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SPINAL REFLEXES AS INDICATOR OF  
MOTOR PREPARATION IN MAN

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**SPINAL REFLEXES AS INDICATOR OF  
MOTOR PREPARATION IN MAN**

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## Summary

During a fixed foreperiod (4 s) of a reaction time experiment with 80 subjects Hoffmann (H) and Achilles Tendon (T) reflexes were simultaneously evoked in both legs in a pseudo random order at 13 different measuring points. Subjects had to respond after the response signal by a plantar flexion of either the right or left foot. Thus, reflexes were evoked via the motoneuron pool relevant for the response and the homologous pool. The time course of amplitude changes in both legs, involved and non involved in the response were investigated. With H reflexes no difference between the amplitudes in involved and non involved muscles was found. T reflexes showed a selective increase of amplitudes in the involved leg during at least the last 500 ms before the presentation of the response signal. This effect presumably is part of a motor preparation process in which the gamma motoneurons seem to play an important role. In the beginning of a session amplitudes in the non involved leg also are larger. At the end this effect is no longer present. Subjects learn to activate selectively the motoneuron pool, relevant for the response to be given.

Preparation for a standard movement can be investigated in reaction time (RT) experiments with a fixed inter-stimulus-interval (ISI) between a warning stimulus (WS) and the response stimulus (RS). The use of a WS causes a shortening of the mean RT. This performance improvement implies an earlier discharge of the motoneurons innervating the muscles, used to respond with.

The excitability of these motoneurons may be estimated by means of monosynaptic reflexes evoked via the same motoneuron pool (Gerilowsky & Tsekov, 1975; Paillard, 1955; Requin, 1969). Changes in amplitude indicate changes in the output of the motoneuron pool and are consequently an index of fluctuations in (1) motoneuron excitability and (2) presynaptic inhibition of the Ia fibres, which conduct the afferent volley to the motoneuron pool. The present study will be limited to the recording of the amplitudes of reflexes, evoked via the motoneuron pool involved in a standard movement.

This standard movement is a plantar flexion of the foot, made as quickly as possible after the RS. The reflexes are evoked in the calf muscles by mechanical or electrical stimulation. A tap on the Achilles tendon, stretching the intrafusal fibres of the muscle spindles, causes a depolarization of the alpha motoneurons. The sensitivity of the muscle spindles is conditioned by the fusimotor neurons. Thus, the amplitude of the tendon (T) reflex is an index of changes in the excitability of both alpha and gamma motoneurons. The Hoffmann (H) reflex is evoked by electrical stimulation of the Ia afferent fibres of the tibial nerve in the popliteal fossa, thus bypassing the muscle spindle. Hence, the amplitudes are considered an index of

changes in the excitability of the alpha motoneurons.

In the experiments to be presented we evoked H or T reflexes simultaneously in both legs at different moments of the ISI. The response had to be given by one leg. This provides the opportunity to study the time course of changes in the output of motoneuron pools, involved and not involved in the response. Up to now only ISIs of one s have been investigated (Gerilowski & Tsekov, 1975; Mitchie, Clarke, Sinden & Glue, 1976; Requin, 1969; Requin, Bonnet, Semjen, 1977; Semjen, Bonnet, Requin, 1973). In a study of Papakostopoulos and Cooper (1973) a 2 s ISI was used, but subjects had to respond with their left hand. Because the same paradigm is used in CNV research (Walter, Cooper, Aldridge, McCallum & Winter, 1964) and clear indications of motor preparation have been found, using an ISI of longer duration than the classic one s (Gaillard, 1978; Loveless & Sanford, 1974; Loveless, 1977; Rohrbaugh, Sydulko & Lindsley, 1976), we decided to study reflex amplitude changes during an ISI of four s.

#### Material and methods

Subjects were seated comfortably in a specially devised chair. T reflexes were evoked simultaneously in both legs by means of two Brüel and Kjaer 4809 vibration exciters, H reflexes by constant current square waves of one ms. The tibial nerve was stimulated by a Simon electrode in the popliteal fossa, the anode being placed proximal of the knee.

Presentation of a tone (WS) and of a light (RS) as well as triggering the stimulation equipment was done with a DEC Lab 8E computer. The reflexes were recorded by means of Ag-AgCl electrodes,

attached to the soleus muscles, four cm apart. Peak-to-peak amplitudes were measured on-line.

Each ISI of four s was followed by an inter trial interval (ITI) of 16 s. Reflexes were evoked in a random order, 10 times at each of 13 different measuring points during the ISI: at 100, 200, 300, 500, 1000, 1500, 2000, 2500, 3000, 3500, 3700, 3800 or 3900 ms after the WS. During each ITI reflexes were evoked at random between six and ten s after the RS. For each subject means and standard deviations were calculated per ISI measuring point. The ITI data per subject were taken together and considered one point. The values of the 13 different measuring points were expressed as a percentage of the mean ITI level.

Two experiments were carried out, one with H, the other with T reflexes. Each experiment consisted of two conditions. Half of the subjects had to respond with their right foot, the other half with their left one. The data of the involved leg from both conditions were taken together, as were those of the non-involved leg. Each condition was performed by 20 subjects of both sexes. The total range of age was 18-25 years.

To study possible changes in the time course of the amplitudes within one session, the mean of the first and last three reflexes evoked at each measuring point were calculated per subject as well.

An analysis of variance (Anova) with a two factor design: "involvedness" and "measuring points" with repeated measurements

was carried out on the scores of each experiment. Separate analyses were carried out for the five measuring points of the last s of the ISI. The first and last group of three reflexes were analyzed per experiment by an anova with a two factor design: "first-last" and "measuring points" with repeated measurements. This was done for the data of the involved and the non involved leg separately.

### Results

The results are presented in Figures 1, 2 and 3 and Tables 1, 2 and 3.

H reflexes do not show an involvedness main effect (Table 1). The measuring point main effect indicates changes in amplitude in the course of the ISI. This effect is only significant in the first three s of the ISI (Table 1). Mean amplitudes during the ISI are larger than during the ITI (Figure 1). No significant interaction is found. Comparable results are present when the mean amplitudes of the first and last three reflexes per measuring point are studied (Table 2, Figure 2). For both involved and non involved muscles no systematic changes between first and last group are found. (The data of two subjects have been eliminated because they were incomplete). Summarizing, there is no indication of a change in the time course of H reflex amplitudes, specifically related to the involvedness in the reaction.

T reflexes show an involvedness main effect (Table 1). During the last s of the ISI amplitudes are larger in the involved leg (Figure 1). The measuring point main effect indicates

changes in amplitude in the course of the ISI. An early increase is present from 100 - 300 ms after the WS in both the involved and non involved leg (Figure 1). Mean amplitudes during the ISI are larger than during the ITI. The significant interaction implies a different time course of the reflexes in the involved and non involved leg. A significant first-last main effect in the non involved leg is found. This effect is also significant in the last s of the ISI. This indicates that reflex amplitudes during the last s of the ISI are larger in the beginning of the experiment than at the end. A similar effect is not present in the involved leg. As can be seen in Figure 3 only a slight decrease during the last s of the ISI is found: amplitudes remain at a higher level. Summarizing, a selective increase of T reflex amplitudes is found in the involved leg at least 500 ms before the RS is presented.

### Discussion

H reflexes show a slight increase of amplitudes to the end of the ISI. This effect is not different for involved and non involved muscles. Thus, there is no indication for a specific motor preparation phenomenon. No systematic differences are found between the beginning and the end of the experiment. This implies that no habituation is present.

T reflexes show an early increase some hundreds of ms after the WS, which is not different for involved and non involved muscles. Thus, a relation to motor preparation is not probable. In both cases amplitudes are larger in the beginning than at the end of the experiments, which is likely to be due to habituation. To the end of the ISI a selective late increase of amplitudes is present in the involved leg only. This might be



part of a motor preparation process. If the mean amplitude of the first and last group of reflexes during the last s of the ISI are compared, an interesting difference between the involved and non involved leg is present (Figure 3). In the non involved leg a significant decrease of amplitudes is found, whereas in the involved leg the amplitudes remain at a rather constant level (Table 3). Apparently, in the beginning of the experiment the excitability of the motoneuron pool of the homologous non involved muscle also is increased. Later on this effect becomes restricted to the motoneuron pool involved in the response. This might be due to a learning process. A further argument for the interpretation of the late increase as part of a motor preparation process is the lack of this effect when the response has to be given by hand (Brunia, 1979).

The early increase of T reflex amplitudes is present in both the involved and non involved calf-muscles. Similar findings have been reported by Requin, Bonnet and Semjen (1977), who studied H reflexes during an ISI of one s. An increase of H reflex amplitudes after presentation of a sound has also been found by Mellvill Jones, Watt and Rossignol (1973), whereas the knee jerk shows a similar increase after an auditory stimulus (Beale, 1971). In the latter case no motor response had to be given. Davis and Beaton (1968) report a differential effect of tones of different intensity, the stronger stimulus being followed by larger reflex amplitudes. A final argument might be the comparable increase after a WS found when the response has to be given by hand (Brunia, 1979). Thus, the early increase seems to be related to the WS rather than to the RS.

Nevertheless, Gottlieb and Agarwal (1973 a) point to a considerable similarity of the early facilitation after an audio-visual stimulus and the facilitation observed in the active limb during voluntary contraction. In contrast to this opinion we think to be confronted with two different processes. One is an increase of amplitudes, due to an audiospinal facilitation of the motoneurone pool (Mellvill Jones et al. 1973), the other is an increase due to motor preparation. In the experimental set up of Gottlieb and Agarwal (1973 a) it is not possible to discriminate between the two processes, because their audio-visual signal is followed immediately by a voluntary movement. In other words they make their subjects perform a reaction time (RT) experiment, without a foreperiod. A RT experiment with a foreperiod (ISI) gives a better possibility to study motor preparation. If the length of the ISI is sufficiently long, the discrimination between the two processes becomes possible, because of their different time course.

It has been argued for some time, that not facilitation, but inhibition is the important process in motor preparation (Gerilowsky and Tsekov, 1975; Requin, 1969; Requin and Paillard, 1971). Thus, Requin et al (1977) report after the early increase in amplitudes a decrease, which reaches its lowest value at 900 or 1000 ms. This decline, being interpreted as inhibition, seems to be a very general phenomenon: their H reflex amplitudes show the same time course during an ISI of one s, both when agonistic or antagonistic movements of the foot are made by the subjects.

Our H reflexes do not show the inhibition, mentioned by

Requin et al (1977), although there is a slight decrease from 200 to 1000 ms after the WS. (Wilcoxon matched pairs signed ranks test:  $p < 0.10$  for the involved,  $p < .04$  for the non involved side). This discrepancy might be caused by the differently chosen zero level. Requin et al. (1977) take the moment the WS is presented or 200 ms earlier as reference, whereas in our experiments the reflexes evoked at random in the middle of the ITI have that function. If anticipation of the WS or its presentation causes a relative increase of the motoneuron excitability, then the zero level at 200 ms before or at the very presentation of the WS is larger than in our experiments. Consequently the decrease after the early top at 100-200 ms reaches lower levels. This could imply that the decrease is nothing more than a disfacilitation or the end of a disinhibitive process.

The use of a larger ISI in our experiments reveals at the end of the ISI a new process, i.e. a selective increase of T reflex amplitudes on the involved side. This late increase is present during the whole experiment, whereas on the non involved side it is found in the beginning of the experiment only. These results are in contrast to the data found when the response had to be given by hand. In that case no increase in the excitability of the motoneurons of the calf muscles is recorded (Brunia, 1979). This might indicate that subjects in the course of the experiment learn to activate selectively the motoneuron pools, relevant for the response to be given, while they initially activated the homologous but non involved muscles as well.

The different reaction of H and T reflexes might be realized by a specific element in the T reflex circuitry. The

supposition that the fusimotor outflow might be increased without a parallel rise in skeletomotor activity is not in line with the alpha-gamma coactivation, which has been found during voluntary contraction (Hagbarth and Vallbo, 1968; Vallbo, 1973).

However, preparation for a movement and the very execution of that movement may be differently realized. This implies that a selective rise of fusimotor outflow in the situation we studied, remains possible. A further insight into this problem might be obtained by single fibre studies, using the same paradigm. If coactivation will be proven to be present, than the selective T reflex increase has to be explained otherwise. The Ia fibres, stimulated electrically perhaps are partly different from the fibres which are activated by a tap on the tendon. In that case a selective disinhibition of the latter could explain the results too.

So far we have found an increase of reflex amplitudes at two different moments during the ISI. At the first glance one might be inclined to relate the late increase during the ISI to the increase, reported by different authors prior to a voluntary movement. Thus, Pierrot-Deseilligny, Lacert and Cathala (1971) recorded an increase of H and T reflex amplitudes in an involved leg 80 ms prior to gastrocnemius-soleus contraction. Other data, pointing to a final increase of amplitudes before the movement are reported by Coquery and Coulmance (1971), Gottlieb and Agarwal (1973 a,b), Kots (1969) and Mitchie, Clarke, Linden and Glue (1975). However, there is an important difference. The rise in amplitudes found in their studies, is closer time-locked to the movement than in our experiments, for in the latter case it still takes 200-350 ms after the RS before the response is

given. This implies that after the presumably selective rise in excitability of the involved gamma motoneurons, new processes follow, which are of final importance for the movement to be executed.

At least two factors are to be mentioned: the influence of the stimulus properties of the RS, with a possible increase and decrease in motoneuron excitability, comparable to the effect of the WS. Secondly, the final rise in reflex amplitudes in the involved leg, about 100 ms before the movement.

Thus, on the basis of our data and the findings of others, it might be hypothesized that, using a RT paradigm with an ISI of four s, three times an increase of reflex amplitudes can be recorded:

1. An early increase, present in H, but more pronounced in T reflexes. It is related to the properties of the WS.
2. A late increase, which is an element of motor preparation. It concerns selectively the T reflexes.
3. A final increase, presumably again similar for H and T reflexes, which can be recorded just before the onset of the movement. It shows the alpha-gamma coactivation, which is found during the voluntary movement.

#### ACKNOWLEDGEMENT

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TABLE 1

Anova's on amplitudes of T and H reflexes evoked in involved and non involved muscles

	Complete ISI		Last second of ISI	
	df	F	df	F
T REFLEX				
involvedness	1,39	4.127*	1,39	8.065**
measuring point	12,468	10.593****	4,156	11.576****
involvedness X measuring point	12,468	3.646****	4.156	3.179*
H REFLEX				
involvedness	1,39	1.570	1,39	0.739
measuring point	12,468	10.400****	4,156	2.183
involvedness X measuring point	12,468	0.556	4,156	1.061

\* $p < .05$     \*\* $p < .01$     \*\*\* $p < .001$     \*\*\*\* $p < .0001$

TABLE 2

Anova's on amplitudes of H reflexes in non involved and involved muscles

NON-INVOLVED MUSCLE	Complete ISI		Last second of ISI	
	df	F	df	F
first / last measuring point	1,37	1.165	1,37	0.464
first / last X measuring point	12,444	2.728 <sup>xx</sup>	4,148	3.506 <sup>xx</sup>
	12,444	1.038	4,148	0.830
INVOLVED MUSCLE	df	F	df	F
first / last measuring point	1,37	0.535	1,37	0.285
first / last X measuring point	12,444	5.837 <sup>xxxx</sup>	4,148	0.795
	12,444	1.770	4,148	1.970

<sup>x</sup>p < .05      <sup>xx</sup>p < .01      <sup>xxx</sup>p < .001      <sup>xxxx</sup>p < .0001



TABLE 3

Anova's on amplitudes of T reflexes in non involved and involved muscles

NON-INVOLVED MUSCLE	Complete ISI		Last second of ISI	
	df	F	df	F
first / last	1, 39	27.174 <sup>xxxx</sup>	1, 39	9.955 <sup>xx</sup>
measuring point	12, 468	3.172 <sup>xxx</sup>	4, 156	1.378
first/last X measuring point	12, 468	2.192 <sup>x</sup>	4, 156	1.918
INVOLVED MUSCLE	df	F	df	F
first / last	1, 39	2.115	1, 39	1.252
measuring point	12, 468	5.449 <sup>xxxx</sup>	4, 156	6.656 <sup>xxx</sup>
first/last X measuring point	12, 468	1.136	4, 156	0.891

<sup>x</sup>p < .05

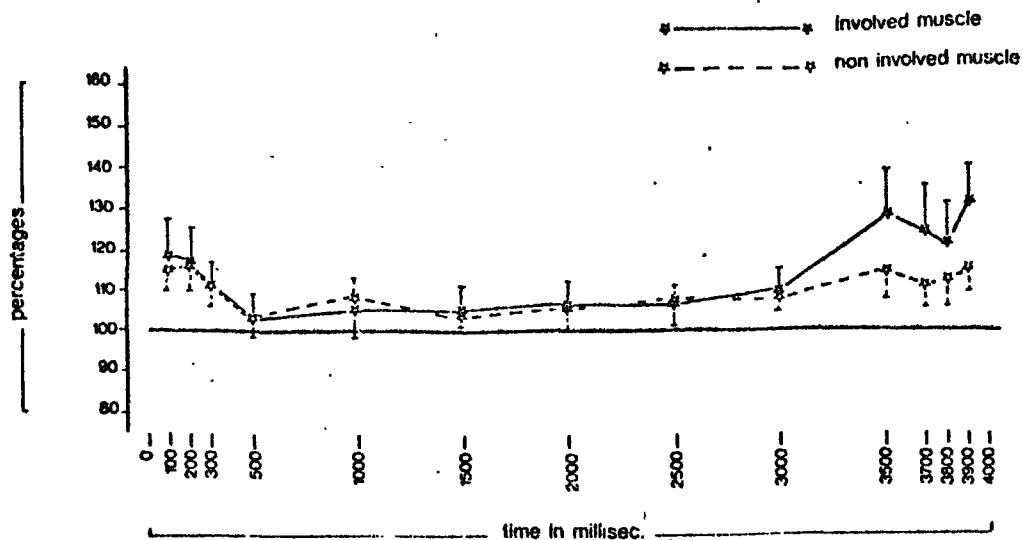
<sup>xx</sup>p < .01

<sup>xxx</sup>p < .001

<sup>xxxx</sup>p < .0001

### ACHILLES TENDON REFLEX

RESPONSE: FOOT



### HOFFMANN REFLEX

RESPONSE: FOOT

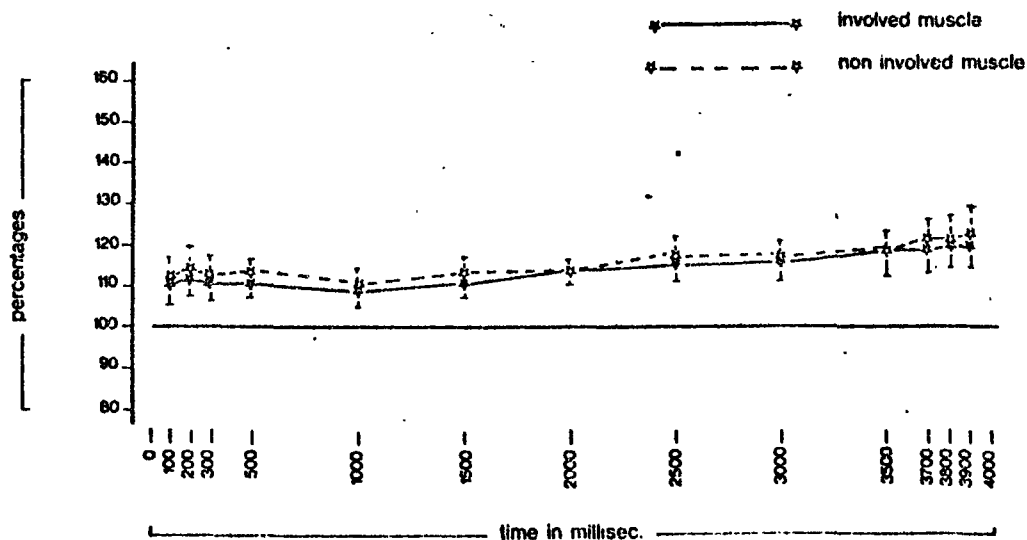
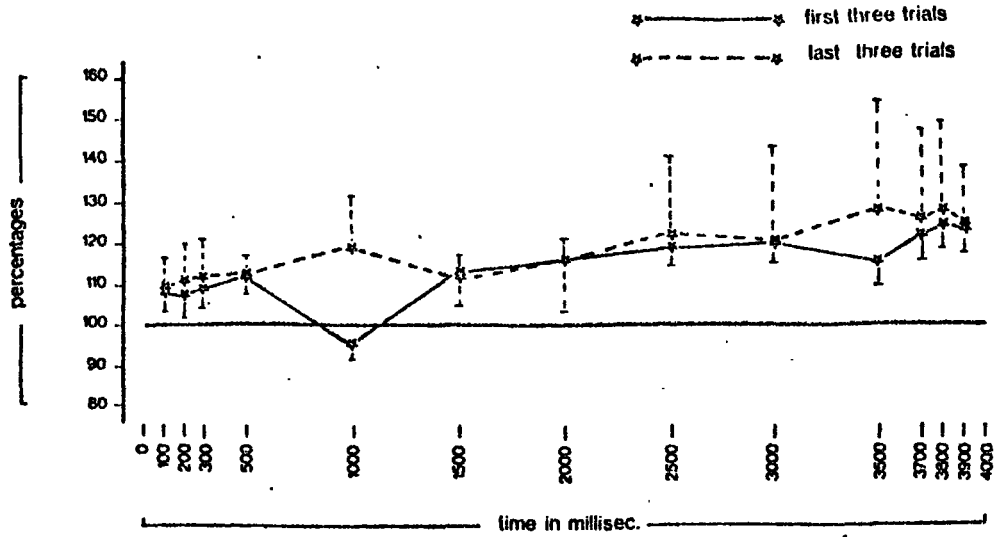


Figure 1: Mean amplitudes of H and T reflexes, evoked in involved and non involved muscles at 13 different measuring points of an ISI of 4 s. The reflexes recorded during the ITI per subject are taken as control (= 100%). Data of 40 subjects are averaged. Vertical lines indicate the 95% level of confidence. Note that the ISI amplitudes are larger than the mean ITI level.

### HOFFMANN REFLEX

RESPONSE: FOOT  
INVOLVED MUSCLE



### HOFFMANN REFLEX

RESPONSE: FOOT  
NON INVOLVED MUSCLE

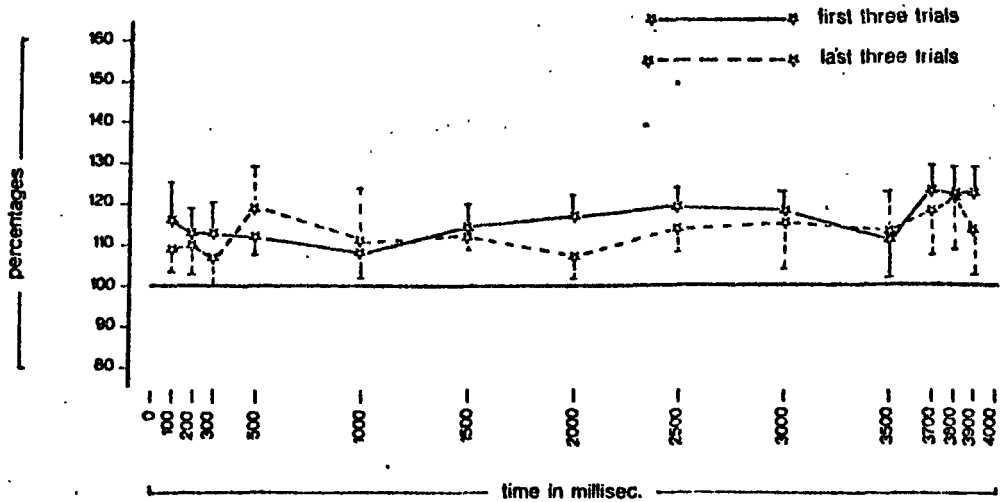
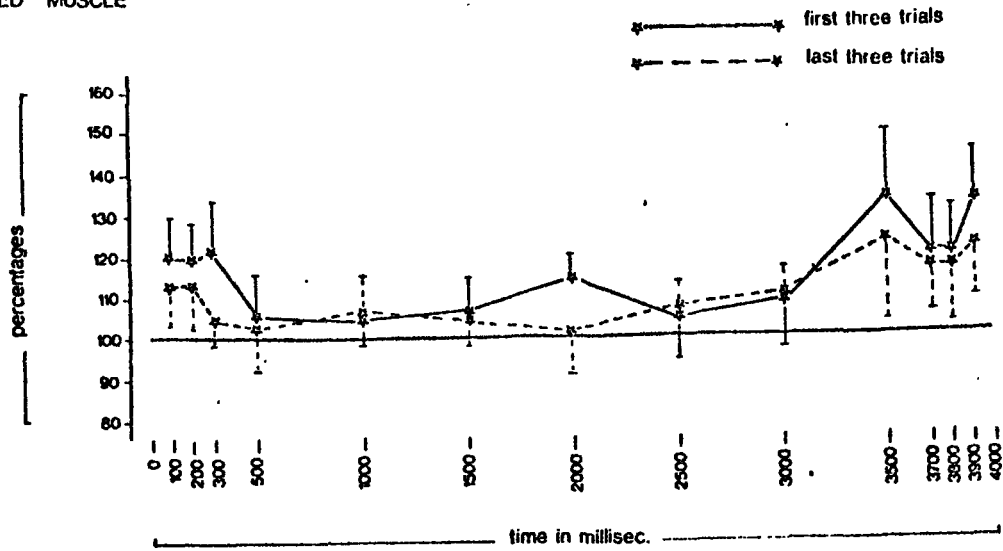


Figure 2: Mean amplitudes of H reflexes, evoked in a non involved and involved muscles. The mean of the first and last three amplitudes per measuring point is calculated per subject and expressed as percentage of the mean ITI level. The data are averaged over 38 subjects. Vertical lines indicate the 95% level of confidence.

### ACHILLES TENDON REFLEX

RESPONSE: FOOT  
INVOLVED MUSCLE



### ACHILLES TENDON REFLEX

RESPONSE: FOOT  
NON INVOLVED MUSCLE

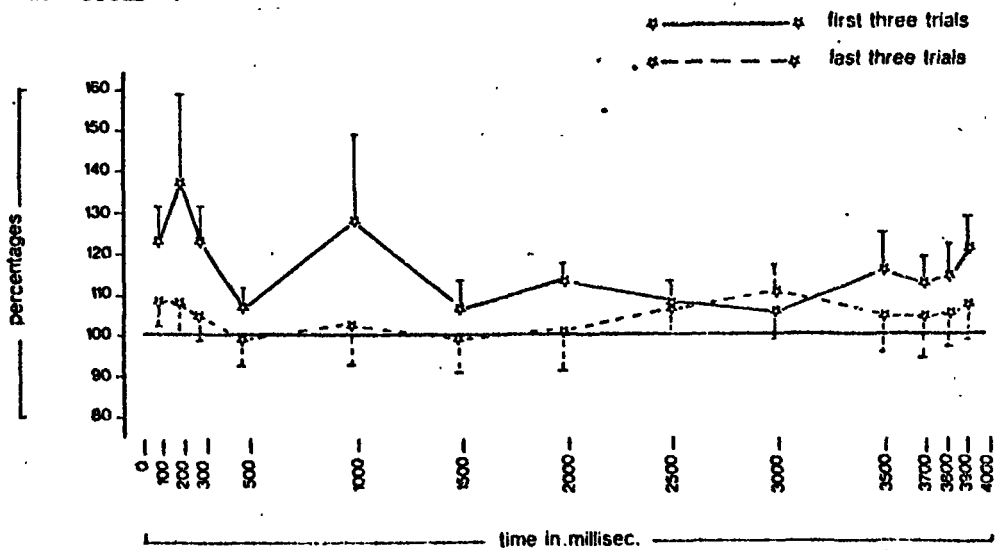


Figure 3: Mean amplitudes of T reflexes, evoked in a non involved and involved muscles. The mean of the first and last three amplitudes per measuring point is calculated per subject and expressed as percentage of the ITI. The data are averaged over 40 subjects. Vertical lines indicate the 95% level of confidence.

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