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Cooperative hand movements in tetraplegic spinal cord injury patients: Preserved neural coupling

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HIGHLIGHTS

- Contralateral reflex responses are present during cooperative hand movements in spinal cord injury (SCI) patients.
- Ipsilateral SSEP during cooperative and also non-cooperative hand movements are enhanced in SCI patients.
- Cooperative hand movements involve ipsi- and contralateral tract fibers.

ABSTRACT

Objectives: To evaluate whether the task-specific neural coupling mechanism during the performance of cooperative hand movements is preserved in tetraplegic subjects.
Methods: Recordings of ipsilateral and contralateral electromyographic reflex responses in activated forearm muscles and bilateral somatosensory potentials (SSEP) to unilateral ulnar nerve stimulations during rest, cooperative and non-cooperative hand movements.
Results: Contralateral reflex responses were present in almost all patients during cooperative hand movements but small in amplitude when hand function was severely impaired. Ipsilateral SSEP potentials were enhanced during both cooperative and, in contrast to healthy subjects, also non-cooperative bimanual movements.
Conclusions: Both results indicate a strong involvement of ipsilateral non-damaged cervical tracts and hemispheres in the control of bimanual hand movements in tetraplegic subjects.
Significance: This study on the neural control of bimanual movements in patients suffering a cervical injury allows designing therapeutic approaches for the improvement of hand function that are based on physiological insights.

1. Introduction

This study is based on a newly discovered task-specific, neural coupling' mechanism underlying cooperative hand movements (Dietz et al., 2015). This neural coupling is reflected in the observation that during cooperative hand movements (e.g. opening a bottle) electromyographic (EMG) reflex responses can task-specifically be induced in activated forearm muscles of both sides following unilateral arm nerve stimulation. Furthermore, recordings of somatosensory evoked potential (SSEP) showed larger ipsilateral potentials during cooperative compared to non-cooperative bimanual hand movements (Schrafl-Altermatt and Dietz, 2014). It is suggested that the contralateral reflexes and the ipsilateral SSEP reflect distinct aspects (i.e. efferent and afferent links, respectively) of the neural coupling mechanism.

In moderately affected post-stroke subjects the neural coupling was shown to be partially preserved (Schrafl-Altermatt and Dietz, 2016a). Stimulation of the unaffected arm led to bilateral reflex responses while stimulation of the affected arm failed to elicit any EMG responses. Furthermore, ipsilateral SSEP were larger when recorded over the unaffected hemisphere during cooperative

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hand movements (Schrafl-Altermatt and Dietz, 2016a, 2016b). Such an unmasking of ipsilateral pathways is one of the mechanisms that are suggested to contribute to the recovery of hand function after stroke (Teasell et al., 2005; Baker, 2011; Bradnam et al., 2013).

Also in spinal cord injury (SCI) there is evidence that ipsilateral pathways become strengthened which might contribute to functional recovery (Carmel et al., 2013; Yague et al., 2014). In contrast to stroke subjects in SCI subjects cervical tracts of both sides are damaged but the cerebral processing of afferent input is preserved.

This study aims to evaluate the capacity to activate ipsi-and contralateral non-damaged tracts in incomplete cervical SCI and consequently the potential to use the neural coupling mechanism for the training of cooperative hand movement tasks with the goal to improve outcome of hand function after a cervical injury. While healthy subjects use a balanced proportion of ipsi-to contralateral tract fibers for the neural coupling it is hypothesized that in patients with a cervical SCI all available, non-damaged, fibers of both sides become activated to maintain the mechanism of neural coupling. Thus it is expected that the ipsilateral hemisphere becomes more involved in movement performance compared to healthy subjects.

2. Methods

This study was approved by the Ethics Committee of the Canton of Zurich and conformed to the standards set by the Declaration of Helsinki. After informing the participants about the study goal and experimental procedures, they gave their written informed consent for participation.

18 patients with a traumatic cervical spinal cord injury (SCI) (mean age of 55.17 ± 13.58 years; 1 female) participated in this study. The characteristics of the patients are shown in Table 1.

Only patients with some remaining hand function were included (cf. Graded Redefined Assessment of Strength, Sensibility, and Prehension (GRASSP) values in Table 1), i.e. patients who were able to perform cooperative wrist flexion and extension movements. These patients were able to exert sufficient voluntary muscle activation that is needed to evoke ipsi-and contralateral reflex EMG responses in the forearm muscles of both sides to unilateral nerve stimulation. In addition, the damage of the peripheral nervous system (motoneurons and roots originating in the cervical cord) has limited the inclusion of patients as some impulse conduction from the ulnar nerve to the spinal cord had to be preserved.

2.1. Clinical data

The level of lesion as well as the severity of spinal cord injury was determined according to the abbreviated injury scale (AIS) of the standards of the American Spinal Injury Association (ASIA) (Maynard et al., 1997) (cf. Table 1). Focus of the clinical examination was the hand function of each side which was assessed using the GRASSP test (Kalsi-Ryan et al., 2012; Velstra et al., 2015). This test comprises a total maximum of 232 score points with a maximum of 48 points in the sensory subtest (24 points per side; taken for the SSEP recordings).

2.2. Experimental protocol

The protocol included one rest (Rest) and two movement conditions (cf. Fig. 1): A cooperative hand movement (Coop) and a bimanual non-cooperative pro-supination control task (Db). Two dumbbells (0.5 kg) were used for the non-cooperative task. Subjects with more severely impaired hand function performed the task without holding a weight. For the cooperative movements a device was used that allowed counteractive rotations of the handles, similar to that described previously (Dietz et al., 2015; Schrafl-Altermatt and Dietz, 2016a). The cooperative hand movements mimicked opening and closing of a bottle by wrist flexion and extension movements. The resistance of the handles of the device was adjusted to the subjects' abilities. Each condition and side of nerve stimulation was performed in a pseudo-randomized order.

2.3. Ulnar nerve conduction study

The integrity of the ulnar nerve on both sides had to be ensured before recording SSEPs and reflex responses. Peripheral nerve conduction was assessed by supramaximal distal (at the wrist) and proximal (at the elbow) stimulation of the nerve. To be included in the study protocol patients had to show preserved M wave in

Table 1
Clinical data of patients included in the study: Subject ID, sex (M = male and F = female), age, the abbreviated injury scale (AIS) according to the American Spinal Injury Association (ASIA), and lesion level – *: excluded subjects due to peripheral nerve damage, **: excluded for electromyographic analysis caused by technical problems and also no Graded Redefined Assessment of Strength, Sensibility, and Prehension (GRASSP) test values were measured, *** no data of somatosensory evoked potential available because of technical problems.

ID	Sex	Age	ASIA	Lesion	GRASSPsensory		GRASSPsensory	GRASSPtotal
					Left	Right	Total	
SCI_HS_01	M	54	D	C5	19	10	29	210
SCI_HS_02*	M	44	C	C5	22	18	40	88
SCI_HS_03	M	69	D	C6	23	23	46	181
SCI_HS_04	M	58	D	C4	11	9	20	140
SCI_HS_05*	M	65	A	C7	11	13	24	134
SCI_HS_06	M	73	D	C3	22	15	37	196
SCI_HS_07	M	63	D	C2	23	23	46	229
SCI_HS_08	M	71	D	C3	20	21	41	225
SCI_HS_09**	M	69	D	C4	–	–	–	–
SCI_HS_10	M	33	A	C5	17	13	30	90
SCI_HS_11	M	44	D	C5	24	24	48	225
SCI_HS_12*	M	50	B	C7	5	10	15	71
SCI_HS_13	M	64	D	C3	17	17	34	210
SCI_HS_14	M	40	C	C6	24	24	48	229
SCI_HS_15***	F	66	D	C5	14	15	29	171
SCI_HS_16***	M	53	B	C7	21	20	41	188
SCI_HS_17	M	27	B	C6	24	9	33	158
SCI_HS_18	M	50	D	C2	24	24	48	232