Clinical Neurophysiology 127 (2016) 748–754

Contents lists available at ScienceDirect

Clinical Neurophysiology

journal homepage: www.elsevier.com/locate/clinph

Cooperative hand movements in post-stroke subjects: Neural reorganization

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ARTICLE INFO

Article history:
Accepted 5 July 2015
Available online 9 July 2015

Keywords:
Cooperative hand movements
Electrophysiology
Neural coupling
Reflex activity
Stroke

HIGHLIGHTS

- A defective neural coupling underlies cooperative hand movements after stroke.
- The unaffected hemisphere is involved in the control of paretic hand movements.
- The impaired neural coupling correlates with the severity of hand movement deficit.

ABSTRACT

Objective: Recent research indicates a task-specific neural coupling controlling cooperative hand movements reflected in bilateral electromyographic reflex responses in arm muscles following unilateral nerve stimulation. Reorganization of this mechanism was explored in post-stroke patients in this study.
Methods: Electromyographic reflex responses in forearm muscles to unilateral electrical ulnar nerve stimulation were examined during cooperative and non-cooperative hand movements.
Results: Stimulation of the unaffected arm during cooperative hand movements led to electromyographic responses in bilateral forearm muscles, similar to those seen in healthy subjects, while stimulation of the affected side was followed only by ipsilateral responses. No contralateral reflex responses could be evoked in severely affected patients. The presence of contralateral responses correlated with the clinical motor impairment as assessed by the Fugl–Meyer test.
Conclusion: The observations suggest that after stroke an impaired processing of afferent input from the affected side leads to a defective neural coupling and is associated with a greater involvement of fiber tracts from the unaffected hemisphere during cooperative hand movements.
Significance: The mechanism of neural coupling underlying cooperative hand movements is shown to be defective in post-stroke patients. The neural re-organizations observed have consequences for the rehabilitation of hand function.
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1. Introduction

Bimanual tasks are assumed to require a specific form of inter-limb coordination controlled by distributed neural networks, involving cortical and subcortical areas (Donchin et al., 1998; Kazennikov et al., 1999; Kermadi et al., 2000; Debaere et al., 2001; Swinnen, 2002). Alongside these general control mechanisms, task-specificity of neural control seems to exist for different bimanual movements (Ohki and Johansson, 1999; Bracewell et al., 2003; Wiesendanger and Serrien, 2004; White et al., 2008; Alberts and Wolf, 2009). In particular, a task-specific, meaningful coordination of bimanual (Dimitriou et al., 2012; Diedrichsen et al., 2010; Omrani et al., 2013) or postural (Marsden et al., 1981) motor responses to single limb perturbations was shown to occur.

Cooperative hand movements represent a special type of bimanual task. They differ from other bimanual movements in that not only both hands are acting in synchrony but that, in order to accomplish the task, the action of one hand is supported by an appropriate counteraction of the other one, e.g. in opening a bottle. The neural control of a cooperative task has recently been studied in healthy subjects by investigating reflex responses following unilateral arm nerve stimulation (Dietz et al., 2015). Unilateral non-noxious electrical stimulations of the ulnar nerve were followed by bilateral reflex EMG responses in the forearm muscles

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http://dx.doi.org/10.1016/j.clinph.2015.07.004
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of both sides during the cooperative movement task, indicating a task-specific neural coupling. In contrast, only ipsilateral reflex responses were generated during non-cooperative bimanual control tasks. In addition, ipsilateral somatosensory potentials were larger in amplitude during cooperative hand movements compared to bimanual control tasks indicating a task-specific involvement of ipsilateral pathways in this neural coupling (Schrafl-Altermatt and Dietz, 2014).

A similar task-dependent neural coupling of arm and leg movements underlies interlimb coordination during walking (Dietz et al., 2001; Michel et al., 2008), a mechanism which is defective in stroke patients (Kloter et al., 2011).

The aim of this study was to investigate the reorganization of neural coupling underlying cooperative hand movements in post-stroke patients. The goal was to evaluate in how far this mechanism is defective and to what extent this is related to the clinical impairment of hand functions required during activities of daily living (ADL).

2. Methods

This study was approved by the local ethics committee (Kantonale Ethikkommission Zürich) and all participants gave their written informed consent.

The study was performed on 15 post-stroke patients (4 females) with a mean age of 56.2 ± 10.5 years (Table 1). All subjects had a mild to moderate hemiparesis (FM score of the affected upper limb: 51.1 ± 6.7; (Woodbury et al., 2013)) and slightly impaired perception of light touch on the affected side resulting from either an ischaemic or haemorrhagic stroke occurring at least 6 months before enrolment (time since stroke: 64.4 ± 51.0 months). Post-stroke subjects were selected according to their clinical impairments, i.e. hemiparesis resulting in the Fugl–Meyer score of the upper limb between 35 and 60 and without or only mild affection of sensory perception. Radiology reports were only available from the acute phase and did little relate to the clinical impairments. Patients with clinically apparent cognitive deficits preventing from a full understanding of task instructions and patients with diseases other than stroke impairing arm or hand function were excluded. 12 age (55.3 ± 10.4 years) and gender (4 females) matched healthy volunteers served as a control group.

2.1. General procedures and experimental conditions

The study protocol comprised of two different movement conditions, a cooperative movement task ('coop') using a device previously described (Dietz et al., 2015) and a bimanual synchronous but non-cooperative pro-/supination task ('pro-sup') with dumb-bells.

In the coop condition, patients with a right hemiparesis and right handed volunteers performed rhythmic opening movements (extension of the right wrist and flexion of the left wrist) in a continuous manner. Patients with a left hemiplegia and left handed volunteers performed corresponding closing movements. Although, handedness has been ruled out as influencing factor in previous experiments (not published) the set set-up for this study was chosen in a way that all patients performed the wrist extension movement of the coop task with their paretic hand, while healthy volunteers performed this extension movement with their dominant hand.

The resistance to the movements was set at 20% maximal voluntary force which was tested at the beginning of the experiment. For the pro-sup task, subjects held a dumb-bell in each hand. The weight was adjusted depending on the EMG background activity which was set to approximately match the EMG background activity during the coop condition. As in the coop condition, the movements were performed continuously and rhythmically. The frequency was set at 45/min for both tasks which was indicated by a metronome. Therefore, an entire movement cycle lasted for about 1.33 sec and the subsequent cycle started immediately after completion of the previous one. Every subject completed a total of about 120 movement cycles per condition.

2.2. EMG recordings

For the EMG recordings, dual surface electrodes with an inter-electrode distance of 2 cm were placed over the wrist flexor (flexor carpi ulnaris) and extensor (extensor carpi radialis) muscles of both arms. According to pilot EMG recordings, these muscles were most involved in the performance of the movement tasks investigated. EMG signals were sampled at 1500 Hz and recorded with a wireless EMG system (Noraxon, Scottsdale, AZ, USA). The signals were filtered with a band-pass filter (10–10,000 Hz), amplified (500-fold) and transferred to a personal computer. Further

Table 1
Characteristics of stroke subjects included in the study.

ID	Age (*y*)	Sex	FM score	Time since stroke (months)	Arm affected	Cause	Contralateral response N2			Reflex group	Latency group
							Aff arm	Unaff arm	Latency aff arm		
S_01	60	M	51	83	Right	Isch.	x		74	1	1
S_02	38	M	50	137	Right	Isch.	x		88	1	1
S_03	56	M	52	105	Right	Haem.	x	x	105	2	2
S_04	49	M	58	57	Right	Isch.	x	x	131	2	2
S_05	50	M	47	73	Right	Haem.	x		88	1	1
S_06	64	F	54	56	Right	Isch.	x		82	1	1
S_07	56	F	38	38	Right	Isch.				0	
S_08	64	F	42	14	Right	Haem.	x		84	1	1
S_09	47	M	44	63	Left	Jaem.				0	
S_10	63	M	46	209	Left	Isch.				0	
S_11	56	M	60	26	Left	Isch.	x	x	108	2	2
S_12	73	M	59	20	Left	Isch.	x	x	118	2	2
S_13	34	M	57	35	Left	Isch.				0	
S_14	49	F	43	29	Right	Isch.				0	
S_15	69	M	56	21	Left	Isch.	x		124	1	2

Left: Clinical characteristics of the post-stroke subjects included in the study with Fugl–Meyer (FM) score and the cause of spastic paresis (isch = ischemia, haem = hemorrhage). Right: Characteristics of the contralateral responses to nerve stimulation of the affected (aff) and unaffected (unaff) arm respectively. Contralateral N2 response 'aff arm': responses in affected forearm muscles following nerve stimulation of the unaffected arm and vice versa for the response 'unaff arm'. The "reflex group" refers to the number of contralateral reflex responses and the "latency group" refers to a short latency (1) and a long latency (2) of the contralateral reflex response in the affected arm to stimulation of the unaffected arm.

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