

An oscillatory component of the H-reflex

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SUMMARY H-reflex recovery curves studied in 57 normal volunteers could be divided into three groups: one with sinusoidal properties having one or more periods, one having primarily linear or exponential properties, and a third, indeterminate group.

Since the original publication by Hoffmann,¹ numerous reports have appeared describing various features of the H-reflex in normal and pathological subjects. Studies by Magladery and McDougal² and Paillard³ stimulated interest in the relationship of the H-reflex recovery curve to neuropathological states such as Parkinson's disease, stroke, cord trauma, and various other neurological diseases.^{4–6} In reviewing this literature, we have noted that the configuration of the H-reflex recovery curve is invariably described as having an initial period of facilitation (8–12 ms delay), best shown at near threshold stimulation, a "secondary facilitation" at 100–300 ms delay, followed by a trough, and then gradual return to 100% excitability in 5–10 seconds. During the course of our studies on the determinates of recovery curve parameters, we have found evidence that the H-reflex recovery curve is more complex than has been reported previously.

Methods

Fifty-seven volunteer adults were studied, ranging in age from 18 to 44 years. All were screened for the presence of neurological disease and for a family history of mental or neurological abnormalities. Twin square-wave pulses of 1 ms duration were delivered to the posterior tibial nerve via a bipolar surface stimulating electrode placed in the popliteal fossa. Recording was achieved with metal disc electrodes placed over the tendon and belly of the soleus muscle. Responses were amplified with a Grass P511 pre-amplifier and were displayed on a Tektronix storage oscilloscope D13 or processed by a PDP-8 computer. Stimulus strength

was adjusted to achieve a maximal H-response. In most cases, S1–S2 delay intervals used were 30, 50, 70, 90, 100, 150, 200, 300, 400, 600, 800, 1000, 2000, and 5000 ms. Five determinations per delay were taken for these data and curves plotted from mean H2/H1 values at each delay. In two additional studies, recovery was sampled at equidistant 50 and 100 ms intervals between 50 and 2000 ms. Three determinations per delay were taken for these data. While no direct determination of variability in stimulus strength was made, stimuli were presented in a random sequence of S1–S2 delay intervals, so any random fluctuations in stimulus intensity would be unlikely sources of recovery variations.

Results

When studied at a stimulus strength eliciting a maximal H-response, the initial facilitation at 8–12 ms was not seen. Secondary facilitation (Hx) between 100–300 ms was reached at an average value of $66.3 \pm 29.9\%$, which is similar to that reported by others. The presence or absence of a small M response was not significantly correlated with recovery curve parameters. On inspection of the individual recovery curve graphs it seemed plausible that the large standard deviation for the group as a whole might be due to sub-groups of H-reflex curve types. Three predominant categories of curves could be distinguished. One group of curves appeared to have sinusoidal properties, marked by one, two, or more periods (fig 1A, 1B). Higher order facilitatory peaks are also discernible in the curves illustrated in fig 2, where small uniform (50 ms) increments in S1–S2 delay increase curve resolution. A second group of curves was characterised by monotonic increasing functions, that is, linear or exponential behaviour (fig 1C, 1D). The last group consisted of curves that could

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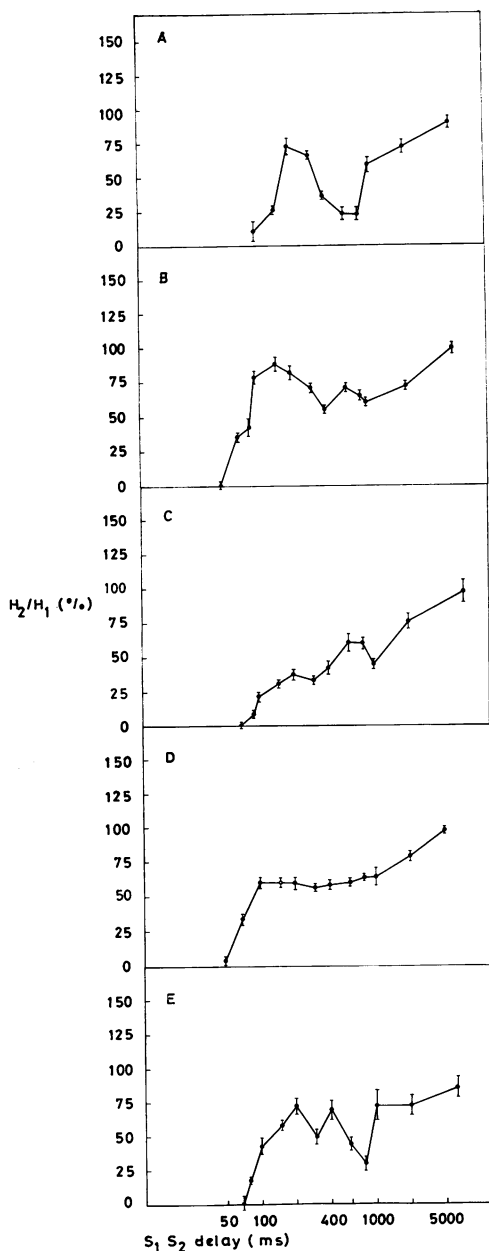


Fig 1 *H*-reflex recovery curves. Each curve represents recovery in a single individual; each point is the mean of five determinations. A Curve with a single facilitatory peak, group I curve. B Two distinct facilitatory peaks, group I curve. C "Linear" curve, group II curve. D Exponential curve, group II curve. E Uncertain curve, group III curve. Vertical bars indicate standard error of the mean.

not clearly be classified into either of the above categories (fig 1E).

Classification was made by an independent rater who was given a description of the curve types and asked to classify each curve accordingly. Curves exhibiting sinusoidal properties comprised 54.4% of the total (31/57), of which 83.9% (26/31) gave evidence of two peaks prior to 1000 ms delay. Twenty-one curves (36.8%) were classified as monotonically increasing. The remainder of the curves (5/57, or 8.8%) were categorised as uncertain. There was no relationship between age or sex and curve types. Given these curve types, one might hope to predict them from some feature of the recovery curve. If each curve is seen as being indicative of the response of a second order non-linear servomechanism, oscillatory curves might be construed as under-damped curves and exponential or linear curves as over-damped curves.⁷ Thus, the value of recovery at secondary facilitation (Hx) would tend to be higher for under-damped curves and therefore higher for the sinusoidal category of curve type. Likewise, Hx would tend to be lower for over-damped curves and therefore lower for the monotonically increasing category of curve type. To test this hypothesis, a hierarchical cluster analysis was performed on Hx. The particular technique used was the nearest neighbour method by which groups are generated according to the distance between single indi-

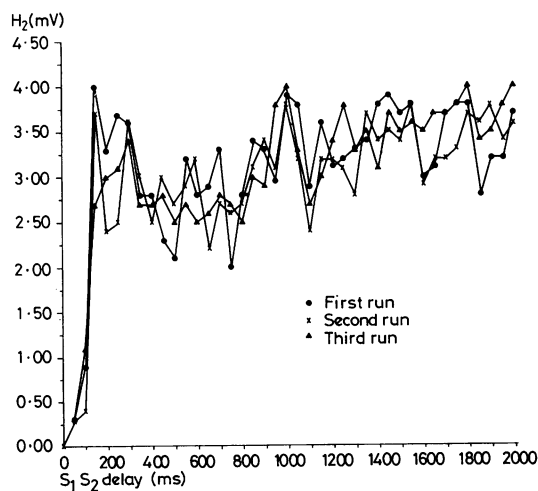


Fig 2 *H*-reflex recovery curve. Equi-interval method. *S*₁-*S*₂ increments of 50 ms. Each curve is a run and each point a single determination. The presence of peaks at 150 and 1000 ms delay are clearly seen. Other smaller peaks may also be present.

viduals, the smallest distance being fused to the group. A detailed account of this technique is given by Johnson.⁸ Each element is agglomerated until some specified minimum number of groups is achieved. The number of groups selected of Hx was three to complement the three curve types. The descriptive statistics for each cluster are summarised in table 1.

If the hypothesis that the value of Hx is correlated with curve type holds, then a cross tabulation of Hx-cluster with curve type should demonstrate that curves with sinusoidal properties will occur predominately in cluster one (high Hx) to some extent in cluster two (medium Hx), and rarely in cluster three (low Hx). Likewise, curves with monotonically increasing properties should occur predominately in cluster three (low Hx), to some extent in cluster two (medium Hx), and rarely in cluster one (high Hx). The third category of curve type should not be skewed with respect to any one category.

Table 2 summarises the results. Oscillatory curve types are contained almost exclusively (28/31 or 90.3%) in the high and medium Hx clusters. Cluster one consists of 84.6% (11/13) oscillatory curve type, while cluster two consists of 65.4% (17/26) and cluster three contains only 16.7% (3/18) of that type. The low Hx cluster consists of 72.2% of such curves. The third group of curves is not skewed over the clusters. The chi-square value for table 2 is 17.4438 for 4 degrees of freedom ($p < 0.001$).

Table 1 Values for Hx in each cluster

Statistic	Cluster one (High H _x)	Cluster two (Medium H _x)	Cluster three (Low H _x)
Mean	106.7	70.5	31.6
Standard deviation	12.73	9.63	9.39
Median	106.0	71.0	31.0
N—% Total	13—22.8%	26—45.6%	18—31.6%

Table 2 Crosstabulation of Hx clusters and curve groups

Clusters	Groups			Total
	One (Oscillatory)	Two (Monotonic)	Three (Uncertain)	
One (High H _x)	11 (35.5%)	1 (4.8%)	1 (20.0%)	13 (22.8%)
Two (Medium H _x)	17 (54.8%)	7 (33.3%)	2 (40.0%)	26 (45.6%)
Three (Low H _x)	3 (9.7%)	13 (61.9%)	2 (40.0%)	18 (31.6%)
Total	31 (54.4%)	21 (36.8%)	5 (8.8%)	57

Given the high predictability of curve type from Hx, we sought other possible associated features. Correlations were sought between S1 S2 delay at the onset of recovery, at Hx, at Hy (the value of H2/H1% for the first trough following Hx), and at 100% recovery. None of these measures approached statistical significance as predictors of curve type. It is possible that some combination of measures would be more accurate predictors of curve types and might lead to more refined delineation of curves.

Discussion

The H-reflex recovery curve consists of not just a "primary" and "secondary" facilitation. In some cases there are tertiary and higher order facilitations of diminishing amplitude as recovery becomes complete. In the case of the recovery curve illustrated in fig 2, recovery is quite possibly not a matter of one or two but of many facilitations. A more detailed analysis of this curve and others generated with small equi-interval S1S2 delays may permit a more precise mathematical expression of the recovery function. Preliminary mathematical modelling has suggested that recovery curves can be mathematically approximated by a function that includes an exponential component. Not all individuals have clearly oscillatory recovery. In some cases recovery appears to follow an exponential function only, with little or no oscillatory behaviour. Such curves may be classified as "overdamped" (for example, fig 1c).

Oscillatory behaviour of neuro-muscular systems is common, for example, in rhythmic heartbeat and respiration. Such oscillatory movement can arise from a number of sources. Oguztoreli and Stein⁹ list five sources: intrinsic muscular oscillation, load interaction oscillation, oscillations due to instabilities in neural feedback control mechanisms, oscillations contained within the CNS, and oscillation imposed by another oscillatory system. Intrinsic oscillations are not observable under normal conditions. Phenomena like "physiological" tremor (8–12Hz) generally fall into the load-interaction category.^{7–10} Parkinsonian tremor and that of cerebellar diseases (4–6 Hz) probably fall into the central generation category¹¹ or the imposed category.¹² The source of oscillations described here is not immediately apparent, although the most likely sources are probably oscillations in the stretch-reflex servo-loop. Other possible mechanisms to be considered are long-loop supraspinal influences,¹³ and Renshaw cell recurrent inhibition.¹⁰ It is interesting to note the

probable identification of oscillatory H-reflex recovery curves in other recent studies. Hayes *et al*¹⁴ comment tentatively on a 12.5 Hz periodicity to H-reflex recovery curves and Katz *et al*¹⁵ present data that could well be most accurately described by an oscillatory function (for example, their fig 4). In both cases, the oscillatory features of the recovery curve were revealed by studying the recovery curve with small (25–100 ms) inter-stimulus intervals.

The data suggest that an important determinant of the shape of the H-reflex recovery curve is the frequency and extent of damping of oscillations in the system. The amplitude of the secondary facilitatory peak and the depth of the following trough would then be significantly affected by the amplitude and frequency of the underlying oscillations.

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