Spinal Interneurons That Receive Input From Muscle Afferents Are Differentially Modulated by Dorsolateral Descending Systems

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Spinal interneurons that receive input from muscle afferents are differentially modulated by dorsolateral descending systems. J Neurophysiol 85: 1005–1008, 2001. The possibility that descending systems have differential actions on the spinal interneurons that receive input from muscle afferents was investigated. Prolonged, physiological inputs were generated by stretch of the triceps surae muscles. The resulting firing patterns of 25 lumbosacral interneurons were recorded before and during a reversible cold block of the dorsolateral white matter at the thoracic level in nonparalyzed, decerebrate preparations. The strength of group I muscle afferent input was assessed from the response to sinusoidal tendon vibration, which activated muscle spindle Ia afferents directly and tendon organ Ib afferents via the resulting reflex force. The stretch-evoked responses of interneurons with strong responses to vibration were markedly suppressed by dorsal cold block, whereas the stretch-evoked responses of interneurons with weak vibration input were enhanced. The methods most strongly activated by vibration received their primary input from Ia afferents and all of these cells were inhibited by the cold block. These results suggest that a disruption of the descending system, such as occurs in spinal cord injury, will lead to a suppression of the interneuronal pathways with group Ia input while enhancing excitability within interneuronal pathways transmitting actions from higher threshold afferents. One possible consequence of this suppression would be a decreased activity among the Ia inhibitory interneurons that mediate reciprocal inhibition, resulting in abnormal reciprocal relations between antagonists and promoting anomalous muscle cocontraction.

METHODS

The extracellular discharge patterns of 25 stretch-responsive interneurons were recorded in the lumbosacral cord (L7–S1) before and during reversible, bilateral cold block of the dorsolateral white matter at T10–L1 in eight unparalyzed, decerebrate cats. Surgical preparations, including the precollicular decerebration, were carried out under gaseous anesthesia (1.5–3.0% isoflurane in a 3:1 mixture of N2O and O2) at temperatures of 30–34°C. We evaluated the hypothesis that tonically active descending tracts in the dorsolateral quadrants of the cord have differential effects on propriospinal interneurons, with the pattern of facilitation or inhibition depending on the strength of the interneurons’ input from Ia afferents. A portion of these results has been presented in abstract form (Chen et al. 1998).

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of each interneuron throughout the experimental protocols to assure that the same cell was recorded before and during cold block. Electrical stimuli to these unparalyzed preparations were avoided to minimize risk of destabilizing the recording conditions. However, the L7 ventral root was stimulated at 1.5 times threshold to evoke a muscle twitch to aid in identifying the type of muscle afferent input (see RESULTS). Cells with the following characteristics were considered motoneurons and not further studied: an antidromic response to ventral root stimulation or a clear single motor unit action potential in a spike triggered average between the recorded unit and the EMGs of MG and LGS.

Sustained firing patterns were evoked by physiological inputs. The strength of input from group I muscle afferents was assessed from the average firing rate evoked by tendon vibration (180 Hz, 80 μm), which selectively activates muscle spindle Ia afferents and, via the reflexively generated force, also activates Golgi tendon organ Ib afferents (Matthews 1972). A moderate stretch (2.5 mm at 40 mm/s) superimposed in the middle of a period of vibration was used to generate strong firing in muscle spindle group II afferents (Matthews 1972). A larger ramp and hold stretch (5 mm at 40 mm/s) was applied by itself to simultaneously activate a wide range of muscle afferents, including free nerve endings (Cleland and Rymer 1993).

RESULTS

The firing patterns of an interneuron with strong input from the group I afferents activated by tendon vibration are illustrated in Fig. 1, A and B. The vibration evoked firing at an average of ~160 Hz (Fig. 1A). Furthermore there were brief periods where the firing was phase-locked to the vibration frequency (180 Hz). This cell was the only interneuron recorded that exhibited this phase-locked behavior. The stretch superimposed in the middle of the vibration period evoked only a transient increase in firing. A larger stretch without vibration evoked a peak firing rate of ~300 Hz and a tonic rate of ~100 Hz (Fig. 1B). During dorsal cold block, however, the stretch-evoked response was markedly reduced, with tonic firing rate falling to ~25 Hz.

Cells with a weak or inhibitory response to vibration behaved very differently during cold block. The interneuron illustrated in Fig. 1, C and D, was slightly inhibited by vibration during control conditions. Stretch superimposed on the vibration (Fig. 1C) or by itself (Fig. 1D, solid line) gave strong excitation, suggesting a strong excitatory group II input was superimposed on the Ia inhibition. During dorsolateral cold block, the response to stretch was slightly increased and then was followed by a prolonged afterdischarge (Fig. 1D, thin line).

Figure 2 provides a summary of the effect of cold block on the stretch-evoked responses of all 25 cells. Cells with a strong input from vibration in the control state tended to show reductions in their responses to stretch during cold block, whereas
cells with weak vibration input showed enhanced responses ($r = -0.68$, $P < 0.01$, $n = 25$). Cold block also induced changes in the tonic firing evoked by vibration, and the magnitude of this change was also inversely correlated with the strength of the vibration response in the control state ($r = -0.67$, $P < 0.05$; $n = 18$). Cold block invariably reduced the force during stretch (Fig. 1, B and D) due to the onset of clasp knife inhibition (Cleland and Rymer 1993; Miller et al. 1995). This decrease occurred regardless of whether the firing rate of the cell was increased (Fig. 1D) or decreased (Fig. 1B). Thus changes in firing rate did not correlate with the cold-block-induced decreases in muscle force ($P > 0.05$).

Although all interneurons responded to stretch, only 9 of the 25 cells (see Fig. 2) had response patterns that were consistent with a predominant input from a single type of muscle afferent. Five cells were classified as having a predominant input from muscle spindle Ia afferents, including the one shown in Fig. 1, A and B, on the basis of a vibration-evoked response exceeding 50 Hz and a pause in firing to the ventral root evoked muscle twitch. Two cells were considered group II interneurons, based on a weak response to vibration but a strong response to stretch superimposed on vibration (as illustrated by the cell in Fig. 1, C and D). Only one cell was classified as a Ib interneuron, with firing rate proportional to muscle force and with a burst of firing to the muscle twitch. One cell was considered to have its major input from free nerve endings, having phasic responses to stretch onset and offset (Cleland and Rymer 1993). Well over half (16 of 25) of the sample of cells did not fit readily in these classification schemes. This was not unexpected, because spinal interneurons often get input from multiple muscles, whereas our stretch stimuli were confined to MG and LGS.

Although the numbers of cells in each class were small, it was notable that all five interneurons classified as Ia interneurons were inhibited by dorsal cold block (Fig. 2). The one interneuron with a moderately strong response to vibration but with an increased response to stretch during cold block was the putative Ib interneuron (Fig. 2). This suggests that Ia input is the predominant factor determining whether the descending input eliminated by the cold block was excitatory or inhibitory. Furthermore the relationship shown in Fig. 2 remained statistically significant ($r = -0.64$; $P < 0.01$) even when the analysis was restricted to the 16 cells that were not classified. This strong connection between vibration responses and cold block effects suggests the existence of a rather close and continuous relationship between group I input and descending control in a wide variety of stretch-sensitive interneurons.

In control conditions, afterdischarges following the end of stretch were relatively rare, being present only in a few cells with weak group I input responses to tendon vibration (e.g., Fig. 1D). The afterdischarges in these cells increased during cold block. The five cells classified as Ia interneurons did not show any significant tendency for afterdischarges in control or cold block conditions.

**DISCUSSION**

This study shows that interneurons with a strong group I input are preferentially facilitated by tonically active pathways descending in the dorsolateral quadrants, while interneurons with weak group I input are inhibited. These tonically active pathways include the dorsal reticulospinal tract and may also include the rubrospinal tract and long propriospinal tracts (Baldissera et al. 1981; Jankowska 1992). A contribution from corticospinal tracts can be discounted in the decerebrate preparation. Vestibulospinal inputs excite Ia inhibitory interneurons (Hultborn et al. 1976), but we have previously shown that the dorsally applied cold block does not significantly affect transmission in ventral pathways (Miller et al. 1995). We did not exclude the possibility that some of the interneurons could have been ascending tract cells. However, the cells classified here as Ia, II, or Ib interneurons are probably not ascending tract cells, as ascending tract cells transmitting proprioceptive information (e.g., spinocerebellar tract cells) are either more rostral than L1 (Aoyama et al. 1988) or receive only relatively weak proprioceptive input (Jankowska et al. 1979).

The classic test for Ia inhibitory interneurons, which is to show inhibition mediated by ventral root stimulation (Jankowska 1992), was difficult to interpret in these experiments because ventral root stimulation also produced a muscle twitch that unloaded muscle spindles. However, the stretch and vibration evoked firing patterns of the five cells classified as Ia interneurons are precisely what would be expected for Ia inhibitory interneurons. Therefore Ia inhibitory interneuron discharge might be suppressed by injuries to the cord that disrupt dorsolateral descending inputs.

Differences between sustained physiological inputs versus transient inputs may be important for descending control of reciprocal inhibition. Reciprocal inhibitory postsynaptic potentials evoked by single electrical shocks may be enhanced in spinal injury (Boorman et al. 1991; Hongo et al. 1984), but our results and data from humans patients (Boorman et al. 1996) indicate that reciprocal inhibition from sustained physiological inputs is suppressed. As a result, it is conceivable that much of the normal reciprocal relations between antagonist muscles could be lost, promoting inappropriate muscular cocontraction. These changes may seriously impede efforts at restoring locomotor patterns, which require strong reciprocal relations between antagonists (Fung et al. 1990; Harkema et al. 1997).
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REFERENCES


