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THE RELATION BETWEEN MONOSYNAPTIC SPINAL REFLEX AMPLITUDES AND SOME EEG ALPHA ACTIVITY PARAMETERS *

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It has been found that in normal man the reflex amplitude gradually decreases throughout a series of continuously evoked spinal tendon (T) reflexes, when the subject is in rest (Davis and Beaton 1968; Brunia 1971; Hollis 1971). The decrement was found to be stronger when the T reflexes were increased by a sensori-motor task (Brunia 1971) or by a loud tone preceding each tendon tap (Davis and Beaton 1968). Coquery (1969) showed that a warning sound in a reaction time experiment elevated the T reflex but that the elevation diminished during successive trials. Clarke (1967a) found a facilitation of the T reflex when the tap was preceded by 2 light flashes but no facilitation could be observed when 30 flashes were given. Amplitude decrease has also been found as the result of sustained muscular contraction. Clarke (1967b) found that a Jendrassik manoeuvre had no effect on the T reflex when it was maintained during 10 sec preceding the tendon tap, while a contraction of 1 sec duration had a facilitative effect.

These findings have in common that the T reflex is subject to a decrement with successive trials that, according to some authors, may be called habituation and should be considered to be of supraspinal (reticular) origin. One may question whether the concept of

habituation is an adequate one, since it is unknown whether the decrement exhibits the parametric characteristics of habituation, as outlined for a variety of physiological and behavioural responses by Thompson and Spencer (1966). It is unknown to what extent the decrement is of supraspinal origin. Neither Prosser and Hunter (1936) nor Spencer et al. (1966) could observe depression of repetitively evoked monosynaptic reflexes in the spinal cat. Dimitrijević and Nathan (1973), however, found a steady decrease of regularly elicited T reflexes in spinal man, and Farel et al. (1973) provided a model of monosynaptic depression in the isolated frog spinal cord, which conformed to the parametric relations characteristic of habituation.

An argument against the T reflex decrement as a spinal process could be provided if the reflex amplitude were to covary with changes in activation at supraspinal level. Because concomitant variations in fusimotor and cortical activity (von Euler and Söderberg 1957; Buchwald and Eldred 1961; Hongo et al. 1963) exist, and since both are supposed to reflect the same activating reticular influences, we selected the EEG alpha activity as an indication of changes in supraspinal activation. We hypothesized that no T reflex decrement will be observed if the alpha parameters remain constant. On the other hand a change of alpha parameters, indicating a decrease of cortical activation, may be correlated with a decrease in reflex amplitude.

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Experiment 1

The first experiment investigated whether stability of alpha parameters would correspond with stability of T reflex amplitudes. Nineteen normal students, males and females, aged between 18 and 29 years, volunteered as subjects for this experiment.

Method

Reflexes

The experiments were performed in a soundproof electrically shielded cubicle, with the control and recording apparatus located in an adjacent room. The subjects were seated comfortably with eyes closed in a specially designed chair that had supports for head, arms and legs. Legs and feet were fixed while knees and ankle joints were flexed about 120° and 100° respectively.

During 40 min Achilles tendon (T) and Hoffmann (H) reflexes were evoked simultaneously at the rate of 1/10 sec, according to the method of Paillard (1955). Higher stimulus frequencies were avoided to eliminate low frequency depression (Cook 1968; Hollis 1971). Tendon taps were delivered by an electromagnetic hammer (Racia). Since it has been shown that the peak force of the tendon tap is the most important stimulus parameter in determining the reflex response (Clarke et al. 1973), we measured it by means of a piezoelectric crystal mounted in the head of the hammer. The signal was converted linearly into a square pulse to be stored on a magnetic tape-recorder (SE 5000). At the tap the contralateral tibial nerve was stimulated transcutaneously and bipolarly (Welsh selfretaining electrocardiographic electrodes, infant size) in the popliteal fossa by a 1 msec constant current square pulse. The current strength was adjusted so that a small direct motor response (M), usually accompanied by a submaximal H reflex, was seen. Nonpolarizable recording electrodes (Siemens) were placed on the midline of the soleus muscle for both T and H, their centres 4 cm apart. Before placement of

the recording electrodes the skin was grazed over a very small surface to reduce the impedance.

The reflex potentials were amplified (Hellige EE pre-amplifiers, input impedance 10 M Ω , -3 dB at 16 c/sec and 1 kc/sec) and stored on magnetic tape. The peak-to-peak amplitudes of M, H and T were measured digitally off-line and punched in paper tape.

EEG

EEG alpha parameters of interest were amplitude, frequency and % of time alpha was present (alpha index). In order to attain stability of these parameters during a 40 min period the subjects received feedback about the degree of alpha presence. Because Kreitman and Shaw (1965) showed that auditory stimuli produce neither enhancement nor suppression of alpha activity, auditory feedback, administered by headphones, was chosen.

The EEG was derived from Fp2-O2. The signal was amplified (Hellige EE, -3 dB at 5.3 and 35 c/sec), led to an analogue feedback circuit consisting of a bandpass filter (-3 dB at 8.3 and 12 c/sec, 20 dB down/octave) and an audio-oscillator, and recorded on magnetic tape.

The frequency of the feedback signal varied continuously as a sinusoidal function of time with peak values of 400 and 500 c/sec. The frequency function was synchronized with the alpha waves; a positive alpha peak corresponded with a sound frequency of 400 c/sec and a negative peak with a frequency of 500 c/sec. The intensity of the sound was linearly related to the alpha amplitude and was adjusted for each subject to prevent distraction.

Alpha was defined as a signal greater than 25% of the maximum amplitude in a 10 min baseline recording in rest, which preceded the experiment. The subjects were instructed to enhance alpha amplitude and density as much as possible during the whole experiment. Before the experiment each subject had received a few (4-7) 40 min feedback training sessions, with evoked reflexes in the last session only. After a subject attained the criterion of 40

Fig. 1. Mean values of H and T reflex amplitudes and EEG alpha parameters of 19 subjects in a 40 min rest experiment with alpha feedback. The values of the individual subjects have been computed for periods of 5 min. The vertical bars indicate the 95% confidence intervals.

min reasonably constant alpha, the experiment was done. The subjects were not selected on alpha quantity.

It is reported that, in the absence of visual stimulation, subjects do not learn to enhance their alpha quantity above their baseline level but only learn, after fairly little training, to maintain their maximum baseline level, that does not increase with further training (Peper and Mulholland 1970; Paskewitz and Orne 1973; Strayer et al. 1973). We therefore ex-

pected that the feedback procedure would rather lead to stability of alpha parameters during the experiment.

Results

Individual data were analysed for periods of 5 min for each variable. For M, H and T, means and standard deviations were calculated. In order to allow averaging the means of different subjects, individual period means

were expressed in z-scores, computed with reference to the mean of all reflexes in the experiment and to the within-periods variance estimate. For each 5 min period the mean z-score of all subjects and its 95% confidence interval were computed (Fig. 1, *a-c*).

To test whether M, H and T changed significantly during the course of the experiment, on each of them an analysis of variance was performed (two-factor design with repeated measures on one factor and replications within cells). None of the three variables showed a significant periods effect ($P > 0.20$). The percentage of total variance attributable to the periods factor was respectively 0.59, 0.22 and 0.14% for M, H and T.

The square pulses, representing the force of the tendon tap, and the alpha activity were analysed off-line by a DEC LAB 8/e computer. The period means of the tap force were expressed as a percentage of the value in period 1 and averaged over subjects. These values did not deviate more than 6% from the initial value in period 1 (0.73 N). Small fluctuations in stimulus intensity of this magnitude are without detectable consequences for the reflex

amplitude (Dietrichson and Sørbye 1971).

Period means and standard deviations were computed for alpha amplitude (peak value histogram) and alpha wave period (primary zero crossings analysis) and transformed into z-scores (Fig. 1, *e* and *f*). The alpha index values of the periods were averaged over subjects (Fig. 1, *d*). Alpha amplitude and alpha index did not show gross changes; they showed a slight increase in the second part of the experiment.

To reveal the intra-individual relations between the dependent variables, product-moment intercorrelations between H, T and alpha parameters were computed for each subject. Because it is not desirable to draw conclusions from data of individual subjects, a chi-square test of combined probabilities of the correlation coefficients (Guilford and Fruchter 1973). In order to compute the probabilities of the correlation coefficients of individuals, this procedure requires that expectations about the sign of the correlations were specified. Our expectations were based on the results of Jovanović (1971) who found

TABLE I

Chi-square test of combined probabilities of intra-individual intercorrelations between T and H reflex amplitudes and EEG alpha parameters.

Pearson r	Expected correlation *	40 min rest with alpha feedback (for all tests combined $df = 38$)		40 min rest without alpha feedback (for all tests combined $df = 40$)	
		Summed chi-square	Combined probability	Summed chi-square	Combined probability
H-T	+	71.84	$0.001 < P < 0.01$	92.73	$P < 0.001$
H-% time alpha	+	37.37	$P > 0.05$	62.94	$0.01 < P < 0.05$
T-% time alpha	+	45.45	$P > 0.05$	68.92	$0.001 < P < 0.01$
H-alpha amplitude	+	44.74	$P > 0.05$	63.66	$0.01 < P < 0.05$
T-alpha amplitude	+	40.40	$P > 0.05$	66.99	$0.001 < P < 0.01$
H-alpha period	-	76.75	$P < 0.001$	78.23	$P < 0.001$
T-alpha period	-	58.31	$0.01 < P < 0.05$	57.78	$0.01 < P < 0.05$
% time alpha-alpha amplitude	+	161.47	$P < 0.001$	174.12	$P < 0.001$
% time alpha-alpha period	-	40.84	$P > 0.05$	70.91	$0.001 < P < 0.01$
Alpha amplitude-alpha period	-	33.42	$P > 0.05$	73.47	$P < 0.001$

* +: positive correlation to be expected; -: negative correlation to be expected.

Fig. 2. Mean values of H and T reflex amplitudes and EEG alpha parameters of 20 subjects in a 40 min rest experiment without alpha feedback. The values of the individual subjects have been computed for periods of 5 min. The vertical bars indicate the 95% confidence intervals.

that alpha index and amplitude decreased with increasing drowsiness while alpha wave period increased, and on results of Coquery et al. (1965) who found a decrease of H and T reflexes under the same conditions. The expectations and the results of the combined probabilities tests are shown in Table I. A positive relationship was found between H and T reflexes. Both correlated negatively with the alpha wave period. No relationship

was found between the reflex amplitudes and alpha index or alpha amplitude. Only one of the expectations about the relations between the alpha parameters was confirmed: a positive relationship between alpha index and alpha amplitude was obtained. The relations between index and wave period, and amplitude and wave period, were not negative, as expected, but were shown to be significantly positive (respectively $P < 0.01$ and $P < 0.05$).

Experiment 2

The second experiment investigated whether a change of alpha parameters, indicating a decrease of cortical activation, would be accompanied by a decrease of reflex amplitudes. Twenty normal students, males and females, aged between 18 and 27 years, volunteered in the experiment.

Method

The subjects in this experiment did not receive alpha feedback. They were habituated to the experimental situation before the experiment was conducted. Despite the fact that they were instructed to remain awake it was expected that, because of the monotonous and restful situation, they would become drowsy which would entail a decrease of alpha amplitude, index and frequency. All methods and statistical procedures were identical to those in experiment 1.

Results

The mean values and 95% confidence intervals of M, H, T and alpha parameters are shown in Fig. 2. An analysis of variance revealed that the periods effect was significant for H and T ($P < 0.001$) while the M response did not change significantly ($P > 0.20$). The percentage of total variance attributable to the periods factor was respectively 0.03, 0.49 and 1.45% for M, H and T.

The mean tendon tap force values did not deviate more than 6% from the initial value in period 1 (0.71 N).

The alpha index decreased continuously during the experiment. That this parameter was obviously influenced by the feedback is illustrated by the dashed line in Fig. 2, *d* which indicates the alpha level in experiment 1. Like the reflex amplitudes the alpha amplitude decreased with time but recovered partly in the last periods of the experiment. The alpha wave period increased steadily. Table I gives the combined probabilities of the intra-

individual intercorrelations between reflex amplitudes and alpha parameters. All relations were in accordance with the expectations.

Discussion

The present experiments indicate that, under conditions of fairly stable alpha index and amplitude, T and H reflex amplitudes do not change significantly. But when the alpha parameters reflect a decreasing cortical activation, the reflex amplitudes decrease. The results support the idea that the decrease of the repetitively evoked T reflex is of supraspinal origin. They agree with the finding that the decrement is counteracted by systematic increase of the demand of an induced sensorimotor task (Brunia et al. 1973).

The identical behaviour of T and H reflex in both experiment 1 and experiment 2 suggests that during rest, when high levels of cortical activation are avoided, the supraspinal influences are mediated by alpha motoneurons. Coquery et al. (1965) found parallel changes of H and T during successive stages of sleep. Pompeiano (1966) has reported similar variations of H and T during synchronized and desynchronized sleep in unrestrained, unanaesthetized cats.

The relations between alpha parameters and reflex amplitudes in experiment 2 are more clear-cut than in experiment 1. This is probably due to the fact that the range of most dependent variables is smaller in experiment 1 than in experiment 2; the greater the range the higher the correlation, other things being equal (Guilford and Fruchter 1973).

The alpha changes in experiment 2 can be interpreted as oncoming drowsiness. Loss of alpha as a result of rising activation, due to stress or discomfort, seems improbable, the more so as the alpha wave period increased. The subjects were habituated to the experimental situation and most of them reported afterwards that they had difficulty in overcoming sleepiness. A number of them reported that the sleepiness passed off towards the end of the experiment. This may explain the

slight recovery of reflex amplitudes, alpha amplitude and alpha index in the last periods of the experiment.

In experiment 1 seemingly paradoxical alpha changes have been observed: during the entire experiment alpha wave period increased while in the second half index and amplitude increased somewhat. Jovanović (1971) observed similar results for monopolar occipital, parietal and frontal derivations in subjects who relaxed. The waning of alpha that is characteristic of sleep onset was often preceded by this stage of alpha augmentation. Kasamatsu and Hirai (1966) observed similar changes in Zen masters after they started meditation. Jovanović (1971) found a more pronounced increase of alpha in frontal than in occipital or parietal regions. Rubin (1938) found that index changes may be nonproportional for the two hemispheres. These results imply that the relations between alpha parameters and reflex amplitudes may depend on the derivations that are studied.

It should be emphasized that the variability of the intra-individual alpha-reflex correlations was considerable. Also the course of the reflex amplitudes with time was partly a unique property of the subject. The subjects—periods interaction was significant in experiment 1 and experiment 2 ($P < 0.001$) for both H and T. In both experiments the interaction contributed more to the total variance than the periods effect. The variance attributable to the interaction in experiment 1 was: H 10.1%, T 1.9% and in experiment 2: H 2.0%, T 6.6% (in both experiments the greater part of the variance was due to the subjects factor). As these phenomena are not uncommon in electrophysiological research with human subjects, general principles found in this field should be evaluated against the background of the importance of individual characteristics of the subjects.

Summary

Some investigators have found that in normal human subjects the amplitudes of repeti-

tively evoked tendon reflexes decrease as the number of evoked reflexes progresses. The question whether this decrement is a spinal phenomenon or that it can be ascribed to supraspinal influences that are related to the degree of cortical activation was investigated in two experiments designed to test whether a relation exists between the Hoffmann (H) and Achilles tendon (T) reflex amplitudes and EEG alpha activity parameters during a rest condition. The principal results can be summarized as follows:

1. A constant alpha index was accompanied by stable reflex amplitudes.
2. A decreasing alpha index was accompanied by decreasing reflex amplitudes.
3. A positive relation was found between H and T reflex amplitudes.
4. A positive relation was found between alpha index and alpha amplitude.
5. No circumscribed relation was found between the alpha wave period on the one side and the alpha index and amplitude on the other side. Apparently these relations are dependent on the state of activation of the subject.
6. The relations between the reflex amplitudes and the alpha parameters showed great interindividual differences.

Résumé

Relation entre l'amplitude des réflexes mono-synaptiques et quelques paramètres de l'activité EEG alpha

Plusieurs travaux ont montré que chez l'homme normal l'évocation répétée d'un réflexe tendineux entraîne une diminution de son amplitude. Afin de déterminer si cette diminution est un phénomène spinal ou si elle résulte d'influences supraspinales accompagnant des variations du niveau d'activation corticale, deux séries d'expériences ont été effectuées en vue d'examiner s'il existe une relation entre l'amplitude des réflexes de Hoffmann et tendineux achilléen d'une part et

l'activité EEG alpha en état de repos d'autre part. Les résultats principaux se résument ainsi:

1. Pour un pourcentage de temps d'activité alpha constant, l'amplitude des réflexes ne changeait pas significativement.

2. Une diminution de ce pourcentage s'est accompagnée d'une réduction des amplitudes des réflexes.

3. Il a été établi une relation positive entre l'amplitude des réflexes de Hoffmann et celle des réflexes tendineux.

4. Il a été établi une relation positive entre le pourcentage de temps alpha et l'amplitude alpha.

5. Aucune relation évidente n'a pu être décelée entre la période des ondes alpha d'une part et le pourcentage de temps et l'amplitude alpha d'autre part. Apparemment, la relation est fonction de l'état d'activation du sujet.

6. Les relations entre amplitudes des réflexes et paramètres de l'activité alpha ont accusé de grandes différences inter-individuelles.

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