Contribution of Commissural Projections to Bulbospinal Activation of Locomotion in the In Vitro Neonatal Rat Spinal Cord

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Cowley KC, Zaporozhets E, Joudi RA, Schmidt BJ. Contribution of commissural projections to bulbospinal activation of locomotion in the in vitro neonatal rat spinal cord. J Neurophysiol 101: 1171–1178, 2009. First published December 31, 2008; doi:10.1152/jn.91212.2008. Commis-sural projections are required for left-right coordination during locomotion. However, their role, if any, in rhythm production is unknown. This study uses the neonatal rat in vitro brain stem–spinal cord model to examine the rostrocaudal distribution of locomotor-related commissural projections and study whether commissural connections are needed for the generation of hindlimb rhythmic activity in response to electrical stimulation of the brain stem. Mid-sagittal lesions were made at a wide range of rostrocaudal levels. Locomotor-like activity persisted in some preparations despite mid-sagittal lesions extending from C4 to the mid-L4 level or from the conus medullaris to the T12/L1 junction. In some preparations, mid-sagittal lesions throughout the entire spinal cord had no effect on locomotor-like activity if two or three contiguous segments remained intact. Those bridging segments had to include the T13 and/or L1 levels. These observations suggested that commissural projections in the thoracolumbar junction region were critical. However, locomotor-like activity was also elicited in preparations with limited mid-sagittal lesions focused on the thoracolumbar junction (T12 through L1 or L2 inclusive). In other experiments, locomotor-like activity was evoked by bath-applied 5-hydroxytryptamine (5-HT) and N-methyl-D-aspartate (NMDA). Appropriate side-to-side coordination was observed, even when only one segment remained bilaterally intact. Commis-sural projections traversing the thoracolumbar junction region were most effective. In combination, these results suggest that locomotor-related commissural projections are redundantly distributed along a bi-directional gradient that centers on the thoracolumbar junction. This commissural system not only provides a robust left-right coordinating mechanism but also supports locomotor rhythm generation in response to brain stem stimulation.

INTRODUCTION

It has long been established that the generation of a locomotor pattern is an intrinsic property of the spinal cord, but with important contributions from afferent input (for review, see Stuart and Hultborn 2008). Thus the anatomically isolated lumbosacral spinal cord retains the capacity to generate rhythmic hindlimb movements. However, experiments involving mammalian spinalized preparations, whether in vivo (Barbeau and Rossignol 1987, 1994; Forssberg et al. 1980) or in vitro (Kudo and Yamada 1987; Smith and Feldman 1987), raise the question of whether specific segments of the spinal cord contain critical commissural projections for left-right coordination and whether commissural projections are needed to support locomotor rhythm production. Preliminary results were presented previously in abstract form (Zaporozhets et al. 2006a).

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METHODS

Experimental protocols used in this study were in compliance with the guidelines set by the Canadian Council on Animal Care and the University of Manitoba. Isolation of the spinal cord, as well as methods of extracellular recording, were described previously (Cowley and Schmidt 1995). In brief, Sprague-Dawley rats (1–5 days old) were anesthetized with isoflurane, decerebrated at the midcollicular level, eviscerated, and placed in a bath chamber containing artificial cerebrospinal fluid (ACSF) composed as follows (in mM): 128 NaCl, 4.0 KCl, 0.5 NaHPO4, 1.5 CaCl2, 21 NaHCO3, 1.0 MgSO4, and 30 glucose, equilibrated to pH 7.4 with 95% O2–5% CO2. The brain stem and spinal cord were isolated. Experiments were conducted at room temperature (ACSF ~ 22°C). In some experiments, the spinal cord bath was partitioned using a barrier made of plastic that was sealed at cord contact edges with petroleum jelly.

Midsagittal lesions of the spinal cord were made in the regions of interest using sharpened iris scissors or a fine insect pin. Completeness of the lesion was confirmed by visualizing the bottom of the bath chamber between the separated halves of the spinal cord. Preparations were left for ~1 h before attempting to elicit locomotor-like activity via electrical stimulation of the brain stem. In some preparations, rhythmic activity could not be elicited 1 h after making the lesion but did appear in response to stimulation applied after 2 or 3 h. Thus if initial attempts to evoke rhythmic activity failed, further brain stem stimulation was administered periodically for at least 4 h before concluding locomotor-like activity was abolihed.

Ventral root recordings were obtained using glass suction electrodes. The records were band-pass filtered (30–3,000 Hz), digitized, and captured using Axoscope (v 9.0, Axon Instruments) software. Axoscope files were converted to an appropriate binary format for further analysis using special purpose software (developed by the Spinal Cord Research Centre, University of Manitoba).

Electrical stimulation of the brain stem was performed as previously detailed (Zaporozhets et al. 2004). In brief, an ACSF-filled glass electrode, with a tip diameter of 200–300 μm, was placed in contact with the ventral surface of the brain stem. Bipolar stimulation was used to deliver monophasic rectangular current pulses (4–20 ms, 0.5–10 mA, 0.8–2.0 Hz). Stimulation was applied for a maximum of 2–3 min per test episode.

N-methyl-D-aspartate (NMDA) and 5-hydroxytryptamine (5-HT) were applied to the spinal cord from concentrated stock solutions (10 mM). All concentrations refer to final bath concentrations (ranges: NMDA, 3–5 μM; 5-HT, 5–50 μM).

The criteria used to classify motor output as locomotor-like are as described previously (Cowley et al. 2008). Discharge was considered rhythmic if the coefficient of variation (CV) of the cycle period was ≤25%. The ventral root discharge pattern was deemed locomotor-like if 1) alternation was observed between the left and right sides at L2 and/or between left and right sides at the L4 level and 2) ipsilateral alternation was present between L1 (predominantly flexor-related activity) and L5 (predominantly extensor-related activity) on at least one side. Polar plot analysis was used to determine whether there was a statistically significant phase relationship for bursts in ventral roots of interest (Batschelet 1981; Cowley et al. 2005; Zar 1974).

RESULTS

General observations on abolished locomotor-like activity in brain stem–stimulated and in neurochemically activated preparations

In the following results, 145 brain stem–stimulated preparations are described in which locomotor-like activity was abolished after various midsagittal lesions, despite testing a range of stimulation durations and intensities (up to 4–5 times the preselion stimulation threshold). Among these preparations, 111 displayed tonic ventral root activity without any bursts. When a particular midsagittal lesion was sufficient to abolish locomotor-like activity in all experiments, only tonic ventral root discharge was observed in each and every preparation in that lesion group. However, 34 preparations showed some degree of phasic ventral root discharge (typically displaying a few bursts in 1 or 2 ventral roots) but failed to meet criteria for a locomotor-like pattern (see METHODS). The occurrence of rhythmic, but non–locomotor-like, discharge was associated with lesions that still allowed the development of a locomotor-like pattern in at least some preparations receiving the same lesion.

By comparison, when midsagittal lesions abolished locomotor-like activity in neurochemically stimulated preparations (n = 62 preparations), tonic activity was observed in only 11. The majority (n = 51/62) showed rhythmic, albeit non–locomotor-like, discharge.

Effect of midsagittal lesions extending caudally from C1

Locomotor-like discharge was elicited in the lumbar region in response to electrical stimulation of the brain stem despite midsagittal separation of the left and right halves of the entire cervical and thoracic cord. More specifically, locomotor-like activity was observed in four of four preparations with midsagittal lesions from C1 through T12, two of three preparations with lesions from C1 through T13, and one of three preparations with lesions from C1 to mid-L1 inclusive (Fig. 1, A and C). However, brain stem stimulation consistently failed to evoke rhythmic ventral root discharge if the midsagittal lesion extended slightly more caudal to include the entire L1 segment (n = 5) or rostral half of the L2 segment (n = 6; Fig. 1C). In these preparations, only tonic activity was observed.

Effect of midsagittal lesions extending rostrally from the conus medullaris

Locomotor-like activity, including appropriate left-right alternation, was elicited during brain stem stimulation in 14/19 preparations with midsagittal lesions beginning at the conus medullaris and extending rostrally to the L1/L2 junction (Fig. 1C). Locomotor-like activity was elicited by brain stem stimulation in 2/11 preparations with midsagittal lesions extending from the conus medullaris to the T13/L1 junction and in 1/7 preparations with lesions extending to the mid-T13 level (Fig. 1, B and C). However, rhythmic activity was abolished and only tonic activity was recorded in all eight preparations with midsagittal lesions extending rostrally from the conus medullaris through the entire T13 segment (i.e., to the T12/T13 junction; Fig. 1C).

The results of the first two series of experiments, involving preparations with midsagittal lesions extending from the Cl segment caudally or from the conus medullaris rostrally, indicate that no specific segmental level is essential for eliciting locomotor discharge in response to electrical stimulation of the brain stem. However, the results also show that, in the presence of extensive midsagittal separation of the lumbar-sacral cord, brain stem–evoked locomotor-like activity was possible only if the remaining intact segments included the T13 segment. In the case of extensive cervicothoracic midsagittal separation, connections in the rostral lumbar (L1–L2) region had to be
Effect of midsagittal lesions localized to the caudal thoracolumbar region

To test this hypothesis, midsagittal lesions were localized to the caudal thoracic and lumbar regions. Midsagittal lesions from T13 to L2 inclusive failed to abolish locomotor-like activity in 6/11 preparations (Fig. 2B). Locomotor-like activity was also elicited by stimulation of the brain stem in 2/13 preparations with slightly more extensive lesions that included the T12 segment (i.e., T12–L2 inclusive; Fig. 2B) and in 2/9 preparations with midsagittal lesions involving T12–L1 inclusive (Fig. 2, A and B). These findings support the concept that, although the caudal thoracic and rostral lumbar segments seem to contain important locomotor-related commissural connections, no specific level is essential for brain stem–induced locomotor-like activity.

Whereas focal midsagittal lesions involving T13 through L2, or even T12 through L2, failed to abolish locomotor-like activity in some preparations, rhythmic activity was abolished in all preparations if the lesion extended to more caudal lumbar cord segments. Thus 10/10 preparations with midsagittal lesions from T12 to L5 failed to develop locomotor-like activity in response to brain stem stimulation (Fig. 2B). On the other hand, 3/9 preparations lesioned from T13 to L5 inclusive, which preserved commissural fibers in T12 and 4/14 preparations with midsagittal separation from L1 to L5 inclusive, which additionally spared commissural fibers in T13, were capable of displaying locomotor-like activity (Fig. 2B). These results are consistent with the effects of midsagittal lesions extending from the conus medullaris rostrally (Fig. 1C). That is, the key factor in obtaining successful brain stem–evoked locomotor-like activity in the presence of midsagittal separation of the left and right halves of the lumbar spinal cord was whether or not

**FIG. 1.** Distribution of commissural components mediating locomotor-like coordination in response to brain stem electrical stimulation. A: locomotor-like activity, consisting of rhythmic alternation of ipsilateral L2 and L5 ventral roots and left-right alternation (CV = 8–14%), was observed following midsagittal lesions extending from the C1 segment to as far caudal as the mid-L1 segment. For this and subsequent ventral root recordings, regularly occurring spikes are artifacts related to brain stem electrical stimuli. B: locomotor-like activity (CV = 16–23%) was observed after midsagittal lesion extending from the conus medullaris to the mid-T13 segment. C: summary chart showing the number of preparations that displayed locomotor-like activity (black bars) in response to brain stem electrical stimulation after ascending or descending midsagittal lesions through the indicated segments (inclusive). Co, conus medullaris; m, midsegment level (e.g., mL1 = mid-L1 segment).

**FIG. 2.** Midsagittal lesions restricted to the lower thoracic–upper lumbar region did not abolish locomotor-like activity. A: electrical stimulation of the brain stem evoked locomotor-like activity (CV = 4–11%) in this preparation with a midsagittal lesion from the T12 to L1 segment (inclusive). B: summary chart showing the number of preparations that developed locomotor-like activity in response to brain stem electrical stimulation after midsagittal lesions through the indicated segmental levels (inclusive).

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cross-connections were maintained in caudal thoracic (T_{12–T_{13}}) segments.

Location and minimum number of bilaterally intact segments sufficient to support brain stem--evoked locomotor-like activity

In view of the above results that suggest important locomotor-related commissural connections were located in the thoracolumbar junction region, we determined the minimum number of bilaterally intact segments required for brain stem--evoked locomotor-like activity. After combined extensive rostral and caudal midsagittal lesions, electrical stimulation of the brain stem successfully evoked locomotor-like activity in preparations with only three bilaterally intact segments at the T_{13–L_1} level (n = 6/11), T_{13–L_2} (n = 3/4), and L_{1–L_3} (n = 2/3). Locomotor-like activity could not be evoked if the three segment bridges were located rostral to T_{13} (e.g., T_{10–T_{12}}, n = 5) or caudal to L_{1} (L_{2–L_4}, n = 9; Fig. 3A2).

Locomotor-like activity was also observed in some preparations with only two segments preserved bilaterally intact (Fig. 3B). These included preparations with commissural connections at the T_{13–L_1} level (n = 4/13) and at the L_{1–L_2} level (n = 3/8).

These observations, involving just a few bilaterally intact segments, further point to the thoracolumbar junction as a region of particular importance with respect to commissural projections called into play during brain stem--evoked locomotor activity. More specifically, it seems that at least some commissural projections in the T_{13–L_1} segments must remain intact if the left and right halves of the spinal cord are otherwise extensively disconnected. However, the locomotor-related commissural system activated during brain stem electrical stimulation does show some distributed and redundant features. For instance, neither T_{13} nor L_{1} was essential if other spinal cord segments were intact (e.g., Fig. 2B).

Effect of neurochemical stimulation on preparations with small commissural bridges

The observation that commissural connections are essential for eliciting locomotion in response to electrical stimulation of the brain stem raises the question of whether this is because they are needed for transmission of the descending command signal or because they are critical for rhythm production by the locomotor network. Thus experiments were carried out aimed at activating the locomotor network of midsagittally lesioned preparations, independent of the descending command system, using direct neurochemical activation.

Locomotor-like activity was elicited by electrical stimulation of the brain stem in only 1/21 preparations with a single segment (0/10 T_{13}; 1/11 L_{1}) bilaterally intact. Only tonic ventral root activity was observed (Fig. 4A).

In contrast, locomotor-like activity was observed in 26/88 preparations, with a single segment intact, in response to bath application of 5-HT and NMDA (Fig. 4B). The remaining nonlocomotor preparations (n = 62) responded to 5-HT and NMDA with either tonic activity (n = 11/62) or rhythmic ventral root discharge that failed to meet criteria for a locomotor-like pattern (n = 51/62). In successful experiments, the intact single segment was located at any level from T_{11} to L_{4}. However, a gradient was noted such that the closer the preserved commissural projections were located in relation to the thoracolumbar lumbar junction the greater the likelihood of

![Fig. 3](https://example.com/fig3.png)

**Fig. 3.** Locomotor-like activity evoked in response to electrical stimulation of the brain stem in preparations with only 2 or 3 segments bilaterally intact. A1; in this preparation, locomotor-like activity (CV = 8–14%) was supported by reciprocal commissural connections located within the T_{13–L_1} and L_{2} segments. B1; in another preparation, locomotor-like activity in response to brain stem stimulation was achieved with only 2 segments bilaterally intact (L_{1} and L_{2}, CV = 8–12%). A2 and B2: summary charts showing that commissural connections within the lower thoracic and upper lumbar regions were more effective in supporting brain stem--evoked locomotor-like activity than commissural projections in more rostral or caudal segments.
inducing locomotor-like activity (Fig. 4C). Thus for example, locomotor-like activity was observed in 9/10 preparations bilaterally intact at T13.

Among the 51 preparations displaying ventral root rhythms in response to 5-HT/NMDA, but which otherwise failed to meet criteria for a locomotor-like pattern, 35 had a sufficient amount of rhythmic discharge to allow polar plot analysis of left-right and/or ipsilateral phase relationships. The mean left-right phase relationship (polar plot $r$ value) in these preparations was only 0.28 (range, 0.03–0.44; $cR = 0.44$ at $P = 0.05$), indicating that a one-segment bridge in these particular preparations was not able to maintain a consistent left-right phase relationship (Fig. 5). On the other hand, the mean ipsilateral L2–L5 phase relationship in rhythmic preparations not meeting criteria for locomotor-like activity was 0.86 (range, 0.63–0.98; $cR = 0.65$ at $P = 0.001$); thus the intralimb flexor-extensor phase relationship was relatively preserved despite the extensive separation of the two halves of the spinal cord that abolished left-right coordination (Fig. 5).

Finally in three of nine preparations with complete left-right separation of the spinal cord (i.e., midsagittal lesion from C1 to the conus medullaris inclusive), 5-HT/NMDA evoked rhythmic activity with appropriate ipsilateral phase relationships.

In summary, the experiments comparing electrical stimulation of the brain stem with the effects of 5-HT/NMDA application suggest that, although intralimb rhythm generating circuitry is preserved within each half of the spinal cord, successful bulbospinal activation of this circuitry requires the presence of at least some commissural connections in the thoracolumbar region.

**DISCUSSION**

Previous work by Kato (1998) reported that chronic midsagittal separation of cat spinal cord, from L2 or L3 through L7 or S1, had minimal effect on hindlimb locomotor coordination. Several studies of neurochemically evoked locomotor-like activity, in the in vitro neonatal rat spinal cord, have also included observations on the effect of midsagittal lesions (Cowley and Schmidt 1997; Juvin et al. 2005; Kremer and Lev-Tov 1997). This series is the first systematic examination of the effect of commissural fiber disruption using an in vitro rodent preparation wherein locomotor-like activity is induced by stimulation of bulbospinal pathways. In addition to a well-established role in side-to-side coordination, the results show...
two important additional properties of locomotor-related commissural projections. First, unlike the case in neurochemically activated preparations, the data suggest that commissural projections are needed for locomotor rhythm production in response to brain stem stimulation. Second, locomotor-related commissural projections are rostro-caudally distributed in a redundant fashion.

The completely isolated in vitro hemi-lumbosacral rodent spinal cord is capable of generating a locomotor-like rhythm in the ipsilateral hindlimb in response to NMDA application (Kremer and Lev-Tov 1997; Kudo and Yamada 1987). Even isolated single hemi-spatial cord segments can generate rhythmic discharge in response to bath-applied chemicals (Bonnot and Morin 1998; Cowley and Schmidt 1997), as can synaptically isolated spinal cord neurons (Hochman et al. 1994a,b; Kiehn et al. 1996; Legendre et al. 1989). Thus under certain experimental conditions, commissural connections are clearly not needed for induction of rhythmic activity among neurons in the hemi-spatial cord.

In contrast to bath-applied neurochemicals, this series shows that bulbospinal pathways recruited by means of electrical stimulation of the brain stem are unable to induce spinal rhythmic activity when commissural fibers are sufficiently disrupted. More specifically, separation of the left and right halves of the lumbo-sacral region abolished rhythmic output if the midsagittal lesion extended as far rostral as the T12/L1 junction, despite otherwise intact commissural connections throughout the cervicothoracic region. Initially this finding suggested that lumbo-sacral commissural projections may be essential for locomotor-rhythmogenesis in response to brain stem stimulation. A corollary of this observation is that cross-connections in the forelimb locomotor centers, located in the cervical enlargement, are insufficient in themselves to support the generation of lumbar rhythmic activity during brain stem stimulation. However, subsequent experiments showed that rhythmic activity could be abolished despite preservation of lumbo-sacral commissural projections (e.g., in preparations with midsagittal lesions from C1 to L1 inclusive). These combined observations suggested that cross-connections in the T12/L1 segments, in particular, may be critical. In addition, brain stem stimulation experiments involving preparations with short bridges (2–3 contiguous segments) of bilaterally intact cord further support the concept that caudal thoracic and rostral lumbar segments are relatively dominant in this left-right bridging function (Fig. 3). Ultimately, however, midsagittal sections localized to the caudal thoracic and rostral lumbar region (e.g., T12–L2) failed to abolish locomotor-like activity. Thus it is concluded that locomotor-related commissural projections are rostro-caudally distributed and no specific segmental level is essential; however, cross projections in the thoracolumbar junction region seem to be most effective in this role. This bi-directional gradient, which is maximal in the thoracolumbar region, overlaps with the rostro-caudal gradient of rhythmicogenetic responsiveness shown to exist with respect to direct neurochemical stimulation of the lumbar cord (Ballion et al. 2001; Bertrand and Cazalets 2002; Bonnot et al. 2002; Christie and Whelan 2005; Cowley and Schmidt 1997; Kjaerulf and Kiehn 1996; Kremer and Lev-Tov 1997; Nishimaru et al. 2000).

The results suggest that exogenous neurochemical application more effectively recruits the inherent rhythmicogenic capacity of the spinal cord compared with brain stem stimulation. Almost one third of the preparations with only one bilaterally intact bridging segment developed locomotor-like activity in response to NMDA/5-HT application. In contrast, only rarely (1/25) was brain stem stimulation effective in eliciting locomotor-like activity in preparations with one intact segment. Of note, the rostro-caudal level of the single bridge segment most effective in neurochemically activated preparations centered on the thoracolumbar junction region, which is again consistent with the proposal that commissural projections crossing in this region have a relatively dominant role compared with fibers crossing at other levels.

Preservation of sacro-coccygeal segments seems to influence the capacity of the split lumbar cord to generate locomotor activity in response to brain stem stimulation. Thus, if the sacro-coccygeal region was midsagittally separated along with the entire lumbar region, the T12 segment had to remain intact (Fig. 1C), whereas if the sacro-coccygeal cord was preserved bilaterally intact, midsagittal lesions of the lumbar cord could extend further rostrally to include the T12 segment without abolishing locomotion. This observation is compatible with the fact that the sacro-coccygeal region contains rhythmicogenic circuitry that can help support locomotor activity, via propriospinal input to lumbar segments (Cazalets and Bertrand 2000; Lev-Tov et al. 2000). This ascending influence is mediated, in part, by ascending commissural projections (Gabbay and Lev-Tov 2004; Strauss and Lev-Tov 2003).

Previous studies of the in vitro neonatal rat preparation showed that several neurochemicals can reliably induce rhythmic activity, but these substances vary in their capacity to organize a locomotor-like pattern (Cowley and Schmidt 1994; Kiehn and Kjaerulf 1996). For instance, 5-HT alone was more effective than NMDA or acetylcholine alone in producing a locomotor-like sequence of hindlimb flexor and extensor nerve discharge (Cowley and Schmidt 1994). Many other studies, involving both in vivo and in vitro preparations, also support a key role of 5-HT in mammalian locomotor rhythmogenesis (for review, see Schmidt and Jordan 2000), including several recent reports (Madriaga et al. 2004; Liu and Jordan 2005; Pearlstein et al. 2005). Of particular relevance, 5-HT was shown to enhance the excitability of mouse locomotor-related lumbar commissural interneurons (Carlin et al. 2006; Diaz-Rios et al. 2007; Zhong et al. 2006a). Therefore it is of interest that the effect of midsagittal lesions on locomotor-like activity induced by 5-HT alone is similar to the influence of such lesions in this series using brain stem activation. More specifically, midsagittal section of preparations induced by 5-HT alone is similar to the influence of such lesions in this series using brain stem activation. More specifically, midsagittal section of preparations induced by 5-HT alone, starting at either C1 or the conus medullaris, had no effect on locomotor-like activity such that rhythmic intralimb activity persisted after midsagittal sectioning of all commissural connections, similar to the findings reported by Kremer and Lev-Tov (1997).
numerous studies have examined locomotor-related commissural interneurons located in the mammalian lumbar cord (birinyi et al. 2003; butt and kiehn 2003; carlin et al. 2006; diaz-rios et al. 2007; eide et al. 1999; jankowska et al. 2003, 2005; hammar et al. 2004; kjaerulff and kiehn 1997; lanuza et al. 2004; matsuyama 2004, 2006; nakayama et al. 2002; quinlan and kiehn 2007; stokke et al. 2002; zhong et al. 2006a,b). commissural projections, including ascending projections, play a role in cervico-lumbar interlimb coordination (juvin et al. 2005; reed et al. 2006). although unproven, it is postulated that, in addition to direct projections to contralateral motoneurons, some lumbar commissural interneurons target contralateral rhythm generating components of the locomotor network (kiehn et al. 2008). consistent with this concept, the present demonstration that rhythmic activity is abolished after extensive midsagittal separation suggests that locomotor rhythm generation may well require support from commissural input. although there is no doubt that commissural neurons originating in the lumbar cord have an important role with respect to left-right coordination in the intact animal, these results are congruent with previous data (cowley and schmidt 1997; kato 1988; kremer and lev-tov 1997) suggesting they are not essential in this role. more likely, lumbar commissural neurons are part of a distributed locomotor-related spinal cross-projection system that includes cervicothoracic and sacral regions.

humans with congenital split spinal cord anomalies in thoracic and/or lumbar regions (diastematomyelia), even as adults, often have no evidence of impaired ambulation (akay et al. 2004; poresky et al. 2007). typically, however, these lesions involve only one, or a few, segments. developmental plasticity may also be a factor, and the availability of lower limb afferent feedback in these individuals may contribute to successful recruitment of spinal rhythemogenic circuitry despite disruption of commissural fibers. indeed, kato (1990) proposed that afferent input activated the locomotor pattern generator in cats shown to be capable of four limb locomotion despite chronic “isolation” of the hemi-lumbar cord (hemisection at l2 or l3 combined with midsagittal section from the hemisection level to l3 or s1).

in summary, these results indicate that the spinal locomotor system features a distributed, redundant, and robust left-right coordinating mechanism. appropriate side-to-side relationships can be maintained despite interruption of cross-connecting fibers over extensive rostrocaudal territories, even throughout the entire lumbar region. projections crossing in the caudal thoracic and rostral lumbar segments seem to have a relatively dominant role in this function. the design of therapeutic interventions aimed at restoring locomotor function after spinal cord injury needs to consider the possibility that, in addition to ipsilateral direct and indirect (propriospinal) projections, commissural neurons recruited by bulbospinal projections may have an important role in supporting locomotor rhythm generation.

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