. PMP was measured as the difference P0 − P75 in monopolar records. MP was measured as the difference P0—P75 in the *bipolar*, left versus right precentral record. The P75 measurement was a compromise. Taking the average onset times (87 msec for PMP and 54 msec for MP, cf. Deecke et al. 1976), the difference P0 − P87 in monopolar leads would have been the appropriate potential difference for PMP measurement and P0—P54 in the bipolar C_3'/C_4' derivation the appropriate difference for MP. However, as was checked in a few instances, the error was negligibly small. Potential onset was defined as the first deflection from the baseline. For statistical analysis the Wilcoxon test of paired differences was employed. Significance levels were calculated on the basis of the two-tailed hypothesis.

Results

Central findings

(1) Bereitschaftspotential (BP, readiness potential). Fig. 2 gives a typical set of averaged curves from one of our right-handed subjects. Prior to unilateral (right) movements (A), there is a larger BP over the contralateral precentral region (C_3'), as against its ipsilateral homologue (C_4'). Prior to bilateral movements (B), the BP is not bilaterally symmetrical, but slightly larger over the right, non-dominant hemisphere (see Figs. 2 and 3).

Fig. 4 gives the mean amplitude averaged across 19 right-handed subjects. On the X axes, electrode positions are indicated for left, mid and right precentral, as well as left, mid and right parietal leads. On the Y axes, the amplitudes in $-\mu V$ are given, and on the Z axes, time is plotted in msec preceding movement onset.

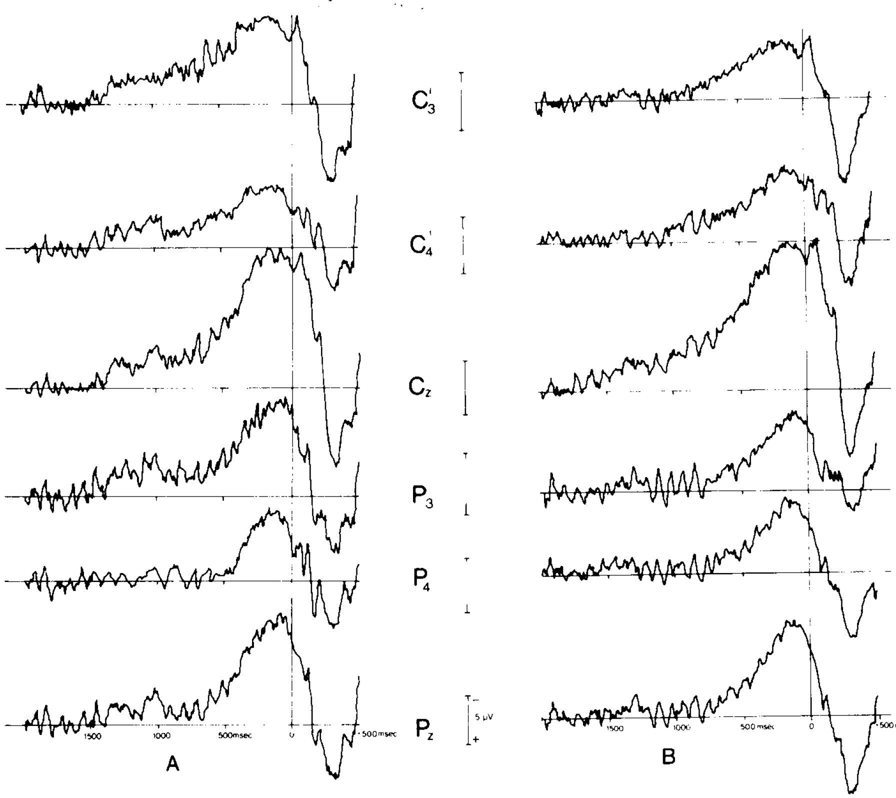

Fig. 2. A set of averaged curves from a typical experiment showing movement-related potentials preceding unilateral right-sided (A) and bilateral movements (B). Electrode positions over: C_3', left precentral; C_4', right precentral; C_z, vertex; P_3, left parietal; P_4, right parietal; P_z, midline parietal. Averages of 256 right-sided and 256 bilateral movements performed alternately in blocks of ca. 128 within the same experiment. With unilateral movements, a larger Bereitschaftspotential can be seen over the contralateral precentral region (C_3'). With bilateral movements, the Bereitschaftspotential is larger over the right, or minor hemisphere of our right-handed subjects. This difference is pronounced in precentral leads and almost missing in parietal leads. The vertex amplitudes tend to be larger with bilateral movements than with unilateral movements.

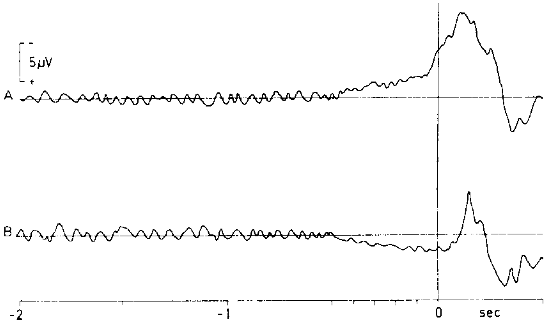

Fig. 3. Typical bipolar records, left versus right precentral (C_3' versus C_4'), representing averages of 256 right unilateral (A) and 256 bilateral movements (B). In A, with right unilateral movements, a contralateral preponderance of negativity starts about 0.5 sec prior to movement onset in the EMG (0). About 50--60 msec prior to EMG onset an additional sharp negative deflection is seen, called the motor potential (MP). In B, with bilateral movements, a preponderance of negativity over the non-dominant precentral region (C_4') is observed (downward deflection). Isopotential course of C_3'/C_4' derivation due to symmetrical activation of both motor cortices in the final 100 msec prior to EMG onset, resulting in the virtual absence of a motor potential.

Differences between bilateral and unilateral movements are well pronounced in precentral leads, but are almost missing in parietal leads. In precentral leads with unilateral movements, the well known contralateral preponderance of the BP can be seen (also cf. Fig. 3). For example, P75 averaged −4.07 μV (S.D. 2.35) at the left precentral lead, and −2.57 μV (S.D. 2.55) at the right precentral lead preceding unilateral right-sided movements ($2P < 0.01$). With bilateral movements, P75 averaged −3.66 μV (S.D. 1.96) at the left precentral lead, but right precentrally it averaged −4.82 μV (S.D. 3.73), which is significant at $2P < 0.01$. This indicates that, with bilateral movements, there is a larger BP over the minor hemisphere, as compared to the dominant hemisphere. At the midline, a strong trend towards greater negativity was observed prior to bilateral movements in comparison to unilateral movements. For example, P75 at the vertex location, C_z, averaged −8.15 μV (S.D. 5.61) with bilateral movements and −6.62 μV (S.D. 3.88) with unilateral movements. Although this difference by itself was not significant, a significant difference could be demonstrated by taking the arithmetic mean of all 3 precentral amplitudes (left, mid and right). With bilateral movements, the mean amplitude was −5.49 μV (S.D. 3.43) and with unilateral movements it was only −4.42 μV (S.D. 2.58), a significant difference at $2P < 0.05$. This indicates that the overall level of activation in the precentral cortex is greater with bilateral than with unilateral movements. Onset times of the BP in the different leads (Fig. 5) showed some rather small differences between bilateral and unilateral movements. As measured across all 6 leads, bilateral movements averaged 951 msec (S.D. 305) and unilateral movements 1031 msec (S.D. 358) for their onset times. This means that even though, on the average, cerebral potentials preceding bilateral movements showed greater amplitude, they started marginally later than unilateral right-sided movements.

(2) Pre-motion positivity (PMP). The PMP was well pronounced with both unilateral and bilateral movements. Fig. 6 shows the time course of the potential in the last 150 msec prior to the onset of bilateral (double lines) and unilateral movements (single lines). Points of measurement were at 150, 75 and 0 msec prior to movement onset. The PMP was measured as the difference between the measurements at 75 and 0 msec. With unilateral movements we confirmed our previous reports on the PMP topography. This potential can be observed over the ipsilateral precentral region, the midline and both parietal cortices. It cannot be observed over the contralateral precentral region, due to an assumed superposition with the MP. With bilateral movements, the PMP is distributed almost symmetrically over the hemispheres and is considerably larger in comparison to unilateral movements. For instance, at the vertex, it averaged +1.33 μV (S.D. 4.16) for bilateral, but only +0.15 μV (S.D. 1.42) for unilateral movements ($2P <$ 0.05).

(3) Motor potential (MP). A typical motor

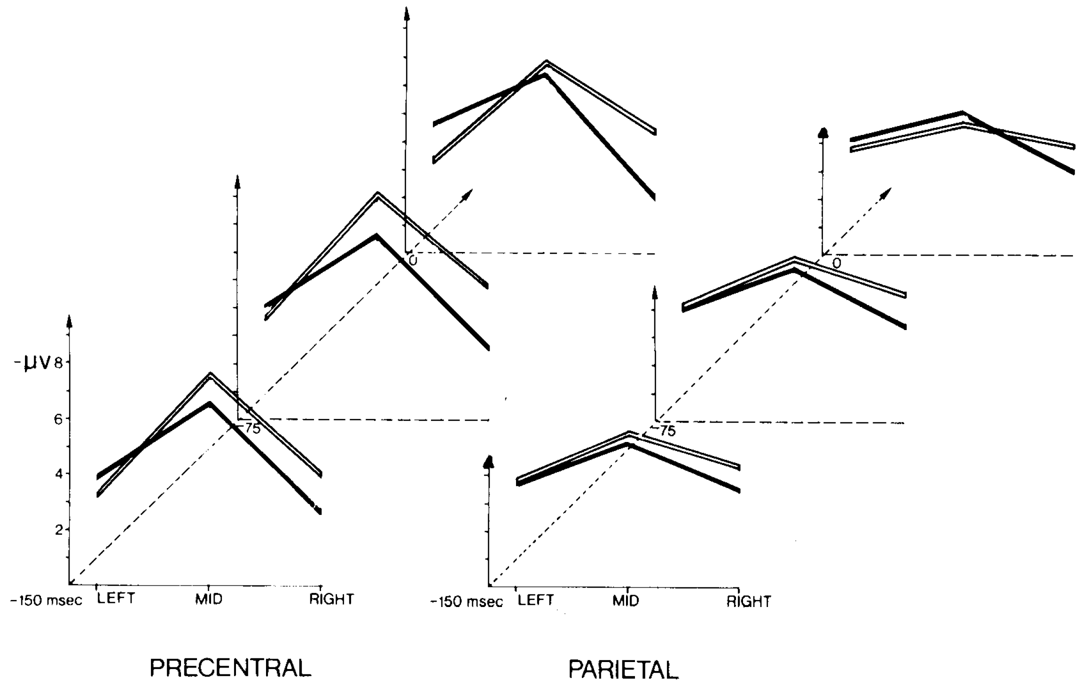

Fig. 4. Lateral distribution of negativity preceding bilateral (double lines) and unilateral movements (single lines). Averages of 19 experiments. X-axis: location of electrodes over left, mid and right cortical regions. Y-axis: amplitudes of negativity in μV. Z-axis: time in msec prior to movement onset. In parietal leads, differences are almost missing. In precentral leads, the Bereitschaftspotential is larger over the contralateral region for unilateral movements, but larger over the right, minor, hemisphere with bilateral movements. Also, at the vertex, the Bereitschaftspotential is larger with bilateral than with unilateral movements.

potential emerging from the contralateral preponderance as an additional sharp negative deflection during the final 50—60 msec prior to EMG onset is seen in Fig. 3A, which shows the bipolar record C_3' versus C_4' with unilateral movements. Thus, our results concerning the MP prior to unilateral movements are in good agreement with our previous data. On the average, a pronounced MP of —1.24 μV (S.D. 1.33) was found prior to unilateral movements in the bipolar C_3'/C_4' record (Fig. 6). The MP was measured as the amplitude difference between measurements at 75 and 0 msec prior to EMG onset in the bipolar left versus right precentral record (see lower graph of Fig. 6). No motor potential can be seen prior to bilateral movements (Fig. 3B). For bilateral movements one might assume bilateral MPs. This would mean that our way of measuring across the midline, i.e. using the bipolar C_3'/C_4' record, is inappropriate for bilateral movements, since no difference between the two amplitudes would not preclude the possible existence of bilateral MPs. But if we use this record in spite of such objections, an average of —0.36 μV (S.D. 0.92) is found. This value is not significantly different from 0, an understandable result in view of the simultaneous activation of the two motor cortices in this condition, but it points towards a trend of more negativity over the dominant motor cortex as compared to the minor one. BP asymmetry cannot be the cause since, in contrast, the BP was larger over the minor precen-

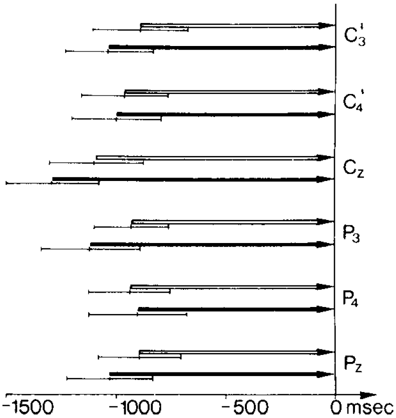

Fig. 5. Bereitschaftspotential onset times in different electrode locations. Onset times are earlier for unilateral movements (single lines) than for bilateral movements (double lines), except for the right parietal lead (P_4). See Fig. 2 for legend of electrode locations.

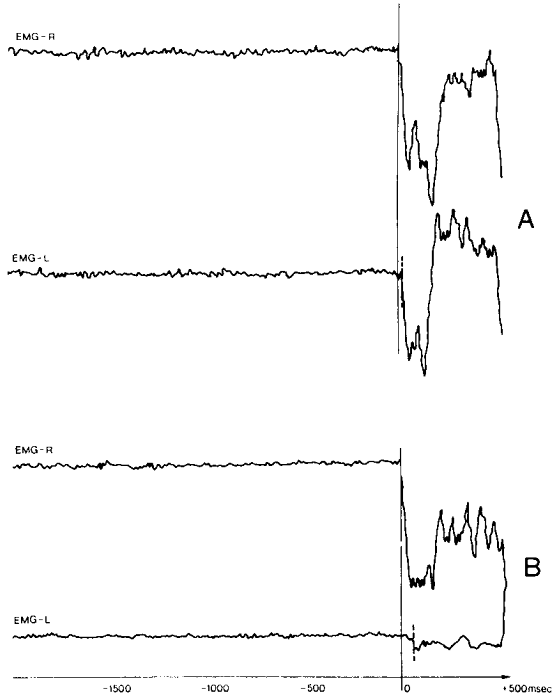

Fig. 7. Averaged EMG records from one subject, showing bilateral movements (A) and unilateral movement (B). With bilateral movements, the EMG onset of the flexor indicis muscle is earlier on the right than on the left side. With right-sided unilateral movements, a smaller and later EMG mirror activity is evident on the left, non-moving, side.

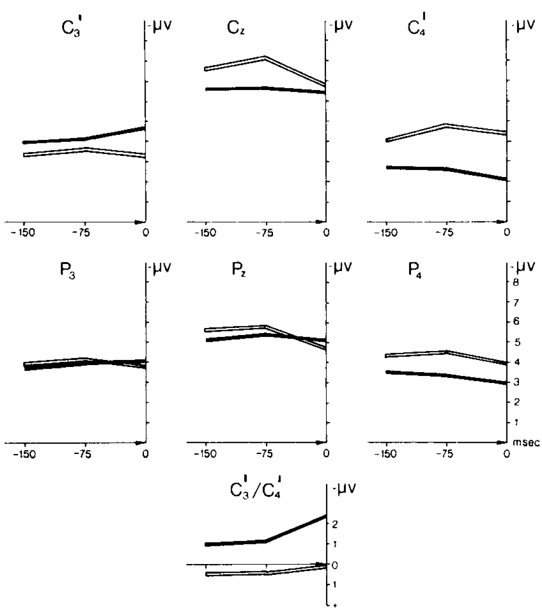

Fig. 6. Time course of potentials 150 msec prior to movement onset (as measured by EMG). Points of measurement were 150, 75 and 0 msec prior to movement onset. With unilateral movements PMP is absent only over the left precentral lead (C_3') due to an assumed superposition of an MP. Note that with bilateral movements, the PMP is larger and almost symmetrical over the two hemispheres.

tral region. It needs to be stressed, however, when comparing the monopolar precentral records in Fig. 6, that no upward deflection comparable to the one noted for contralateral precentral lead (C_3') in unilateral movements was found for bilateral movements.

Peripheral findings

(1) With bilateral movements. In addition to the cortical potentials, the EMG was recorded and averaged. From these records it appears that not all 19 right-handed subjects were able to achieve absolutely simultaneous bilateral movements, even when their onset times were averaged. Fig. 7A gives an example of a subject leading, on the average, with his right index finger ahead of the left. Ten of the 19 subjects showed this pattern, with a mean

time difference of 22 msec (S.D. 15). Five subjects showed no apparent difference between right and left EMG onset, and 4 subjects were earlier in their left index finger muscle. When the data of all 19 subjects were pooled, a time difference of 16 msec (S.D. 15) was found between the two onset times, with the right side leading.

(2) With unilateral movements. With right unilateral movements the left EMG of the non-moving finger was not completely silent but showed a slight and considerably delayed mirror activity in 14 of the 19 subjects. An example is given in Fig. 7B. The mean delay on the left side was 50 msec (S.D. 39) in our 19 subjects.

Discussion

From previous experiments we know that the cerebral activity preceding unilateral movements can be recorded bilaterally over the precentral and parietal regions (Deecke et al. 1969, 1976). Over the parietal region, the Bereitschaftspotential (BP), even preceding unilateral finger movements, is bilaterally symmetrical (Deecke et al. 1976). Over the precentral region, the BP is also symmetrical in the beginning, but at about 400 msec prior to movement onset, gives way to a contralateral preponderance of negativity. It was therefore of interest to study bilateral simultaneous movements and to see whether this contralateral preponderance would then be reduced or even absent. Such a result could be predicted on the basis of experiments in which right as well as left unilateral movements had been investigated in right-handed subjects. In these experiments, a crossed hand-brain dominance was found, i.e., amplitudes were larger over the left precentral region when the right index finger was moved, than they were over the right hemisphere when the left index finger was moved (Deecke et al. unpublished data). Similar findings were reported by Kutas and Donchin (1974). In this sense, it was thought that recording of the BP prior to bilateral simultaneous movements might act as a test for hemispheric dominance.

Surprisingly, the present results with bilateral simultaneous movements show a preponderance of the BP not over the left (dominant) precentral region, as would have been expected, but over the right (minor) precentral region (Fig. 4). The difference was significant at $2P < 0.05$. A similar difference can be seen in Table 1 of Papakostopoulos' (1978) paper where he found a larger BP in the right precentral lead than in its left homologue prior to bilateral movements, a finding that he makes no deliberate reference to in the text.

The functional significance of our findings regarding the BP predominance over the right hemisphere is not clear. It might be speculated, however, that the minor movement system (left hand with minor hemisphere) needs more effort in order to equal the better-trained dominant system in performance. This difference is well-pronounced in precentral leads, but almost missing in parietal leads (Fig. 4). This is in agreement with the well-known bilateral organization of parietal cortical function (Mountcastle et al. 1975). If a parietal bilateral symmetry exists already with unilateral movements (Deecke et al. 1976), it is quite understandable that it should also occur with bilateral movements. The difference between precentral and parietal findings was also evident with reference to the overall amplitude measurements. In precentral leads, particularly at the vertex, a significantly larger BP was seen preceding bilateral movements than could be observed for unilateral movements. But over the parietal region, almost no difference between bilateral and unilateral movements could be seen (Fig. 4). This finding of a greater overall activity over the precentral region with bilateral movement is consistent with the notion that bilateral simultaneous movements require a greater overall activation of muscle contraction, and thus probably require the firing of a greater number of cortical cells.

The onset times of the BP showed only a

general trend towards earlier onset prior to unilateral movements, in comparison with bilateral ones (Fig. 5). Except for the right parietal lead, this trend could be observed in all electrode locations, particularly at the vertex. Yet, due to considerable variation in onset time, the observed mean difference was not significant. This result, which indicates a trend towards larger, but later, BP amplitudes prior to bilateral movements than are found with unilateral movements, is surprising in view of previous experiments in which a positive and significant correlation was found between BP amplitudes and onset times (Deecke et al. 1976). It also contrasts with the findings of Becker et al. (1976), concerning slow and fast finger movements, that a larger, as well as earlier, BP was demonstrated for slow movements.

One of the most important findings of the present investigation is the well-pronounced PMP prior to bilateral movements. The relatively large BP is easy to record and, therefore, has been widely confirmed by other authors. This does not apply to the smaller potentials which require a large number of trials for a better signal to noise ratio, careful editing for the elimination of artefacts, and exact triggering conditions. After the positive shift of the PMP immediately prior to movement onset had been described (Deecke et al. 1969, in agreement with Gilden et al. 1968, who call it P1), its existence was sometimes questioned by other authors. However, Gerbrandt (1977), after an initial failure, later confirmed the existence of the PMP (although his interpretation is different from ours) as did Shibasaki and Kato (1975).

In the present experiments, the vertex PMP was considerably larger prior to bilateral movements than it was with unilateral movements (+1.33 μV as opposed to +0.15 μV, Fig. 6). Furthermore, with bilateral movements the PMP was equally distributed over both hemispheres, even precentrally, where with unilateral movements, a superposition of the motor potential occurs contralaterally (cf. C_3' in Fig. 6). Our observation of a larger PMP prior to bilateral movements is exactly opposite to that of Shibasaki and Kato (1975) who investigated bilateral simultaneous thumb opposition and reported a missing PMP prior to bilateral movements, even in those subjects who showed a PMP with unilateral movements. However, their report was based on mere observation without measurements and statistics, since only 4 of their 9 subjects showed regular PMP in the premovement potential wave form. Therefore, we cannot support their hypothesis that an ipsilateral PMP with unilateral movements is the expression of inhibition involving the non-operant cortex.

In the evaluation of the motor potential (MP) prior to bilateral movements, we reached the limits of our methods. In previous experiments we had assessed the MP as the additional negativity in the last 50—60 msec (average 54) prior to movement onset, and for measurement we used bipolar left-versus-right precentral recording. Since the motor potential is the only unilateral potential prior to unilateral finger movements (see Fig. 3A), this was the best method for extracting the MP from other potentials such as the BP and the PMP, which are assumed to be superimposed on each other in the last 150 msec prior to movement onset. The use of P0—P75 instead of P0—P54 in bipolar C_3'/C_4' records for MP measurement in the present experiments causes an error. But this error is negligibly small, particularly when comparing bilateral versus unilateral movement, using exactly the same type of measurement with either kind of movement.

In the case of bilateral movements both motor cortices can be considered to be active. Therefore the motor potential cannot be assessed by means of bipolar bihemispheric recording (see Fig. 3B). The only statement that can be made using this type of recording is one in terms of hand-brain dominance, whereby it is taken for granted that the movements of the two sides are approximately equal in force and performance. Slightly more negativity was found over the left motor cortex within the last 75 msec prior to movement onset. This difference of $-0.36\ \mu V$ was, however, not significant, a finding which contrasts with previous experiments on unilateral movements. There, a significantly larger MP was found for the dominant system (right hand with left motor cortex) than for the non-dominant system. Another way of assessing the MP with bilateral movements could be by means of serial electrode derivations in an anterior-posterior direction crossing the motor cortex leads on both sides.

The peripheral findings were not very strong. As a trend we noticed some earlier activation in the right than in the left flexor indicis muscle in 10 of our 19 subjects, a finding that is statistically non-significant. With unilateral movements, a mirror activation on the non-operant side was observed which occurred 50 msec later. This was an EMG phenomenon occurring without visible contraction. We have thus confirmed previous experiments by Hopf et al. (1974) and Čemáček (1961) who also found co-activation of contralateral homologous muscle in healthy subjects, a contraction which is mostly inapparent to simple observation and detectable only by EMG.

Summary

Cerebral potentials preceding voluntary bilateral simultaneous finger movements were investigated in 19 right-handed young adult subjects, and were compared with unilateral right-sided finger movements within the same experiment. With bilateral movements, the Bereitschaftspotential (BP) was not symmetrical or larger over the dominant hemisphere, but surprisingly, it was larger over the minor hemisphere. The BP averaged $-3.66\ \mu V$ (S.D. 1.96) over the left precentral region and $-4.82\ \mu V$ (S.D. 3.73) over the right precentral region in this condition. The difference was significant at $2P < 0.01$. This difference was pronounced in precentral leads but very small and almost missing in parietal leads.

The pre-motion positivity (PMP) was well developed and even larger with bilateral than with unilateral (right-sided) movements. At the vertex it averaged $+1.33\ \mu V$ (S.D. 4.16) with bilateral movements and only $+0.15\ \mu V$ (S.D. 1.42) with right-sided unilateral movements ($2P < 0.05$). With bilateral movements the PMP could be observed in any record, but with unilateral movements it was missing at the left precentral lead, in accordance with previous publications (Deecke et al. 1969, 1976).

The motor potential (MP), measured in a bipolar record from left and right precentral leads, was larger with unilateral ($-1.25\ \mu V$, S.D. 1.33) than with bilateral movements ($-0.36\ \mu V$, S.D. 0.92).

Onset time differences of the BP preceding unilateral and bilateral movements were very small. However, there was a tendency towards earlier onset with unilateral than with bilateral movements (1031 msec, S.D. 358, as compared with 951 msec, S.D. 305).

The averaged EMG revealed differences in movement onset. Muscular contraction tended to be earlier in the right than in the left m. flexor indicis in our right-handed subjects, on the average by 16 msec (S.D. 15). With unilateral right-sided movements, the left m. flexor indicis was not silent but showed an abortive mirror activity in the EMG, without visible movement. This activity occurred on the average 50 msec (S.D. 39) later on the non-moving side.

Résumé

Potentiels cérébraux précédant des mouvements des doigts, unilatéraux ou simultanés bilatéraux

Chez 19 jeunes adultes droitiers, les potentiels cérébraux précédant des mouvements volontaires simultanés, bilatéraux, des doigts, ont été recueillis et comparés à ceux provoqués par mouvement des doigts limité au côté droit. En cas de mouvement bilatéral, les potentiels de préparation motrice (Bereit-

schaftspotential, BP) n'étaient pas symétriques, ou plus amples sur l'hémisphère dominant, mais bien sur l'hémisphère mineur (amplitudes respectives, —3,66 μV à gauche (D.S. 1,96) et —4,82 μV (D.S. 3,73) à droite). Cette différence était significative à $2P <$ 0,01. Elle était claire en dérivation précentrale, mais faible ou nulle en dérivation pariétale.

La positivité précédant le mouvement (PMP) était bien développée, et même plus ample, lors de mouvements bilatéraux que lors de mouvements unilatéraux droits (respectivement 1,33 μV (D.S. 4,16) et 0,15 μV (D.S. 1,42)), à $2P <$ 0,05. Avec des mouvements bilatéraux, la PMP pouvait être observée dans toutes les dérivations, alors qu'en mouvement unilatéral, elle manquait en dérivation précentrale gauche, ceci conformément aux observations antérieures (Deecke et al. 1969, 1976).

Le potentiel moteur (MP) recueilli en dérivation bipolaire précentrale gauche-droite, était plus grand lors de mouvements unilatéraux (—1,25 μV, D.S. 1,33) que bilatéraux (—0,36 μV, D.S. 0.92).

Les différences de temps d'apparition du BP étaient très faibles, entre mouvement unilatéral ou bilatéral. Encore qu'une tendance se soit dessinée, à des temps inférieurs pour un mouvement bilatéral que pour un mouvement unilatéral (951 msec, D.S. 305; 1031 msec, D.S. 358).

l'EMG moyenné a révélé des différences dans l'installation du mouvement. Pour le fléchisseur de l'index, la contraction musculaire tendait à être plus précoce à droite qu'à gauche, chez les droitiers (16 msec, D.S. 15). Lors de mouvements unilatéraux droits, le fléchisseur de l'index gauche n'était pas silencieux, mais développait une activité faible en miroir, sans mouvement visible avec un retard de 50 msec (D.S. 39).

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