ORIGINAL ARTICLE

Slowed Down: Response Time Deficits in Well-Recovered Subjects With Incomplete Spinal Cord Injury

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Abstract

Objective: To quantify remaining motor deficits in well-recovered subjects with incomplete spinal cord injury.

Design: Case-control study.

Setting: Spinal cord injury center of a university hospital.

Participants: Out of a volunteer sample, we recruited 15 subjects with incomplete paraplegia (mean age, 50y; 67% men; neurologic level from T4 to L4; mean time since injury, 6.3y) and close-to-normal walking pattern. They were compared with 15 age- and sex-matched controls.

Interventions: Not applicable.

Main Outcome Measures: Response time and its 4 subparts, processing time, conduction time, motor time, and movement time. These were assessed with an electromyogram-supported lower-limb response time task and single-pulse transcranial magnetic stimulation to measure the motor-evoked potential latency of the M. tibialis anterior. In addition, participants were tested for lower-extremity muscle strength, gait capacity, visual acuity, and upper-extremity response time.

Results: Well-recovered subjects with incomplete paraplegia still suffered from deficits in conduction and movement time, whereas their processing and motor times were essentially normal. In addition, these patients showed delayed movement times of the upper limb, even if their injury was located in the thoracic or lumbar region.

Conclusions: Well-recovered patients with incomplete paraplegia still experience difficulties with quick and accurate movements. Furthermore, combining transcranial magnetic stimulation, electromyogram, and a response time task proved useful for investigating deficits in executing fast and accurate movements.

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Spinal cord injury (SCI) is a diagnosis with a broad range of possible implications. It causes destruction and demyelination of axonal pathways as well as segmental spinal circuitries and therefore affects conduction of sensory and motor signals across the lesion site. Rehabilitation after SCI is a multidimensional approach. In this population, improvement in function is usually accomplished by 2 mechanisms: "recovery" and "compensation"[1] (similar in the stroke population[2]). However, very few patients

clinically recover completely from an SCI. A U.S. study[3] showed that 1 year postinjury, only 31 out of 1461 patients with SCI (2.1%) were scored with a Frankel[4] (precursor of the American Spinal Injury Association [ASIA] Impairment Scale[5]) grade E, which stands for restitutio ad integrum with respect to motor and sensory function (pinprick and light touch). The same article, however, presents much higher numbers of patients with Frankel grade D, that is, patients with remaining minor motor or sensory deficits (30.0%[3]). This indicates that many well-recovered patients with SCI still suffer from remaining deficits, although they are well capable of performing regular activities of daily living (which has recently been shown for well-recovered stroke patients[6]).

In general, fast-recovering patients with a mild incomplete SCI (iSCI) are not considered to participate in clinical trials because their spontaneous recovery, as quantified with recommended clinical tools such as the International Standards or the Spinal

Cord Independence Measure,[7,8] is so strong that it easily could result in ceiling effects. Therefore, this population tends to be scientifically overlooked and left to its own responsibility, even when there might be potential for further recovery. To better understand its difficulties, we were interested in documenting motor deficits in patients who had recovered well from both a neurologic and functional point of view. Only a few studies so far have searched for sensitive motor measures that related to neurologic damage and remained affected in patients with iSCI after substantial clinical and functional recovery. A recent publication showed, for example, that maximal movement velocity was impaired and related well to corticospinal tract integrity, while impairments in strength as quantified with the ASIA motor score or static dynamometry did not correlate well.[9] However, the authors looked only at movement velocity of the ankle joint in a supine position, whereas we were more interested in a locomotor-relevant movement. Another publication showed that response times also remained affected in patients with ASIA Impairment Scale grade D.[10] Nevertheless, the extent of these remaining motor deficits has not yet been clearly documented in well-recovered subjects with iSCI. To achieve this, we combined reaction time and movement velocity testing into 1 response time test. We further combined this test with electromyogram (EMG) measurements and single-pulse transcranial magnetic stimulation (TMS) to approximately determine the extent of SCI-induced motor deficits in well-recovered subjects with iSCI.

Methods

Participants

Fifteen patients with an ASIA Impairment Scale grade D iSCI participated. They all fulfilled the following requirements: minimally reduced lower-extremity strength (ASIA lower-extremity motor score $\geq$ 48/50 points), maximal score in the Spinal Cord Independence Measure, version III (100/100 points),[11] and maximal score in the revised Walking Index for Spinal Cord Injury, version II (20/20 points).[12] Patients with neurologic disorders other than the SCI were excluded. Mean time since injury was 6.3$\pm$5.5 years, and 6 of the patients were prescribed antispastic medication. For more characteristics, see table 1. To ensure integrity of the upper limb, we only included patients with paraplegia (lesion level T2 to L4). To cover as many patients of the selected population as possible, we did not exclude patients with a lower motor neuron lesion on top of their upper motor neuron lesion.

For all subjects, general characteristics and foot dominance[13] were obtained by questionnaire. To assess strength, we applied the lower-extremity motor score and measured the isometric strength of 3 muscle groups (knee extensors, ankle dorsiflexors, and ankle

List of abbreviations:

ASIA	American Spinal Injury Association
EMG	electromyogram
iSCI	incomplete SCI
LED	light-emitting diode
MEP	motor-evoked potential
MWUT	Mann-Whitney *U* test
SCI	spinal cord injury
TA	tibialis anterior
TMS	transcranial magnetic stimulation
TUG	Timed Up and Go Test

Table 1 Participants' characteristics

Measure	Healthy (n=15)	SCI (n=15)	*P*
Subjects' characteristics			
Age (y)	50.1$\pm$12.3	50.2$\pm$12.4	.98
Female	5	5	NA
Systemic antispastic medication	NA	6	NA
Body height (m)	170.7$\pm$8.2	173.2$\pm$10.4	.30
Body weight (kg)	69.7$\pm$12.5	74.0$\pm$18.0	.28
Visual decimal acuity	1.1$\pm$0.4	0.9$\pm$0.3	.47
Handedness	15 right-handed	15 right-handed	NA
Footedness	14 right-footed	15 right-footed	NA
Clinical characteristics and measures			
Lesion level	NA	T4−12: 8	NA
		L1−4: 7	NA
AIS grade	NA	All D	
LEMS	*50*	*48.9$\pm$0.8*	<.001*
Knee extension strength (kg)	37.7$\pm$13.0	33.7$\pm$14.6	.14
Ankle dorsal flexion strength (kg)	38.4$\pm$16.0	31.3$\pm$12.8	.09
Ankle plantar flexion (kg)	36.6$\pm$6.1	31.8$\pm$8.1	.02*
SCIM II	NA	100$\pm$0	NA
WISCI II	NA	20$\pm$0	NA
TUG (s)	8.1$\pm$0.9	9.2$\pm$1.7	.001*
MEP latency (ms)	31.1$\pm$1.9	35.4$\pm$4.8	<.001*
MEP amplitude (mV)	0.31$\pm$0.14	0.27$\pm$011	.56

NOTE. Values are mean $\pm$ SD or as otherwise indicated.
Abbreviations: AIS, ASIA Impairment Scale; LEMS, lower-extremity motor score; MEP, motor-evoked potential; NA, not applicable; SCIM, Spinal Cord Independence Measure; TUG, Timed Up and Go Test; WISCI, Walking Index for Spinal Cord Injury.
 * Indicates significant *P* value.

plantarflexors) by using a force gauge.[a] As a measure of general function, we assessed the Timed Up and Go Test (TUG).[14] To exclude visual deficits, which might interfere with response time performance, we determined visual acuity.[15] Normative values were obtained from healthy age- and sex-matched volunteers (see table 1). The study protocol was approved by the ethics committee of the Canton of Zurich, and subjects gave written informed consent.

Devices

1. To assess the response time of upper and lower limbs, we used a response time test (for more information, see fig 1, supplemental video [available online only at the *Archives* website, http://www.archives-pmr.org/], and an earlier study[10]). In short, it consists of a platform (57cm×57cm×3.5cm) containing 6 touch sensors with a diameter of 1cm. Five target buttons are positioned in a semicircle 15cm from the tip of the starting position of the hand/foot. In the starting position, 1 button is located under the palm of the hand/heel. Next to each target button, there is a corresponding blue light-emitting diode (LED). Device control software was written in LabVIEW 8.2.1.[b]