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Readiness Potentials Related to Self-Initiated Movement and to Movement Preceded by Time Estimation: A Comparison

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Summary

Two procedures for eliciting premovement potentials were compared: (1) the estimation of a 3 s interval elapsed after a warning auditory signal, and (2) classical "self-pacing". Eleven healthy right-handed subjects participated in the experiment, EEG records from scalp electrodes placed at C_Z, C_{3+} and C_{4+} were analyzed. It has been shown that both procedures induced similar premovement potentials except that in the first procedure the early component of the potential was longer. The time estimation itself induced a negative slow potential consisting of a rapid set-up and a subsequent plateau.

Key words
Readiness potential – Time estimation – Self-paced movements – Instructed movement – Human

Introduction

Most investigations on potentials preceding a self-paced forelimb movement (Readiness Potentials) have shown that these potentials consist of at least two successive components which may reflect distinct mental events in the initiation of a movement (Deecke *et al.* 1976, Elbert *et al.* 1985, Keller and Heckhansen 1990). Conjecturally, one may consider that a decision process concerned with the selection of a determined moment for the execution of the next movement precedes its preparation and execution. Several research groups have attempted to resolve this question but, despite considerable effort, it still remains unclear whether these successive components are due to distinct generators and/or have a different behavioural meaning (Deecke *et al.* 1990, Rektor *et al.* 1994, Tarkka and Hallett 1990). The poorly understood mental operation that triggers movements in the self-pacing paradigm (Libet 1985) may represent a complicating factor. This possibility suggested that a modification of conditions under which the putative decision process takes place could introduce a new aspect into the problem posed by multiple premovement components. In this study, we have selected a paradigm in which the performance of an instructed movement was preceded by estimation of a given time interval which elapsed after a warning stimulus, as used previously by others for other purposes (Damen and Brunia 1987, Brunia 1988, Chwilla and Brunia 1991). The premovement potentials thus obtained were then compared to the classical ones induced by self-paced movements.

Methods

Subjects and recordings

Eleven healthy right-handed subjects (3 men, 8 women, aged 17 to 40 years) participated in the experiment. The subjects laid comfortably on a bed during the recordings. EEG was recorded using three scalp electrodes (Nihon Cohden cups) placed at C_Z, C_{3+} and C_{4+}. Linked mastoids served as a reference. The surface electromyogram from the flexor digitorum communis of the right hand was recorded by similar electrodes. EEG and EMG signals were amplified and processed by a Nihon Cohden Neuropack 4 set (low pass filter 0.03 Hz, high frequency cut-off at 500 Hz). All subjects were instructed how to minimize non-cerebral artifacts arising from eye movements, tongue movements and other muscle activities. Individual records were checked on-line, and artifact-free records were stored for averaging.

The amplitudes were baseline-corrected with respect to the mean amplitude of the sample points in the 0.5 s period preceding the warning signal.

The auditory signals used were tone bursts of 1 kHz, 200 ms duration and 100 dB generated by a loud speaker placed at a distance of 1 m from the subject's head. Intersignal intervals randomly varied between 9–14 s. The requested movement was brisk pressing of a button by fingers of the right hand. The time intervals as estimated by the subject were measured and stored for further evaluation of their variance.

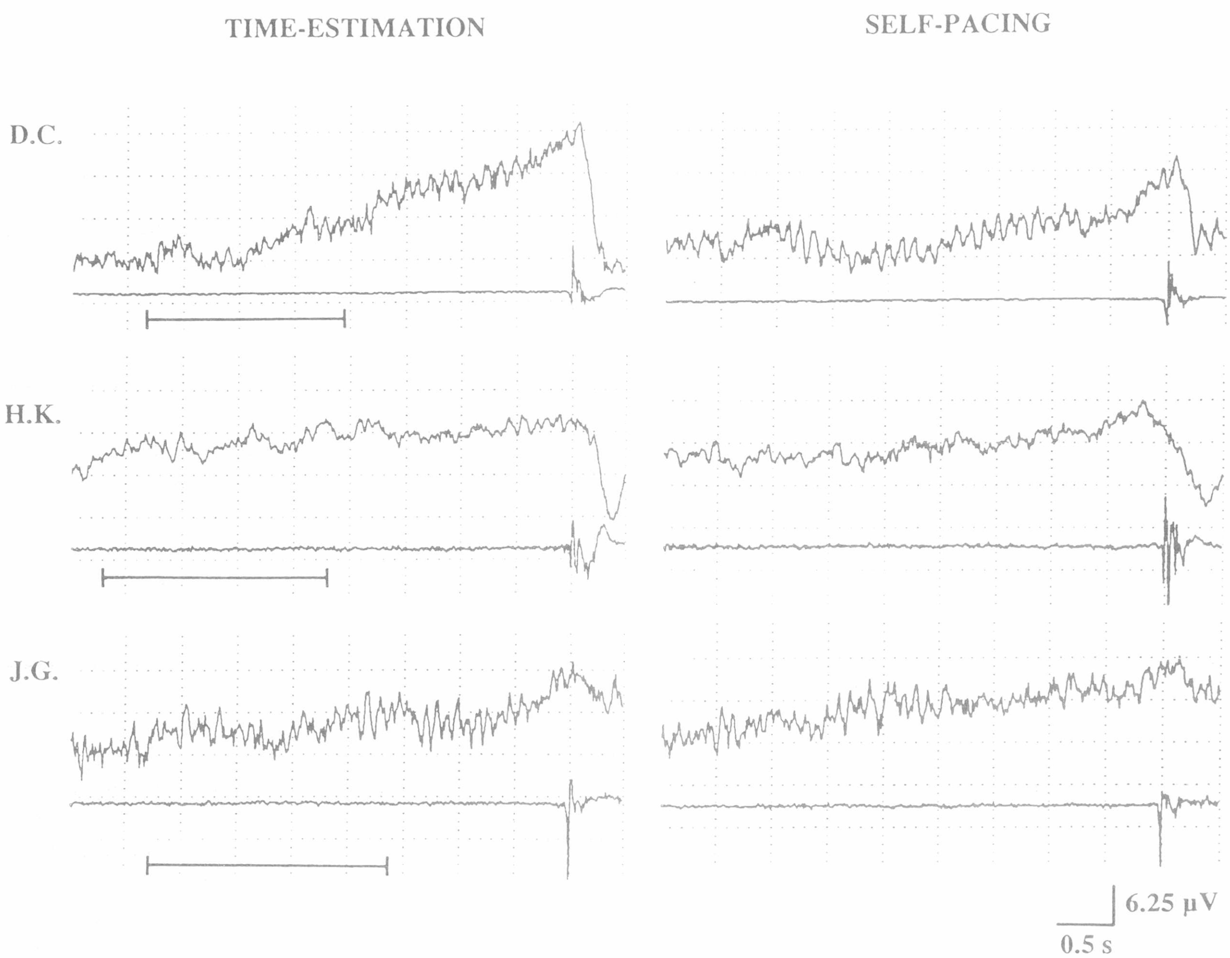

Fig. 1
Comparison between slow potentials recorded in the time estimation paradigm (backward averaging) and self-pacing condition in three subjects, D.C., H.K. and J.G. All EEG recordings from C_{3+}, EMG from flexor digitorum communis. Horizontal bars indicate the time distribution of the warning signals over the 40 trials.

Procedure

Cortical potentials were recorded in four situations. In the first one, no meaning was given to the auditory signal presented. The subjects were merely asked to refrain from any movement and to think of any arbitrary subject. In the second case, the subjects were asked to estimate a 3 s interval after the presentation of the auditory warning signal without performing any movement. They were simply asked to estimate when the time interval had expired. Mental counting was recommended as a mode of time estimation. In the third one, the subjects were asked to estimate an interval of 3 s after the auditory signal and then to press the button. This situation was applied twice, and two different averaging methods were employed in elaborating the records: averaging was either triggered by the auditory signal (forward averaging) or by onset of the movement (backward averaging). In the fourth situation, the subjects were asked to press the button repeatedly without counting or otherwise estimating the time, as in the classical self-paced paradigm. Forty trials were averaged in each condition.

Statistical evaluation of the results was performed by the Wilcoxon matched pairs test, the software program CSS: Statistica, version 3.0 (statSoft, Inc., Tulsa, 1991) was used for the calculations. Means ± S.D. are presented in results.

Results

1. Comparison between premovement potentials in time estimation and in self-paced paradigms

The backward averaging of records in time estimation revealed a slow premovement potential resembling that induced by self-paced movement, i.e. an early flat increase of negativity followed by a second phase with a steeper slope (see Fig. 1). The negative shift from the baseline started at the time of the auditory signal, and its amplitude was the highest in the period immediately preceding the movement. The amplitude of this maximal premovement negativity was significantly larger over the left hemisphere than over the right hemisphere ($P<0.01$).

A comparison between the time estimation and self-paced conditions revealed one difference. In almost all cases, the first negativity started earlier in the time estimation paradigm as compared to the self-paced paradigm (2.9 ± 0.7 s vs 1.9 ± 0.9 s prior to the movement; $P<0.01$). The steeper part of the premovement potential started 0.6 ± 0.1 s prior to the movement in time estimation and 0.54 ± 0.2 s prior to the movement in self-pacing ($P>0.05$). The mean peak amplitude reached -10.2 ± 4.8 μV in time estimation and -7.4 ± 2.2 μV in self-pacing ($P<0.03$).

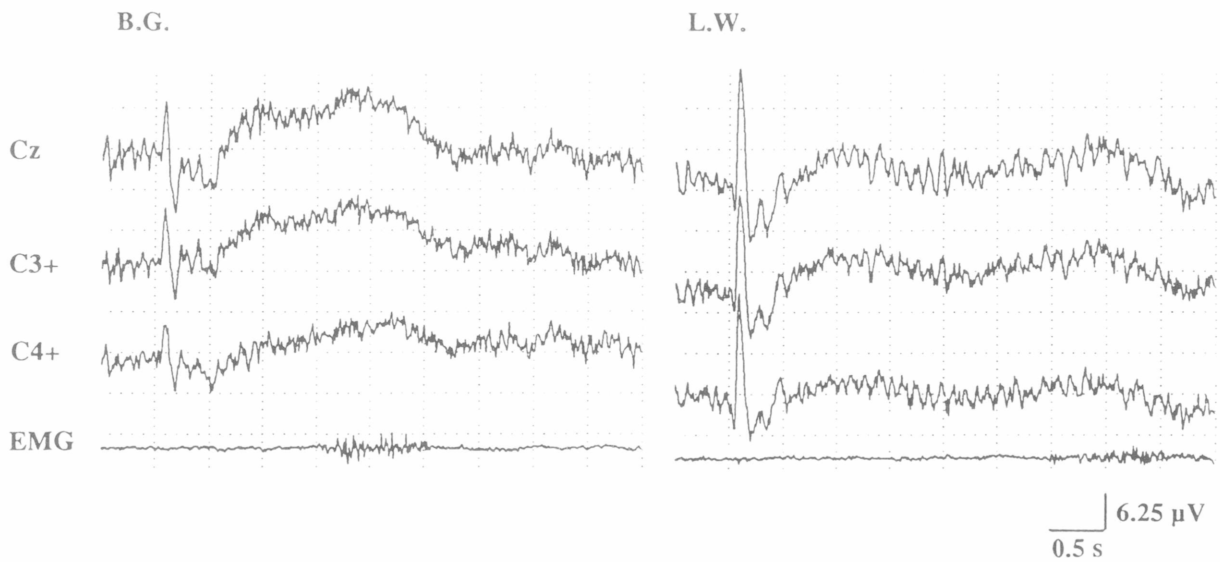

Fig. 2
Forward averaging in the time estimation paradigm in two subjects B.G. and L.W. Electrode positions C_z, C_{3+} and C_{4+}. Bottom record, EMG from flexor digitorum communis. 40 successive movements were performed.

2. Premovement potentials induced by time estimation – forward averaging

The triggering of averaging at the time of the warning tone revealed a complex potential change composed of the auditory evoked potential, followed by a steep negative shift of the baseline that gave rise to a plateau which depended on the duration of the estimated time intervals. During the performance of movements, the plateau frequently displayed a second increase of negativity (see Fig. 2). The first negative shift terminated 1.0 ± 0.01 s after the signal.

As far as the variability of time estimation is concerned, our data showed extreme values between 2.3 s and 4.5 s (upon instructed estimation of 3 s); the group mean of the estimation was 2.96 ± 0.14 s.

3. Slow potentials related to time estimation

Fig. 3b shows a typical slow potential related to a purely mental estimate of the 3 s interval. The subjects started their estimate at the moment when they perceived the auditory signal and this was terminated by a mental, non-pronounced word "end". A negative shift of the baseline, lasting for several seconds, followed the auditory evoked potential in almost all cases (10 subjects). The onset of negativity had the shape of a convex slope and terminated at 1.0±0.2 s after the auditory signal when the highest value of negativity had been attained. In 6 cases, the trace returned to the baseline level within 5 s of analysis time, in 5 cases the duration of the shift was longer. The amplitude of this shift varied between individuals, its maximal value was −12.5 μV (mean value −9.3±3.3 μV). As a control, evoked potentials without time estimation were also recorded (Fig. 3a). No prolonged negativity was observed in these cases.

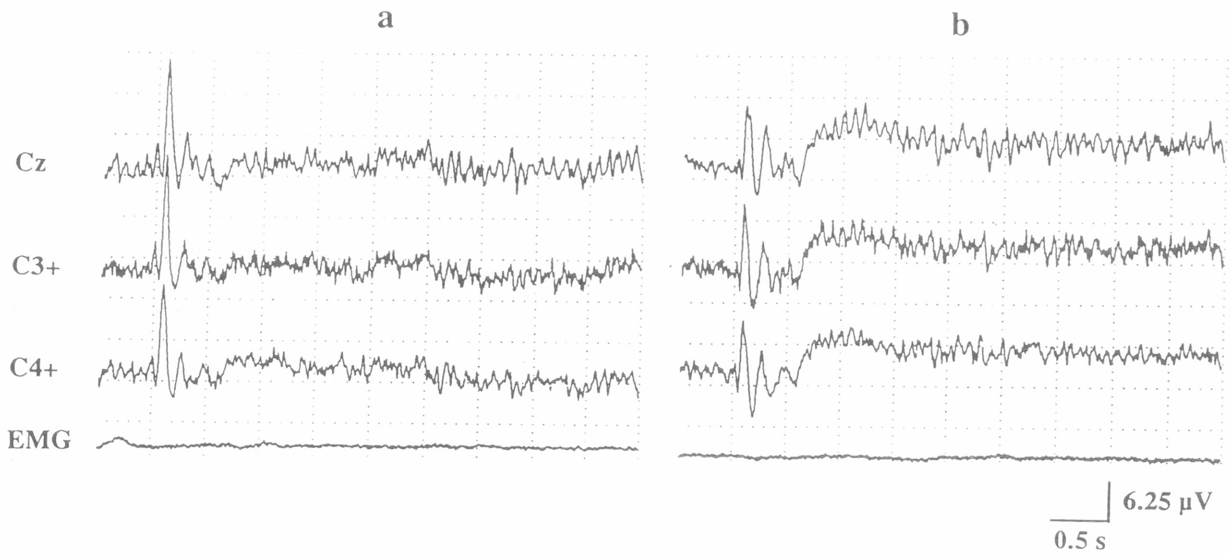

Fig. 3
Comparison between auditory evoked potentials recorded without any particular instruction to the subject (a) and after instruction given to the same subject (J.L.) to mentally estimate the time elapsed after the stimulus (b). Notice post-stimulus prolonged negativity in the second situation.

Discussion

One essential finding of this study concerns the backward averaging of records of the paradigm with time estimation. Our data have demonstrated that the sequence of three distinct brain operations (perception of a warning stimulus, estimation of a 3 s interval thereafter, performance of an instructed movement) is accompanied by a premovement potential resembling that induced by self-paced movements, i.e. an early slow increase of negativity followed by a second phase with a steeper slope. The shape of this potential is evidently dependent on the mode of averaging. When the averaging is triggered by an auditory signal, the negative shift coinciding with the putative onset of the time estimation attains its peak value shortly after the warning stimulus, and then remains more or less stable. When the averaging is initiated at the onset of a movement, a potential with two successive slope components is obtained. The transition between the two slopes occurs at about 0.6 s prior to the movement.

When all relevant data are taken together, the premovement potential in the time estimation paradigm may appear as a steep increase of negativity followed by a period with a quasi-stable level of the negative shift and a second steep slope immediately preceding the movement. The absence of a prominent slope before the movement in forward averaging, as well as the absence of a clearly visible onset of the negative shift at the putative onset of time estimation in backward averaging, is very probably the consequence of low synchronization of these events in repeated trials due to the inaccuracy in estimating time intervals.

When comparing the premovement potential in time estimation, using backward averaging, with the classical paradigm induced by self-paced movements, no substantial difference appears at the onset or in the amplitude of the late component. On the other hand, the onset of the first negativity mostly occurs earlier in the time estimation paradigm. Speculatively, one may consider that the precocity of premovement negativity in the time estimation paradigm is causally related to the time estimation itself. There are two possible ways in which this may occur: either the time estimation adds a new, very early negative component of distinct origin, thus only modifying the initial part of the readiness potential, or it actually modulates this component without significantly altering the second one. The latter hypothesis would necessarily imply that both components arise from two distinct generators.

That the two components are of different nature and/or different origin is further corroborated by two other findings. Firstly, the unequal interhaemispheric distribution of the early vs late components has been mapped; the early premovement negativity is bilaterally symmetrical while the later negativity attains its maximal amplitude over the contralateral hemisphere (Deecke *et al.* 1976). Secondly, the potentials preceding occasional spontaneous wrist movements of various origin (with no particular instruction given to a subject) consist only of the late negative potential (Keller and Heckhausen 1990).

Whether a decision process based on covert estimation of an elapsed interval following a previous trial also plays a role in building up the early negativity of the readiness potential in the classical self-pacing paradigm remains a matter for further investigations.

References

BRUNIA C.H.M.: Movement and stimulus preceding negativity. *Biol. Psychol.* **26:** 165–178, 1988.

CHWILLA D.J., BRUNIA C.H.M.: Event-related potentials to different feedback stimuli. *Psychophysiology* **28:** 123–132, 1991.

DAMEN E.J.P., BRUNIA,C.H.M.: Changes in heart rate and slow brain potentials related to motor preparation and stimulus anticipation in a time estimation task. *Psychophysiology* **24:** 700–713, 1987.

DEECKE L., GROZINGER B., KORNHUBER H.H.: Voluntary finger movements in man: cerebral potentials and theory. *Biol. Cybernet.* **23:** 99–119, 1976.

DEECKE L., LANG W., UHL F., PODRECKA I.: Looking where the action is: negative DC shifts as indicators of cortical activity. In: *From Neuron To Action.* L. DEECKE, J.C. ECCLES, V.B. MOUNTCASTLE (eds), Springer, Heidelberg, 1990, pp. 25–41.

ELBERT T., HOMMEL J., LUTZENBERGER W.: The perception of Neckercube reversal interacts with the Bereitschaftspotential. *Int. J. Psychophysiol.* **3:** 5–12, 1985.

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

LIBET B.: Unconscious cerebral initiative and the role of the conscious will in voluntary action. *Behav. Brain Sci.* **8:** 529–566,1985.

REKTOR I., FEVE A., BUSER P., BATHIEN N., LAMARCHE M.: Intracerebral recording of movement related readiness potentials: an exploration in epileptic patients. *Electroenceph. Clin. Neurophysiol.* **90:** 273–283, 1994.

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

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