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Recovery of motor function after stroke: A polymyography-based analysis

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ABSTRACT

We present a method for assessing muscle activation patterns during goal-directed movement. We present a cohort study from a randomized clinical trial that followed the recovery of motor function during and after intensive gait training, assisted by sensor-driven, four-channel electrical stimulation. The instrument that we developed allows for the simultaneous recordings of up to 16 channels that are wirelessly sent to a host computer, which then provides feedback to the subject. The inputs to the portable instrument support electromyography (EMG) amplifiers, inertial sensors and goniometers. We show that this method is sensitive enough to show changes in muscle activation patterns in stroke patients before and after gait training (four weeks, five days a week, 30 min daily). We also show that the recovery decreases the differences between patterns of muscle activities (e.g., levels of muscle activations and median frequencies) assessed in hemiplegic and healthy subjects. This method allows for the analysis of muscle contributions and activation patterns; therefore, it might be possible to better understand the physiology behind the recovery of function. This EMG analysis provides a quantification of recovery that is a valuable addition to other measures, such as the Fugl-Meyer score, the Berg-Balance score, gait speed, and the symmetry index.

1. Introduction

Cerebrovascular accidents (stroke) often cause serious long-term disability, including hemiparesis, which affects many sensory-motor functions, including the ability to walk. Basic research related to the plasticity of the central nervous system and clinical work with hemiparetic subjects suggest that intensive gait exercise augmented with robots, which provide partial body weight support and generate near-normal movements, can contribute to the re-training of motor function (Visintin et al., 1998; Werner et al., 2002; Hesse et al., 2003; Moseley et al., 2005; Miyai et al., 2006; Daly et al., 2007; McCain and Smith, 2007; Mayr et al., 2007; Ivey et al., 2008; Yen et al., 2008; Enzinger et al., 2009; Dean et al., 2010; Yang et al., 2010). There is also evidence that functional electrical stimulation that supports diminished function also contributes to this recovery (Tong et al., 2006; Ng et al., 2008; Kesar et al., 2010; Embrey et al., 2010; Stein et al., 2010). However, the mechanism and determinants of this restorative process are not completely understood. Methods for studying the physiological basis of the eventual recovery concentrate on correlations of functional status with functional magnetic resonance imaging (fMRI) (Dobkin et al., 2004; Luft et al., 2008; Yen et al., 2008; Everaert et al., 2010) or, more recently, near infrared spectroscopy (NIRS) (Kato et al., 2002). Imaging studies have provided evidence that therapy changes cortical excitability for a period of several hours and that some of these changes have carry-over effects that directly translate into the modification of cortical input to the spinal cord circuitry (Ward et al., 2003; Carey et al., 2004; Enzinger et al., 2008; Sharma et al., 2009; Page et al., 2009). Analysis of evoked potentials using transcranial magnetic stimulation (TMS) confirmed that the changes in cortical excitability and the carry-over effects are the consequence of augmented intensive training (Richards et al., 2008).

This study presents a polymyographic analysis of the activation patterns of prime joint movers as a useful method to achieve a better understanding of functional recovery in stroke patients. Studies emphasizing the role of activation patterns in the control of movement were the basis for this work (Kautz et al., 2005; d'Avella and Bizzi, 2005; Ivanenko et al., 2006; Katz et al., 2008; Clark et al., 2010; Achache et al., 2010). This analysis was made possible with an instrument that integrated small low-noise amplifiers, a set of sensors that provided information about kinematics, and a data logger that wirelessly communicated with the host computer. The

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Table 1
Basic data of stroke subjects.

Group	Age	Sex	Affected (paretic) side	Days after stroke	Origin of stroke	Fugl-Meyer score (before/after treatment)	Berg-Balance test (before/after treatment)	v (m/s) (before/after treatment)	Symmetry index (before/after treatment)
	69	Male	Right	16	Hemorrhagic	19/30	31/42	0.18/0.36	74/87
	70	Male	Right	25	Ischemic	23/31	36/46	0.31/0.35	77/84
FET	41	Male	Left	16	Ischemic	23/28	39/47	0.28/0.64	84/82
	52	Female	Left	26	Ischemic	19/28	42/43	0.15/0.24	77/83
	69	Male	Left	31	Ischemic	20/30	30/35	0.30/0.34	82/89
	45	Male	Left	16	Ischemic	17/25	33/40	0.20/0.26	78/82
	40	Female	Right	24	Ischemic	16/22	31/37	0.20/0.21	81/86
CON	67	Male	Right	26	Hemorrhagic	28/32	39/44	0.40/0.56	82/83
	67	Male	Left	32	Ischemic	18/28	31/39	0.23/0.31	78/85
	68	Male	Left	20	Ischemic	31/33	45/48	0.41/0.49	84/88

instrument allows for a reproducible analysis of defined movement based on visual feedback provided to the tested subjects (Miljković et al., in press) and can be used for long recording sessions in the clinical environment without any other instrumentation. Wireless communication was introduced for other movement analyses (e.g., free gait and standing). The user-friendly software provided on-line tracking of the experiments and on-line data analysis.

The illustration of the instrument and the method of analysis come from a cohort study of the efficacy of functional electrical therapy (FET) in stroke patients (Kojović et al., 2009). This method was used for the analysis of a single joint movement (dorsiflexion). The clinical outcomes used in these cohort studies were the Fugl-Meyer (FM) score for lower extremities and the Berg-Balance (BB) score. Gait speed and symmetry index were also considered as measures of the recovery.

2. Methods and materials

2.1. Subjects

The benchmark data were created from experiments with 10 age-matched (57 ± 11 age of years), healthy volunteers with no known neurological or orthopedic deficits (HEALTHY group).

The FET group included five out of seven patients who underwent FET and five out of six patients who exercised walking in the same manner as the FET group but without electrical stimulation (CON group) at the Institute of Rehabilitation "Dr. Miroslav Zotović", Belgrade, Serbia (Table 1). All subjects received the therapy typical for rehabilitation in the acute and subacute stages of hemiplegia. In addition, the FET group included 30 min of daily walking (five days a week, for four weeks), assisted by sensor-driven multi-channel electrical stimulation. The CON treatment included 30 min of daily walking five days a week for four weeks without electrical stimulation. Details about the FET instruments and study design have been described by Kojović et al. (2009). Inclusion criteria were the presence of unilateral motor deficit in the lower extremities, the ability to stand independently or with the assistance of a therapist, and being in the acute or subacute phase of stroke. Patients who had cognitive deficits were excluded because of their inability to follow the protocol; three subjects who participated in the clinical trial were excluded due to their inability to participate in all of the testing sessions.

Patients were evaluated for motor impairment and the severity of the impairment by a licensed physical therapist. The motor recovery status of those patients was assessed with the FM scale for the lower extremities. The motor score ranges from 0 to a maximum of 34 points (normal motor performance). The other test used was the BB test, which is a commonly used assessment tool for identifying balance impairment. Overall scores can range from 0 (severely impaired balance) to 56 (normal balance).

The symmetry index (SI) was calculated by modifying the formula proposed by Robinson et al. (1987) so that higher value reflected better symmetry. The symmetry index can be estimated for the stance or swing phase and for the whole stride as follows:

$$\mathrm{SI}\quad[\%] = \left[1 - 2\frac{T_{\mathrm{paretic}} - T_{\mathrm{nonparetic}}}{T_{\mathrm{paretic}} + T_{\mathrm{nonparetic}}}\right] \times 100$$

where terms T_{paretic} and $T_{\mathrm{nonparetic}}$ are the duration of the gait phases for the paretic and nonparetic legs. The ideal SI is 100. The gait speed and symmetry index were assessed while patients covered a distance of 6 m. In this study, we present the SI for the stance phase.

All subjects signed a written informed consent form approved by the local ethics board.