Excitability of the monosynaptic reflex pathway in the child from birth to four years of age

M F VECCHIERINI-BLINEAU AND P GUIHENEUC

From the Laboratoire de Physiologie, Université de Nantes, Nantes, France

SUMMARY   The excitability of the monosynaptic reflex pathway was tested in infants and children from birth to four years of age during waking and sleeping. The H reflex, evoked in the soleus muscle, was used to calculate the ratio, maximal H to maximal M, construct recruitment curves and test reflex excitability by the paired stimulus method. The excitability of the monosynaptic reflex pathway during the waking state is greatest at birth; it diminishes gradually during the first years of life without reaching the average level observed in adults by the end of the fourth year of age. From birth, regardless of age, sleep always depresses excitability. The mechanisms that underlie this change with age, and with waking or sleeping, are discussed.

The characteristics of monosynaptic reflex responses have formed the subject of numerous studies in normal adult human[1-3] and in the spastic man.[4-9]

In the child, monosynaptic reflexes have been studied most in the upper limbs.[10-12] Few authors have used Hoffmann's monosynaptic reflex evoked in the soleus muscle of the child, despite the fact that this is the only reflex which persists in adults, so allowing comparison between children and adults. Moreover, the excitability of the monosynaptic reflex pathway has not been quantitatively studied. Mayer and Mosser[13] made a qualitative description according to age, and Hodes and Gribetz[11] pointed out the influence of sleep. We have used Hoffmann's reflex evoked in the soleus muscle to obtain data about the amplitude of the H reflex response and to evaluate its variation with the age of the child and with different states of waking and sleeping.

Material and methods

The 126 children examined during this study were born at term and were free of neurological disorders. The method used has been described:[14] the children were placed in a room at a constant temperature of 23°C, at rest in supine or prone position, with the joints held in a fixed position. Continuous polygraphic recording was provided by an EEG apparatus (Mini Huit Alvar), four channels being used for the EEG, one for recording eye movements, and one for the electromyogram of the chin

muscle or of the neck muscles. The two remaining channels were used for the EMG of the soleus muscle and of its antagonist, the tibialis anterior.

The H-reflex was evoked in the soleus muscle by cathodic monopolar stimulus of the sciatic nerve in the popliteal fossa, according to methods described.[14] The maximal amplitude of the H reflex response (maximum H) and of the direct motor response (maximum M) were measured and the value of the ratio between maximum H and maximum M was determined. These measurements were obtained from (a) 93 awake children classed by age-group: 2 to 30 days (14 cases), 1 to 6 months (14), 6 to 12 months (14), 1 to 2 years (24), 2 to 3 years (16) and 3 to 5 years (11); and (b) from 33 children either when falling asleep or in phase II slow-wave sleep, classed by age as follows: 1 to 6 months (5 cases), 6 to 12 months (5), 1 to 2 years (10), 2 to 3 years (9) and 3 to 5 years (4). In addition, the recruitment curve of H and M responses, according to stimulus intensity in relation to threshold intensity, was constructed for 67 children in a quiet waking state and for 33 in light sleep. Finally, the excitability cycle of the soleus H response was obtained by introducing a test stimulus producing an isolated maximum H response, which was preceded by a conditioning stimulus of the same maximum H level. The amplitude of the test response was measured for three consecutive responses, the first response in a sequence being discarded. The amplitude of the test response is expressed as a percentage of the amplitude of the conditioning shock in the same series; the delays between conditioning and test shocks are shown as logarithmic abscissae. The phases of the excitability cycle are numbered according to Paillard's description.[2] This study was carried out on 25 awake children: 1 day to 6 months (6 cases), 6 to 12 months (11) and 1 to 4 years (8); 33 children during sleep: 2 days to 6 months during synchronised sleep (8), 6 to

12 months during phase II slow-wave sleep (10), 1 to 4 years during phase II slow-wave sleep (10) or phase III and IV slow-wave sleep (5); and 7 adults in a quiet waking state.

Measurements and statistics The amplitude of the responses was determined from the peak-to-peak voltage of the recordings by averaging three sweeps at constant stimulus intensity. For each group of subjects, measurement of the averages and of Standard Deviations was made according to Student's distribution. The *t* test was used in studying differences between two groups.

Results

MAXIMUM H/MAXIMUM M RATIO: AMPLITUDE OF THE REFLEX RESPONSE

Change according to age (table)
In quiet waking, the amplitude of the maximum H/ maximum M ratio diminished from birth to one year of age, from 0.65 ± 0.10 during the first month of

Table *Change in the value of the soleus maximum H/ maximum M ratio, according to age, during waking and drowsiness*

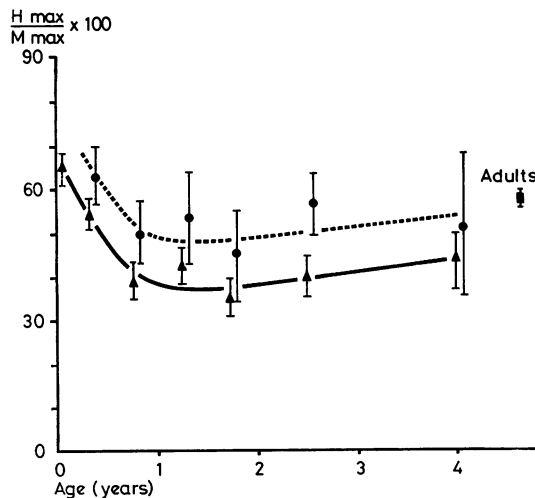| Age	Relaxed waking	Drowsiness
0 to 30 days	0.65 ± 0.10	—
1 to 6 months	0.55 ± 0.13	0.63 ± 0.10
6 to 12 months	0.40 ± 0.13	0.50 ± 0.15
1 to 2 years	0.40 ± 0.13	0.49 ± 0.20
2 to 3 years	0.41 ± 0.18	0.57 ± 0.23
3 to 5 years	0.44 ± 0.22	0.53 ± 0.28

Fig 1 *Amplitude of the soleus monosynaptic reflex response (maximum H/maximum M ratio) according to age. Black triangles: during relaxed waking. Circles: during drowsiness. On the right: values observed in 39 adults during relaxed waking (black square). Each dot = mean ± 1 S D.*

life to 0.40 ± 0.13 at about age one year. The ratio remained constant until two years of age, then increased reaching 0.45 ± 0.20 at about age four years (fig 1), which still was lower than the values obtained for normal adults (0.58 ± 0.10). The scatter of the results was considerable, more so for children over two years of age than for children under this age. The difference in the results is, however, statistically significant comparing children less than six months of age with those over age one year ($p < 0.01$).

Changes according to state of waking or sleeping
During the period of drowsiness, the amplitude of the maximum H reflex response and the value of the maximum H/maximum M ratio increased by about 25% in comparison with values obtained during waking. The ratio was 0.08 to 0.10 higher on average than that noted in the same child during quiet waking, regardless of age (table). Owing to the small number of subjects examined and the scatter of the results, differences by age were not statistically significant.

When a state of synchronised sleep was reached, or when slow-wave sleep went from phase II to phase IV, the amplitude of the maximum H response and the value of the maximum H/maximum M ratio diminished by 25% to 40% in comparison with the value observed during waking, with no modification of the maximum M response.

During desynchronised or rapid-eye-movement (REM) sleep, the H response was abolished, regardless of the age of the child. Disappearance of the H reflex response preceded the occurrence of eye movements.

RECRUITMENT CURVES

Change according to age
From birth, the curves had the general contour of those described for the adult subject, except that during the first six months the recruitment curve for the H response had a steeper slope and a higher maximal value. The H response threshold was lower than that of the M response during this period. From one year of age on, the H and M response thresholds tended to become similar.

Change according to state of waking or sleeping
The amplitude of the H response recruitment curve diminished when slow-wave sleep became deeper, resulting in a flattening of the curve. No difference was noticeable in the recruitment of responses.

PAIRED STIMULUS EXCITABILITY CURVES

Change according to age
In the awake infant up to six months of age, after a

silent phase the test shock produced a response attaining 70% of that to the conditioning shock for stimuli cccurring six to seven ms apart. Inter-shcck intervals from 15 to 50 ms produced a sharp depression in the test shock response, which occasionally was abolished. When the two shocks were 150 to 200 ms apart the test shock response returned, attaining 100% of the conditioning response (fig 2). No late depression was noted between 300 and 600 ms.
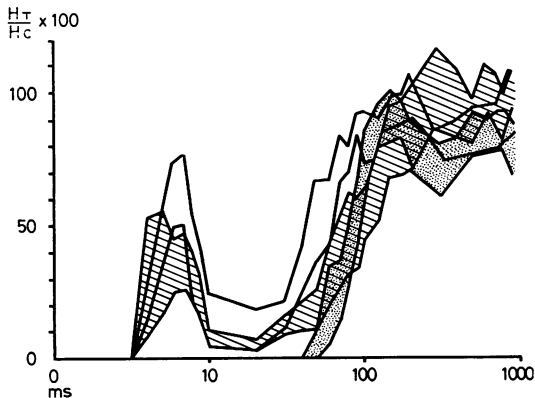
$\frac{H_T}{H_C} \times 100$

Fig 2 *Paired stimulus excitability curves of the soleus H response during relaxed waking. Light area: children less than 200 days of age. Hatched area: children from 1 to 4 yr of age. Shaded area: adults. The area represented corresponds to a surface limited by an interval of ±1 SD of the mean. In abscissa: interval between the conditioning shock (Hc) and the test shock (Ht), in ms. Ordinate: amplitude of the test shock (Ht) response in % of amplitude of response to the conditioning shock (Hc).*

In awake children older than one year of age examined in the same conditions, the contour of the excitability curves was similar to that just described; however, there was a decrease in the amplitude of the test shock responses with intervals between six and seven ms, when the response was only 40% of the conditioning response, and during the phase of intervals, between 15 to 50 ms. In fact, the ratio of the amplitudes of the responses was only 65% at 100 ms and reached 100% only at about 200 ms. Beyond this period, the curves had the same contour, regardless of age (fig 2). In both cases there was neither a rebound nor a late depression. Between six months and one year of age, the excitability curves were intermediate between these two shapes.

Paired stimulus excitability curves in the same experimental conditions in adults showed two differences from those in children (fig 2). Response to the test shock was absent or very weak between 0 and 70 ms, and there was a late depression after 200 ms.

Change according to state of waking or sleeping

It was sometimes possible to record excitability curves from the same child while awake and at different stages of sleep. But rapid variations in the state of waking or sleeping, as well as the long time spent in desynchronised sleep, explain why we were unable to obtain many results in deep slow-wave sleep before the age of six months.

During synchronised or phase II slow-wave sleep, when the amplitude of the maximum H response was only slightly diminished, the excitability cycle was
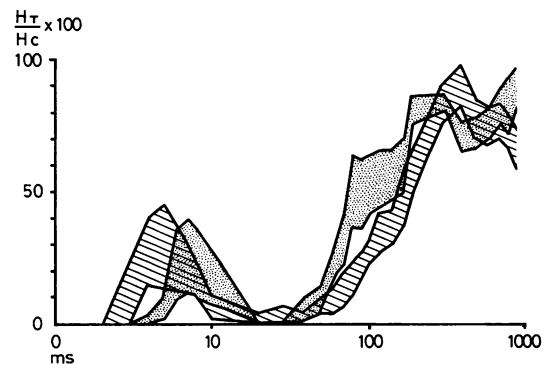
$\frac{H_T}{H_C} \times 100$

Fig 3 *Paired stimulus excitability curves of the soleus H response during synchronised sleep or phase II slow-wave sleep. Shaded area: children less than 200 days of age. Hatched area: children from 1 to 4 yr of age. The area represented corresponds to the surface limited by an interval of ±1 SD of the mean. Same ordinates as for fig 2.*
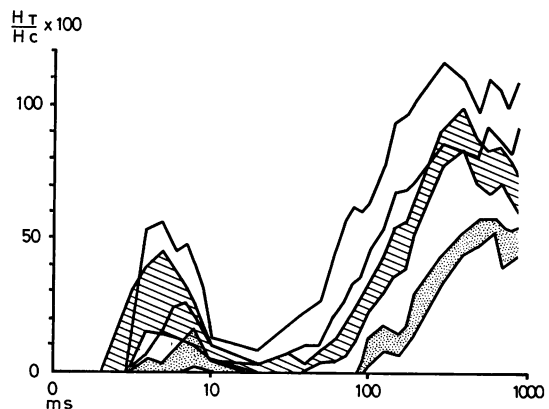
$\frac{H_T}{H_C} \times 100$

Fig 4 *Paired stimulus excitability curves of the soleus H response in children 1 to 4 yr of age. Light area: during relaxed waking. Hatched area: during phase II slow-wave sleep. Shaded area: during phase III-IV slow-wave sleep. The area represented corresponds to the surface limited by an interval of ±1 SD of the mean. Same ordinates as in fig 2.*

altered, showing an inhibition of responses and delayed recovery (fig 3).

During deep slow-wave sleep-phases III and IV inhibition of responses was even greater, recovery took even longer to appear and was incomplete even after 1s (fig 4). No excitability cycle could be recorded during desynchronised sleep.

Thus, regardless of the subject's age, slow-wave sleep, in comparison with relaxed waking, was characterised by a gradual suppressing of the amplitude of the test shock responses throughout the whole range of time periods explored, and by slowness of recovery. Nevertheless, if change in the curves according to age is taken into account, the results obtained in older children during waking differed little from those in younger children during light sleep (fig 5).
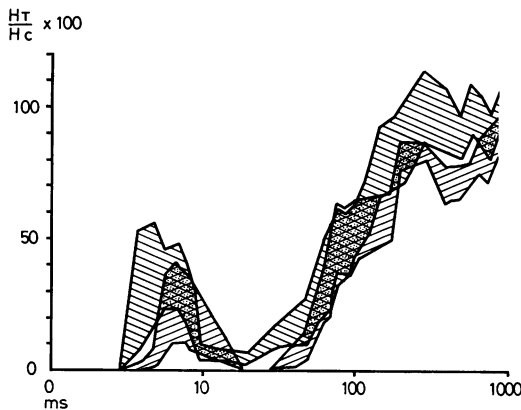

$\frac{HT}{Hc} \times 100$

Fig 5 *Paired stimulus excitability curves of the soleus H response: overlap of the curve recorded in children 1 to 4 yr of age during the waking state* ▨ *and of that in children less than 6 months of age during light sleep* ▨ *The overlap area is shaded.* ⊠ *The area represented corresponds to the surface limited by an interval of ±1 SD of the mean. Same ordinates as in fig 2.*

Discussion

A gradual decrease of monosynaptic reflex excitability occurs in the awake child during the first years of life. Regardless of age, the excitability of the reflex pathway decreased during slow-wave sleep and disappeared during desynchronised sleep.

Change in reflex excitability according to age
The value of the soleus maximum H/maximum M ratio drops during the first year of life, although Duron et al[12] found that the ratio of the cubital H reflex is the same in the newborn as in adults. The

great variability of maximum H/maximum M at any given age in the same experimental conditions (despite attempting to ensure muscular relaxation in agonist and antagonist muscles), makes the maximum H/maximum M ratio unreliable in the child, so that only its extreme values may be taken into account. However, like Tardieu et al[15], we found that though the value of the ratio varies considerably from one child to another it remains constant for a given child. The decrease of the maximum H/maximum M ratio occurred during a period of life when monosynaptic reflexes disappeared in the upper limbs and excitability, tested by paired stimuli, diminished.

The contour of the excitability curves and the absence of rebound and late depression have already been described in newborns[13].

The mechanisms underlying the change in these responses are still uncertain. Skoglund,[16] in a study in the kitten, put forward the hypothesis that alteration of the excitability of the monosynaptic reflex pathway is a result of a differential growth determining the individual maturity of neurons (afferents and synaptic connections); and of modifications in the distribution of electrolytes along the neuronal membrane. He suggested that a high concentration of extracellular potassium alters the excitability of the motoneurons and interneurons. However, there is no correlation between the plasma concentration of K^+ and of the subliminal fringe. The size presumably increases with age,[17] [18] and its excitability is altered by variations in ionic concentration. These modifications of the subliminal fringe undoubtedly account for the greater scatter in our results of the values of the maximum H/maximum M ratio with increasing age. However, Naka,[19] in the kitten, and Schulte,[20] in man, have shown that, from birth, all the fundamental spinal cord mechanisms are present. The refractory period and reciprocal inhibition are present very early in man, so it is probable that suppressor effects on reflex excitability are, for the most part, supraspinal.

A tetanising conditioning stimulus, or a lesion of the motor cortex, makes the H reflex reappear in limb muscles at the level where it exists in the child.[21] Angel and Hoffmann,[4] Landau and Clare,[22] Castaigne et al[23] and Spira[8] also have reported a rise in the maximum H/maximum M ratio in adolescents or adults, spastic as a result of brain lesions, although this finding is variable.[15] [24] However, all authors who have studied, by neurophysiological methods, adult spastics suffering from lesions of the cortex or of the brain stem agree that the H reflex has a lowered threshold, and that it is present in areas where it had disappeared during the first years of life; also, paired stimulus excitability

curves suggest a reflex hyperreflectivity. The curves in spastics are similar to those of the child, showing early facilitation, brief early depression, rapid and complete recovery of facilitation and, finally, weak or absent late depression.

Cortical or subcortical lesions presumably suppress descending inhibitory volleys, especially those affecting extensors, thus disturbing the physiological balance of reciprocal inhibition[9]. Magladery et al[24] and Teasdall et al[25] also believe that lesions of the pathways originating in the inhibitory reticular formation and, perhaps by analogy with the cat, lesions of the cerebello-reticulo-spinal pathways, release facilitory volleys influencing either the spinal afferents or interneurons. Yap[26] has suggested that a long spino-bulbo-spinal pathway may be involved in these events.

Finally, Mayer and Mosser[13] have reminded us that the degree of myelination of different spinal pathways is not the same at birth. In the young child, this anatomical particularity might account for an imbalance in facilitory and inhibitory influences in favor of facilitation.

Change in reflex excitability according to state of waking or sleeping

That sleep depresses reflex excitability is recognised in the adult, having first been explored by Paillard,[2] then by Hodes and Dement,[27] Coquery et al[28] and Dimitrijevic et al.[6] The influence of sleep exists also in the child.[29] The pathways permitting inhibitory mechanisms to come into play during sleep thus are functional from birth onwards.

Hodes and Gribetz,[30] showed in a 15-day-old anencephalic that neither the cortico-spinal pathway nor the cerebellum is necessary for control of reflex activity during sleep. Shimizu et al[31] specify that, in patients with circumscribed lesions of the medulla and pons, the inhibitory pathways capable of abolishing the H reflex during desynchronised sleep are the extrapyramidal tracts coursing along the antero-lateral cord of the medulla. A series of studies carried out by Pompeiano and co-workers in the cat identified the pathways involved and their mechanism of action. Descending pathways originating in the lower inhibitory reticular formation are responsible for inhibitory postsynaptic potentials. Superimposed on a background of tonic inhibition,[32] phasic volleys arrive by means of descending inhibitory influences originating in the sensory-motor cortex and in the median and descending vestibular nuclei. These pathways exercise a presynaptic inhibition on the Ia primary afferents,[33] and are responsible for the abolition of the monosynaptic reflex during desynchronised sleep. In the kitten, the monosynaptic reflex is exaggerated during sleep in the first month

of life before an adult-type control appears, either because the functional properties of the Ia fibers are modified or because the maturation of the supramedullary structures leads to a new hierarchy of influences over motor control.[34]

The alterations in the excitability of the monosynaptic reflex pathway that we have observed in the child seem to be due to a redistribution of the regulatory messages of supraspinal origin (cortical, reticular and vestibular). These descending inhibitory influences would account for the decrease in excitability noted during the first years of life as well as during sleep.

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