Spinal Cord Injury Reveals Unexpected Function of Cutaneous Receptors

K. G. Pearson

Department of Physiology, University of Alberta, Edmonton T6G 2H7, Canada

Submitted 27 August 2003; accepted in final form 27 August 2003

INTRODUCTION

A major challenge for clinical neuroscience is to develop procedures for enhancing functional recovery after damage or disease of the CNS. The advent of powerful molecular and cellular techniques for promoting growth and regeneration of nerve cells, and for the production of engineered cells for incorporation into the nervous system, has yielded a sense of optimism that procedures for routine use will be developed in the near future (Horner and Gage 2000; Schwab 2002). In the meantime, the conventional approaches of drug therapy and rehabilitation therapy will continue to provide the main avenues for treatment combined in some instances with functional electrical stimulation of nerves and muscles. Therefore it is comforting that a number of significant advances have been made over the past decade in the rehabilitation of some groups of patients with damage of the CNS. One is the use of constraint-induced movement therapy to enhance arm and hand movement in stroke patients (Taub and Vaadia 2003; Wolf et al. 2002) and another is the use of treadmill training for improving walking in incomplete spinal cord injured patients (Dietz et al. 1998; Harkema 2001; Ladouceur et al. 1997; Wernig et al. 2000). The development of both of these procedures was based soundly on animal research in monkeys and cats.

With the efficacy of intense training procedures now established (although see van der Lee 2001), attention has turned to gaining an understanding of underlying mechanisms with the hope that knowledge of these mechanisms will lead to further enhancement of therapeutic effectiveness. Two papers appearing in this issue (Bouyer and Rossignol 2003a,b), pages 3625–3653, make a significant contribution to our knowledge of sensory signals that are necessary for the recovery of stepping in cats after a complete transection of the spinal cord.

One of the most useful animals models for examining the effects of training on functional recovery after spinal cord injury is the spinal cat. After complete transection of the spinal cord at the thoracic level, adult animals can be trained to step with their hind legs on a moving treadmill belt (Barbeau and Rossignol 1987; Lovely et al. 1986). With daily training sessions over a period of a few weeks, spinal animals regain the ability to produce weight-bearing stepping of the hind legs. Electromyographic analysis of the motor patterns after cutaneous denervation of the paws revealed that the inability to step correctly was associated with a major restructuring of the motor pattern in the ankle flexor muscles. Instead of the normal reciprocal pattern of activity in ankle flexors and extensors, the ankle flexors were coactivated with extensors during the stance phase and silent during the swing phase. This is an unexpected finding because we know that the normal activity in the paw drastically alters this basic motor pattern with extensors during the stance phase and silent during the swing phase. This finding adds to the growing list of demonstrations of adaptive plasticity in the spinal cord (Pearson 2000; Wolpaw and Tennissen 2001).

The finding that cutaneous signals from the hind paws are essential for stepping in spinal cats comes as a surprise because it has been known for almost a century that deafferentation of the paws of otherwise intact cats has no obvious influence on the ability to walk on flat horizontal terrains (Sherrington 1910). The first paper by Bouyer and Rossignol confirms this early observation, although their careful analysis of leg movements and motor patterns revealed subtle alterations in the regulation of flexion movements of the knee. More dramatic deficits were observed when animals deprived of cutaneous input from the paws walked up and down slopes, and especially when they walked across the rungs of a hori-
zontal ladder. In the latter situation, these animals often re-
quired considerable coaxing to walk on the ladder and, when
they did, they were unable to place their paws correctly on the
rungs. These observations demonstrate an important function
of feedback from cutaneous receptors in the ongoing regulation
of locomotor activity even in situations in which the environ-
ment is reasonably predictable.

By demonstrating the importance of cutaneous feedback in
walking in normal and spinal cats, the authors have broadened
our outlook about which sensory modalities might be manip-
ulated to enhance stepping in spinal-cord-injured patients. Un-
til now most of the focus has been on manipulating feedback
from load-sensitive receptors in muscles by using body-support
devices (Harkema 2001). Thus a question for future research is
whether increasing cutaneous feedback from the feet (perhaps
using a vibrating shoe insert) can enhance the rate of improve-
ment in walking of spinal-cord-injured patients when com-
bined with weight-supported treadmill training. Apart from this
practical point, these reports also raise a number of important
issues related to basic mechanisms generating the motor pat-
tern in walking of spinal-cord-injured patients when com-
bined with weight-supported treadmill training. Apart from this
practical point, these reports also raise a number of important
issues related to basic mechanisms generating the motor pat-
tern for stepping. First, the finding of co-activation of ankle
flexors and extensors after paw deafferentation highlights the
long-standing issue of which features of the normal motor
pattern are normally established by feedback from peripheral
receptors. Second, none of the known influences of cutaneous
signals can explain the radical reorganization of the motor
pattern after deafferentation. And finally, the need for cutane-
ous feedback from the paws for demanding locomotor tasks
implies moment-to-moment integration of cutaneous informa-
tion into supraspinal centers. How this achieved is completely
unknown. Thus by raising these issues the two articles by
Bouyer and Rossignol clearly illustrate how much more we
need to know before we can claim to understand the neuronal
mechanisms controlling walking.

REFERENCES

Barbeau H and Rossignol S. Recovery of locomotion after chronic spinal-

Bouyer LJD and Rossignol S. Contribution of cutaneous inputs from the
hindpaw to the control of locomotion. I. Intact cats. J Neurophysiol 90:

Bouyer LJD and Rossignol S. Contribution of cutaneous inputs from the
hindpaw to the control of locomotion. II. Spinal cats. J Neurophysiol 90:

De Leon RD, Tamaki H, Hodgson JA, Roy RR, and Edgerton VR.
Hindlimb locomotor and postural training modulates glycinergic inhibi-
tion in the spinal cord of the adult spinal cat. J Neurophysiol 82:

Dietz V, Wirz M, Colombo G, and Curt A. Locomotor capacity and recovery
of spinal cord function in paraplegic patients: a clinical and electrophysio-
logical evaluation. Electroencephalogr Clin Neurophysiol 109: 140–153,
1998.

Harkema SJ. Neural plasticity after human spinal cord injury: application of
locomotor training to the rehabilitation of walking. Neuroscientist 7: 455–

Horner PJ and Gage FH. Regenerating the damaged central nervous system.

Ladouceur M, Pepin A, Norman KE, and Barbeau H. Recovery of walking

Lovely RG, Gregor RJ, Roy RR, and Edgerton VR. Effects of training on
the recovery of full-weight bearing stepping in the adult spinal cat. Exp

Pearson KG. Plasticity of neuronal networks in the spinal cord: modifications

Schwab ME. Repairing the injured spinal cord. Science 295: 1029–1031,
2002.

Sherrington CS. Flexor-reflex of the limb, crossed extension reflex, and reflex

Taub E and Vaadia E. Constraint-induced movement therapy: bridging from
primate laboratory to the stroke rehabilitation laboratory. J Rehabil Med 41,

Tillakaratne NJK, De Leon RD, Hoang TX, Roy RR, Edgerton VR, and
Tobin AJ. Use-dependent modulation of inhibitory capacity in the feline

van der Lee JH. Constraint-induced therapy for stroke: more of the same or

Wernig A, Nanassy A, and Müller S. Laufband(LB) therapy in spinal cord

Wolf SL, Blanton S, Baer H, Breshears J, and Butler AJ. Repetitive task

Wolpaw JR and Tennissen AM. Activity-dependent spinal cord plasticity in