Exp Brain Res (2002) 145:126–129
DOI 10.1007/s00221-002-1098-5

RESEARCH NOTE

I. Hammar · U. Slawinska · E. Jankowska

A comparison of postactivation depression of synaptic actions evoked by different afferents and at different locations in the feline spinal cord

Received: 26 November 2001 / Accepted: 6 March 2002 / Published online: 16 May 2002
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Abstract Postactivation depression of synaptic actions of group I and II muscle afferents and low threshold cutaneous afferents was compared with depression of actions of group Ia afferents on α-motoneurones in cats deeply anaesthetised with pentobarbital and α-chloralose. The depression was analysed on field potentials (population EPSPs). The degree of depression was evaluated by analysing changes in the monosynaptic components of the field potentials, in areas within 0.4- to 0.6-ms-long time windows from their onset. When intervals between successive stimuli used to evoke field potentials were reduced from 10 s to 0.4 s, the potentials evoked by Ia afferents in motor nuclei were depressed as described previously. Field potentials evoked by group II afferents and cutaneous afferents in the dorsal horn were similarly depressed. In contrast, monosynaptic components of field potentials evoked in the intermediate zone, by group I or II afferents, were only marginally affected. Postactivation depression of synaptic actions of group I afferents in the intermediate zone was not enhanced when test stimuli were applied 30–40 ms after a train of four conditioning stimuli. These observations indicate that the degree of postactivation depression may differ depending on the type of afferent. In addition, if postactivation depression depends on intrinsic properties of afferent terminals, differences in the degree of depression of postsynaptic potentials evoked by the same group of afferents at different locations may indicate that properties of terminals contacting different neurones may differ.

Keywords Synaptic transmission · Spinal cord · Group I afferents · Group II afferents

I. Hammar (✉) · E. Jankowska
Department of Physiology, Göteborg University, 405 30 Göteborg, Sweden
e-mail: ingela.hammar@physiol.gu.se
Tel.: +46-31-7733508, Fax: +46-31-7733512

U. Slawinska
Nencki Institute of Experimental Biology, 02-093 Warsaw, Poland

Introduction

A long-lasting depression of synaptic actions of afferent fibres following activation of these fibres was first described for actions of group Ia muscle spindle afferents on α-motoneurones (Crone and Nielsen 1989; Hultborn et al. 1996). The depression lasts for several seconds, in contrast to the much shorter lasting presynaptic inhibition evoked by stimulation of other afferents (Nielsen et al. 1993). This postactivation depression has been suggested to be due to a decrease in release probability of synaptic transmitters from terminals of previously active primary afferents (Crone and Nielsen 1989; Hultborn et al. 1996; Kohn et al. 1997).

So far, postactivation depression has only been investigated by analysing effects of group Ia afferents on α-motoneurones, either in cats or in humans (Crone and Nielsen 1989; Nielsen et al. 1993; Voigt and Sinkjaer 1998; Aymard et al. 2000). The aim of the present study was therefore to compare the degree of postactivation depression of synaptic actions of group Ia and other afferents (group Ib, group II and low threshold cutaneous afferents) in order to find out whether effects attributable to postactivation depression are similar for all kinds of afferents. To this end, changes in monosynaptic components of population EPSPs (field potentials) evoked by these afferents were assessed under conditions under which postactivation depression was originally demonstrated. Synaptic actions of group I afferents were compared within and outside motor nuclei and those of group II afferents were compared within the dorsal horn and intermediate zone of the spinal grey matter.

Materials and methods

The reported results were obtained in experiments performed on three deeply anaesthetised cats (2.4–2.8 kg). The anaesthesia was induced with a single dose of sodium pentobarbital (44 mg/kg i.p.) and supplemented with several doses of sodium pentobarbital during surgery (2 mg/kg i.v.) followed by intermittent doses of α-chloralose (up to 50 mg/kg i.v.). The L3–L7 lumbar segments

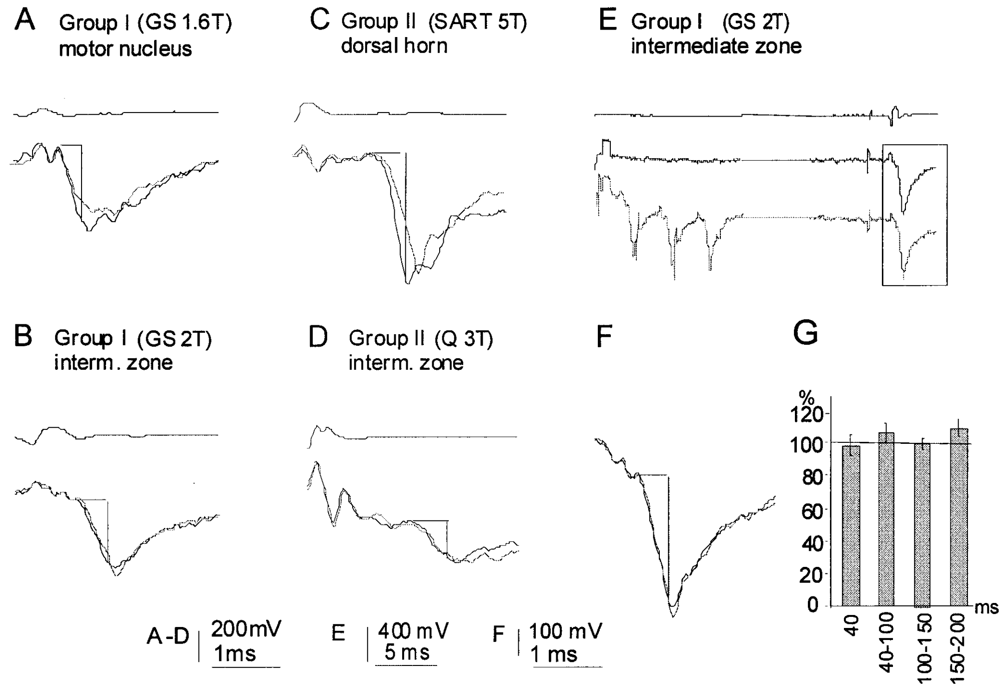

Fig. 1A–G Examples of postactivation depression of field potentials evoked by different afferents and at different locations in the spinal cord. **A–D** Superimposed records of field potentials evoked by single stimuli at intervals of 10 s (*black*) and 400 ms (*grey*) with the afferent origin and location of the potentials indicated above the records. *Dashed lines* show the time windows within which areas and amplitudes were measured. **E** Records illustrating lack of effect of train of conditioning stimuli preceding the test stimuli at an interval of 124 ms (conditioned records *in grey*). **F** Superimposed expanded parts of records within the box in **E**. **G** Means of areas of six field potentials preceded by conditioning stimuli at the indicated time intervals (*abscissa*) as percentages of unconditioned field potentials

were exposed by laminectomy and peripheral hind limb nerves were dissected, transected and mounted on stimulating electrodes; either subcutaneous cuff electrodes [for quadriceps (Q), sartorius (Sart) and saphenus (Saph)] or pairs of silver hook electrodes in a paraffin oil pool [for posterior biceps and semitendinosus (PBST), suralis (Sur), gastrocnemius (GS), deep (DP) and superficial peroneus (SP)]. All the experimental procedures were approved by Göteborg Ethics Committee and followed NIH and EU guidelines of animal care.

Records of field potentials were made using glass micropipettes filled with a 2 M NaCl solution (tip 1.5–2.5 µm, impedance 1.5–3 MΩ) in the L4, L5 and L6 segments. Monosynaptic actions were defined in the following way: for group I afferents, field potentials induced at latencies not exceeding 1 ms, evoked by stimulation of muscle nerves at up to 2 times threshold (T); for low threshold cutaneous afferents, field potentials at latencies up to 1 ms, evoked by stimulation of a skin nerve at 1.2–2 T; and for group II afferents, field potentials at latencies of 1.5–2.5 ms, evoked at stimulus intensities of 3–5 T (see Edgley and Jankowska 1987). The areas of the earliest components (0.4–0.6 ms from their onset) were compared, using averages of ten successive field potentials. Two experimental paradigms were used. The first paradigm was used for all investigated afferents and involved applying single stimuli to the same nerve at different intervals (10 s, 5 s, 2 s, 1 s, 500 ms, 400 ms). Since no postactivation depression was previously found after stimulus intervals of 10 s, field potentials evoked at 10-s intervals were used as a control. The second paradigm was used only in tests involving field potentials evoked by group I afferents in the intermediate zone. In this case, single stimuli applied to a muscle nerve at 2 Hz were or were not preceded by conditioning stimuli (a train of three or four stimuli at 300 or 400 Hz) applied to the same nerve. The conditioning-testing intervals were between 40 and 200 ms. Only extensor muscle nerves (GS, Pl, Q) were used in view of a much weaker presynaptic inhibition of group I afferents from extensors, from which postactivation depression had to be differentiated at these shorter intervals. Statistical significance was calculated using the Wilcoxon signed rank test.

Results

Synaptic actions of group I as well as of group II muscle afferents and low threshold skin afferents were found to display postactivation depression, but only at certain locations. At other locations the postactivation depression was absent or negligible. These differences are exemplified in Fig. 1 with individual records and are summarized in Fig. 2.

Field potentials evoked in GS and PBST motor nuclei (n=5) by group Ia afferents at 400- to 500-ms interstimulus intervals were found to be reduced to 80%, as compared to those evoked at interstimulus intervals of 10 s. The degree of the depression illustrated in Figs. 1A and 2A is of the same order as that (75%) reported previously for EPSPs recorded in individual α-motoneurones (Hultborn et al. 1996). However, only marginal postactivation depression of group I evoked field potentials (n=10) was found in the intermediate zone. The plots in Figs. 1B and 2B show that the area of group I components of intermediate zone field potentials was hardly decreased with the decrease in the interstimulus intervals and that individual field potentials, evoked at intervals of 10 s and 400 ms respectively, practically overlapped. In an attempt to increase the effect of postactivation depression at this location, single stimuli delivered at 2 Hz were preceded by trains of conditioning stimuli. However, even this procedure failed to enhance postactivation depression. This is illustrated with records in Fig. 1E, where field potentials evoked with and without preceding conditioning stimuli are compared. The expanded rightmost parts of these records in Fig. 1F show that they fully overlapped. Data for all field potentials (n=6) tested in this way are summarised in Fig. 1G,

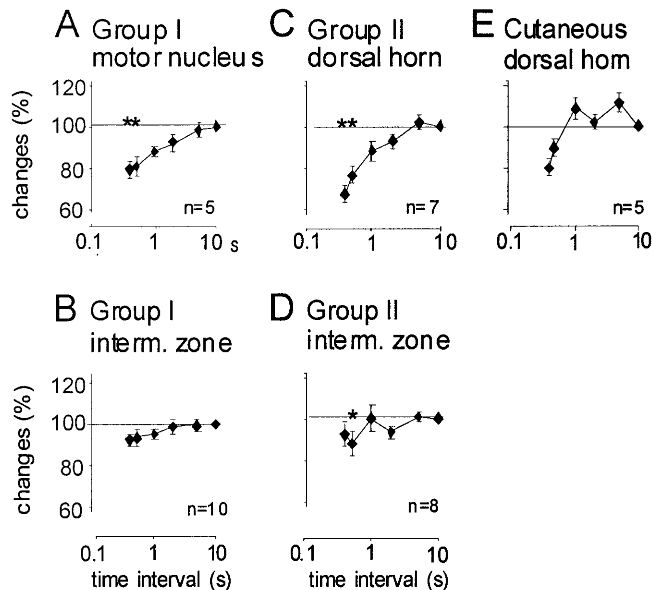

Fig. 2A–E Mean changes in field potentials evoked by group I, group II and cutaneous afferents as a function of stimulus repetition rate. The areas of monosynaptic components of field potentials are plotted against time intervals between successive stimuli. The afferent origin and the number and location of the potentials are indicated in each panel. Potentials were evoked by afferents in GS and PBST **(A)**, Q and GS **(B)**, Q and Sart **(C)**, Q **(D)** and Saph **(E)** [*ordinate* mean areas (%) of control and standard errors of means; *abscissa* time intervals between successive stimuli on a logarithmic scale; *asterisks* indicate statistically significant differences]

where areas of conditioned potentials at conditioning-testing intervals between 40 and 200 ms are plotted. No postactivation depression of any of these field potentials was found at any of the tested intervals.

Effects of postactivation depression of field potentials evoked by group II afferents in the intermediate zone (n=8) were almost as marginal as those on group I evoked potentials at the same location, as shown in Figs. 1D and 2D. For the shortest intervals, a small decrease (to 89% at a stimulus interval of 500 ms) was found to be statistically significant. In contrast, the degree of postactivation depression of dorsal horn field potentials evoked by group II afferents (n=7) was considerable. The area was reduced to 68% for stimulus intervals of 400 ms, as illustrated with single records in Fig. 1C and summarized in Fig. 2C. The depression was even more pronounced and longer lasting than the depression of group Ia evoked field potentials in motor nuclei.

Postactivation depression of field potentials evoked by low threshold cutaneous fibres (n=5) was potent when induced at short stimulus intervals (to 78% at 400-ms intervals, Fig. 2E), but the effect was shorter lasting than on field potentials evoked by either group I or group II afferents and was only marginal at intervals of 1 s or longer.

Discussion

The results of this study show that postactivation depression affects synaptic actions of not only group I afferents but also of group II and low threshold cutaneous afferents. They further show that synaptic actions of the same kind of afferents, and most likely of axons collaterals of the same afferents, may be depressed to different degrees in different areas of the spinal grey matter. The topographically related differences are most striking in the case of group II afferents since morphological studies show that collaterals of the same afferent fibre terminate within the dorsal horn and within the intermediate zone (for references see Jankowska 1992), where they synapse with different types of neurone (Edgley and Jankowska 1987). Minimal or negligible postactivation depression of synaptic actions of group I afferents in the intermediate zone is more difficult to interpret since both group Ia and Ib afferents evoke field potentials at this location. It is, however, likely that at least some postactivation depression of field potentials recorded in the intermediate zone ought to have been seen if actions of Ia afferents in the intermediate zone and in motor nuclei were similarly depressed. It should be stressed in this context that no major differences have been found in the degree of postactivation depression of population EPSPs evoked by group Ia afferents in motor nuclei (Fig. 2A) and of EPSPs of individual intracellularly recorded motoneurones in the original study of Hultborn et al. (1996).

Differences in postactivation depression at different locations suggest that local intrinsic factors may influence the degree of the postactivation depression. It may be due to intrinsic properties of terminals of the afferents (see Hultborn and Nielsen 1998), but a receptor desensitisation within the previously activated synapses could contribute to it as well (Lev-Tov and Pinco 1992). Differences in postactivation depression of synaptic actions of the same afferents at different locations found in this study would also suggest that properties of individual collaterals on which the postactivation depends may be differentially modulated by different target neurones of these collaterals.

Acknowledgement The study was supported by a grant from the Parkinson Association for Neurological Movement Analysis Studies.

References

Aymard C, Katz R, Lafitte C, Lo E, Penicaud A, Pradat-Diehl P, Raoul S (2000) Presynaptic inhibition and homosynaptic depression: a comparison between lower and upper limbs in normal human subjects and patients with hemiplegia. Brain 123:1688–1702

Crone C, Nielsen J (1989) Methodological implications of the post activation depression of the soleus H-reflex in man. Exp Brain Res 78:28–32

Edgley SA, Jankowska E (1987) An interneuronal relay for group I and II muscle afferents in the midlumbar segments of the cat spinal cord. J Physiol Lond 389:647–674

Hultborn H, Nielsen J (1998) Modulation of transmitter release from Ia afferents by their preceding activity – a "postactivation depression". Ann N Y Acad Sci 860:178–191
Hultborn H, Illert M, Nielsen J, Paul A, Ballegaard M, Wiese H (1996) On the mechanism of the post-activation depression of the H-reflex in human subjects. Exp Brain Res 108:450–462
Jankowska E (1992) Interneuronal relay in spinal pathways from proprioceptors. Prog Neurobiol 38:335–378
Kohn AF, Floeter MK, Hallett M (1997) Presynaptic inhibition compared with homosynaptic depression as an explanation for soleus H-reflex depression in humans. Exp Brain Res 116:375–380
Lev-Tov A, Pinco M (1992) In vitro studies of prolonged synaptic depression in the neonatal rat spinal cord. J Physiol 447:149–169
Nielsen J, Petersen N, Ballegaard M, Biering-Sorensen F, Kiehn O (1993) H-reflexes are less depressed following muscle stretch in spastic spinal cord injured patients than in healthy subjects. Exp Brain Res 97:173–176
Voigt M, Sinkjaer T (1998) The H-reflex in the passive human soleus muscle is modulated faster than predicted from post-activation depression. Brain Res 783:332–346