Analysis of Trunk and Upper Limb Synergies

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Abstract. A new method of recording and reconstruction of upper-limb kinematics has been developed in order to analyze the mechanisms of motor recovery in disabled patients. It has been applied to the analysis of non-constrained gestures in normal subjects and in patients with an hemiparesis following stroke. The results show evidence of new motor strategies and new co-ordinations developed to compensate for the motor impairment. In the future, this method could be applied to gesture recognition and synthesis and for the development of enhanced learning environments in rehabilitation.

1 Introduction

After a disease or an accident, inducing a motor impairment people may lose a part of their functional ability and remain handicapped. For example, after a stroke, the patients present a complete paralysis of the limbs contra-lateral to the damaged cerebral hemisphere. In half of the cases, the paralysis recovers partially within a few months but the mechanism of recovery are still disputed. The plasticity of the neural system is now well demonstrated but its relationships with the sensory-motor function, the importance of learning and the specificity of rehabilitation methods remain unclear [1].

The resulting motor function depends on the initial impairment but also on a dynamic process. The patients may adapt their residual motor function through to their environment by motor learning in order to fulfill daily living tasks. This process may include spontaneous recovery due to neural plasticity, the acquisition of some compensatory motor strategies and/or the development of new inter-joint co-ordinations thanks to the redundant properties of the motor system [2]. It is particularly important to distinguish these potential mechanisms for a better understanding of neural plasticity and for the development of functional rehabilitation methods.
The present study was initiated following the hypothesis that the kinematic characteristics of non constrained gestures could give some indications on the underlying recovery process. We had to develop an original method since there was no other suitable or standard one. Four electromagnetic Fastrack Polhemus sensors were used in order to record the position and orientation of the upper limb segments (hand, forearm, upper-arm and scapula). Then an algorithm based on the rigid-body assumption allowed the reconstruction of the 7 inter-joint angles (degrees of freedom) of the upper-limb [3].

2 Methods

2.1 Subjects

15 patients participated in the study: 6 had a left side and 9 a right side hemiplegia after an ischemic stroke in the territory of the middle cerebral artery. 9 of them were examined at least twice at one month interval. 7 normal subjects served as controls.

2.2 Task and Procedure

The experimental set-up was planned to be as functional as possible, to allow natural reaching and grasping gestures in a context similar to everyday life, without artificial limb immobilization. The goal of the task was to grasp a hollow cardboard cone commonly used in occupational therapy. The objects were placed on an horizontal board at seven possible positions. The closer position was 15 cm in front of the subject in the midline, the others were 10 cm on the right or the left and 10 to 20 cm forward.

2.3 Recording Method and Bio-mechanical Reconstruction

Four Polhemus markers were fixed by adhesive tape on the hand, forearm, upper-arm and acromion (upper part of the scapula). They give the three co-ordinates of the origins of marker’s reference frames as well as the Euler angles of marker’s axes rotations relative to stationary axes. The sampling frequency is 30 Hz. In some studies in normal subjects, a 3D accelerometer was also fixed on the hand.

We used a bio-mechanical model of the human upper limb consisting of three rigid links connected by ideal joints and having 7 degrees of freedom (DoF): 3 DoF in the shoulder joint, 2 DoF both in the elbow and in the wrist joints. To reconstruct the joint angles corresponding to each DoF we have first determined the positions of the axes of rotation in the marker’s reference frames. The method of calculation of position of joint centers and axes of rotation was based on the least squares method. This gave the center of the shoulder joint by reference to the scapula marker (3 variables), and the position and direction of the 2 elbow and 2 wrist axes by reference to the corresponding markers. The joint angles around the determined axes of rotation were calculated under the assumption