Excitability of lower limb myotatic reflex arcs under the influence of caloric labyrinthine stimulation

Analysis of the postural effects in man

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SUMMARY The excitability changes of myotatic reflex arcs have been investigated in 36 volunteers by two methods (tendon reflex and tonic vibration reflex) in a bilateral investigation of soleus, quadriceps, biceps femoris, and tibialis anterior after caloric stimulation of the labyrinth. The extensor myotatic reflexes are facilitated during the irrigation and the nystagmus phases. Contrary to the soleus, quadriceps facilitation is not symmetrical during the phase of nystagmus but predominates on the side opposite to the expected axial deviation. The short biceps femoris reflexes are slightly facilitated. The postural modifications arise from differences in the degree of bilateral facilitation of the extensors.

Irrigation of the external auditory meatus in man—a classical clinical test—provokes an axial deviation of the body: ipsilateral after cold stimulation and contralateral after hot stimulation. At present, however, there are few data concerning the pattern of facilitation and inhibition affecting the different muscle groups of the lower limb. This deviation is generally explained by results obtained from animal experiments in which specific vestibular and vestibulospinal stimulation of short duration were used. But, in clinical exploration, the stimulation is of longer duration and more complex, involving cutaneous and vestibular activation (Delwaide and Juprelle, 1977). Hence, there is need for studies in clinical neurophysiology.

The body deviation is associated with reflex adjustments of tone which, in turn, are a function of the level of excitability of myotatic reflex arcs. This level of excitability can be investigated by two complementary methods in clinical neurophysiology: by study of the tendon reflex (Lloyd, 1943; Paillard, 1955), or by activation of the myotatic reflex through vibration of the tendon (Matthews, 1966). The human tonic vibration reflex (TVR) depends on both monosynaptic and polysynaptic activation of motoneurons by the Ia

afferent nerve fibres (Eklund and Hagbarth, 1965; Lance, 1965; Delwaide, 1974). To measure changes of tone in the lower limb, both these methods have been used in a bilateral investigation of the following myotatic reflexes: soleus, quadriceps, tibialis anterior, and short head of biceps femoris, of which the latter two are flexors. The TVR of tibialis anterior is of particular interest since it is not possible to examine tendon reflexes in this muscle. TVR changes in these four muscles have been published in a preliminary note (Delwaide *et al.*, 1976).

Subjects and methods

The investigations were carried out in 36 students aged between 15 and 32 years.

The subjects sat in a specially modified dental chair. The head and trunk were slightly flexed backwards to make an angle of 30° with the vertical; in this position, the superior semicircular canal is in the vertical plane. The head was immobilised in a restraining device throughout the experiments and the eyes were kept closed.

The legs were fixed in a special device (Delwaide *et al.*, 1969) by which the angle between trunk and thigh was maintained at about 120°, the knee flexed at 45°, and the angle between the leg and foot set at 110°. Tendon reflexes were

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evoked every seven seconds, activated by identical taps delivered by an electromagnetic hammer that was rigidly fixed in front of the tendons in such a way as to evoke a maximal response in resting conditions.

The action potentials corresponding to the tendon jerks, derived from DISA 13K60 cutaneous electrodes, were measured peak to peak on a digital oscilloscope (Tektronix 230 Digital Unit) and printed by a Hewlett Packard 5050B.

Tonic vibration reflexes were evoked in soleus, tibialis anterior, quadriceps, and biceps femoris muscle, by the application of a Keydon vibrator to the respective tendons. The vibration frequency was 100 Hz and the amplitude 1.0 mm (Eklund, 1971). The tonic vibration reflex was evaluated by the amplitude of the electromyographic response.

Vestibular stimulation was performed by irrigation of the external auditory meatus with 500 ml of water at a constant rate, at temperatures of 44°, 30°, or 37°C. Ocular movements were recorded by electrodes fixed to the external borders of the orbits and amplified on a Siemens Mingograph.

The experimental protocol was as follows: reflexes were evoked during a control period of about three minutes, and subjects showing large variations were rejected. The evocation of reflexes was continued at the same regular frequency during water irrigation. Values obtained during this period were grouped, as were those obtained during nystagmus. Thus several phases could be distinguished: (1) the phase of control values, (2) during water irrigation, (3) during nystagmus, and (4) post-nystagmus controls.

When several labyrinthine stimulations were carried out in a single subject, each experimental series was separated from the others by an interval of 20 minutes.

None of the subjects showed neurovegetative reactions calling for the experiment to be stopped.

Results

SOLEUS MYOTATIC REFLEX

Changes in myotatic reflex excitability brought about by ipsilateral stimulation were similar after hot or cold water (Fig. 1). The results were identical when the contralateral ear was stimulated. During irrigation there was a marked facilitation which declined regularly during nystagmus. Facilitation proved to be equal during nystagmus. During irrigation there was marked facilitation of the TVR (Fig. 2). This effect was not due to temperature change, since it was also observed after irrigation with water at 37°, although the

Fig. 1 Amplitude changes in soleus tendon reflex after irrigation of ipsilateral external auditory meatus with water at 44° and 30°C. Ordinate: reflex amplitude expressed as percentage of control value = 100. Abscissa: time in minutes. Irrigation was performed between the broken vertical lines; duration of nystagmus is indicated by arrows.

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Fig. 2 Changes in soleus tonic vibration reflex after irrigation of ipsilateral external auditory meatus with water at 37°, 30°, and 44°C. Right and left columns: control. The second column shows that TVR is increased during irrigation irrespective of water temperature. After stimulation at 30° and 44°, facilitation can be seen to persist during nystagmus (third column), there being no difference between hot and cold stimulation.

TVR then returned to control amplitude at the end of irrigation. When nystagmus was induced (after irrigation at 30° or 44°), the TVR remained markedly facilitated, sometimes in a rhythmic manner that was clearly audible through a loud-speaker. The frequency of the rhythm was similar to that of the nystagmus. In some experiments, rhythmic TVR bursts appeared at the same time as nystagmic bursts in the final phase of nystagmus. At the end of the nystagmus, the TVR returned to control amplitude. During the phase of nystagmus, no significant difference was observed between the facilitation induced by hot or cold

stimulation of the ipsilateral labyrinth. When hot or cold stimulation was applied to the contralateral labyrinth, the TVR was facilitated as in Fig. 2 without clear difference. Whatever the combination of water temperature and side stimulated, excitability of the soleus myotatic reflex increased without preponderance on one side or the other.

QUADRICEPS MYOTATIC REFLEX

During the irrigation phase, there was greater facilitation in quadriceps than in soleus (Fig. 3). The values sometimes exceeded 200% (mean 112% during phase 2). Hot or cold and ipsilateral

Fig. 3 Changes in quadriceps tendon reflex after irrigation of external auditory meatus with water at 44° (●) and 30° (○). Ordinate: reflex amplitude expressed as percentage of control value=100. Abscissa: time in minutes. Irrigation was performed between broken vertical lines; duration of nystagmus is indicated by arrows. A: irrigation of ear ipsilateral to tested reflex, B: irrigation of ear contralateral to tested reflex.

Note that facilitation is equal on both sides during irrigation phase, with both hot and cold water, but that during the phase of nystagmus there is greater facilitation on hot ipsilateral and cold contralateral stimulation.

or contralateral stimuli evoked quantitatively equal facilitation during the irrigation phase.

During the phase of nystagmus, facilitation persisted, as in soleus, but diminished progressively. Compared to soleus (Fig. 1), there was an appreciable difference. Facilitation was not equal, but was greater on hot ipsilateral or cold contralateral stimulation. The difference was approximately 40%. Data compiled from 10 subjects showed that there was a significant difference (Student's *t* test) 300 ms after the beginning of the nystagmus. Thus, there was a lateralised and preferential facilitation in quadriceps according to the ear and temperature used.

The TVR gave similar results: facilitation of the TVR was more marked after hot ipsilateral or cold contralateral stimulation.

MYOTATIC REFLEX OF SHORT HEAD OF BICEPS FEMORIS

On biceps femoris (Fig. 4), there was only slight facilitation after warm stimulations, ipsilateral or contralateral either during irrigation (phase 2) or nystagmus (phase 3). Because of the technical difficulties in evoking the short biceps femoris reflex, the experiment was repeated on a large number of occasions, always with the same results (mean facilitation 9.5%). However, the Jendrassik manoeuvre brought about a marked facilitation of this reflex.

Fig. 4 Amplitude of short head of biceps femoris tendon reflex after irrigation of external auditory meatus with water at 44°C. Ordinate: reflex amplitude expressed as percentage of control value=100. Abscissa: time in minutes. Irrigation was performed in the ipsilateral (●) and contralateral (○) ear between the broken vertical lines; the duration of nystagmus is indicated by arrows. Note the facilitation brought about by the Jendrassik manoeuvre (JK), performed after cessation of nystagmus.

The TVR of the short head of biceps femoris was not appreciably modified during either irrigation or nystagmus.

MYOTATIC REFLEX OF TIBIALIS ANTERIOR

As in the case of the short head of biceps femoris, the TVR was unchanged during the phases of both irrigation and nystagmus.

Discussion

The deviation of the body axis after unilateral labyrinthine stimulation is commonly interpreted by clinicians through extrapolation from the results of animal neurophysiology (Brodal, 1967; Gernandt, 1967; Grillner *et al.*, 1971). Descending influences brought about by labyrinthine stimulation exert, directly or through interneurons, a facilitatory effect on the motoneurons of the ipsilateral extensors, the muscles of the trunk and the contralateral flexors. Simultaneously, there is inhibition of their antagonists. Such a combination of facilitatory and inhibitory actions on motor nuclei of antagonistic functions has been demonstrated in the case of the ocular movements in nystagmus (Berthoz, 1974).

However, human caloric labyrinthine stimulation does not mimic the animal physiology methods exactly. Partly for this reason, the results may differ in clinical and animal experiments. For instance, we found no inhibition during the phase of nystagmus, in either ipsilateral flexors or contralateral extensors.

We found parallel responses in TVR and tendon reflexes for all four muscles after a complex stimulus. Irrigation of the external auditory canal is an immediate cutaneous stimulus and, later, by convection, a labyrinthine stimulus with objective effects as demonstrated by nystagmus.

As shown by the facilitation after syringing with water at 37°C, the cutaneous stimulus alone can increase excitability of the lower limb extensor myotatic arcs (Delwaide and Juprelle, 1977). This facilitation is bilateral and ipsi- and contralaterally equal. During the nystagmus phase, the reflex effects may be due to both reticulo- and vestibulospinal impulses, possibly to other structures. As long as nystagmus lasts, facilitation in the soleus is roughly symmetrical. In the quadriceps, facilitation is more pronounced and bilateral, but quantitatively unequal. Quadriceps facilitation is more marked on the side opposite to the axial deviation expected clinically.

The short biceps femoris muscle shows only slight facilitation of excitability of the myotatic reflex during both injection and nystagmus phases.

Similar results were obtained in the tibialis anterior and contrast with those obtained in extensor muscles. In the cat, the vestibulospinal tract inhibits both the alpha and gamma motoneurons of flexor muscles (Kato and Tanji, 1971). The behavioural peculiarity of the short biceps femoris myotatic reflex may be attributed to simultaneous activation of antagonistic mechanisms: facilitatory, particularly of reticular origin, and inhibitory, of a vestibular origin. In any event, the absence of clear facilitation in the flexor muscles indicates that the mechanism involved during water irrigation differs from that involved in the Jendrassik manoeuvre (see Fig. 4).

Fig. 5 Schema of facilitation (+) after irrigation of right ear with hot water. The excitability of the soleus myotatic reflex arcs is facilitated equally in a bilateral manner, while the quadriceps myotatic reflex is facilitated asymmetrically, with preponderance on the side of irrigation.

These results indicate that the postural modifications, secondary to reinforcement of tone in some muscles, can only arise from differences in the degree of bilateral facilitation. In a distal muscle such as the soleus, the difference is not conspicuous, but in a more proximal myotatic reflex, the difference is clear, and determined by the side and type of caloric stimulation. Facilitation predominated on the side of the more active labyrinth, and consequently on the side opposite to the axial deviation. The deviation requires more than preferential facilitation of the quadriceps muscles, but asymmetrical effects on proximal and perhaps axial muscles is probable. On a background of global facilitation, there are fine controls of excitability of the motoneurons of the proximal extensors. We could not determine whether this control works, depending on the side concerned, by additional facilitation or by inhibition. It may be assumed that the vestibulospinal pathway is concerned in the establishment of these gradients of facilitation. Modulation of excitability in the proximal extensors may be related to a particular anatomical arrangement. In the cat (Nyberg-Hansen and Mascetti, 1964; Nyberg-Hansen, 1966), the lateral and medial vestibulospinal tracts terminate in the ventromedial part of the spinal grey matter, in which interneurons particularly influence the motoneurons of proximal muscles (Bernard and Rexed, 1945). A scheme of facilitatory effects (Fig. 5) corresponds to a balance that is disturbed by unequal overloading of two scales, rather than by loading one scale and unloading the other.

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