Coordination of the Dynamic Phases of EMG Activity in Human Elbow Flexors in the Performance of Targeted Tracking Movements

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INTRODUCTION

In many cases hypotheses on the principles of central control of simple one-joint movements are based on the concept of a single-valued relation among main macroparameters characterizing the state of a joint, i.e., external loading, joint angle, and the level of efferent activity coming to the muscles of the joint. According to these hypotheses, the central nervous system (CNS) is capable of positioning the joint in certain equilibrium states due to preliminary formation of corresponding equilibrium stationary levels of the efferent activity. In other words, it is supposed that there is a single-valued code: level of the central efferent activity — equilibrium angle [1-5]. Within this framework, the dynamic phase of a motor command is considered either an event reflecting single transition from one equilibrium level of the efferent activity to another level, or as a segment of the activity related to realization of the equilibrium trajectory providing transition to a necessary equilibrium level.

At the same time, there are rather numerous data about non-linear properties of the muscle contraction itself [6-9]. These data show that the existence of a single-valued dependence among the external loading, length of the muscle, and efferent activity coming to this muscle is doubtful in principle. Studies on the ankle joint in humans showed [10] that, at realization of a targeted movement under conditions of a steady external loading, one and the same position was reached at considerably dissimilar, depending on the movement...
pre-history, levels of the efferent activity coming to the ankle muscles in a position of the steady equilibrium.

Therefore, we can suppose that achievement of a certain joint position (or an equilibrium joint angle) is not fully determined by some stationary level of the motor activity coming to the joint muscles. Consequently, it seemed interesting to examine the following possibility: Can the control of targeted transition of a joint from one equilibrium position to another be realized due to coordination of dynamic phases of motor commands?

It is well known that ballistic movements are controlled mostly by the parameters of dynamic phases of muscle activity and their coordination. This class of movements is characterized by a certain temporal sequence of EMG activities of the antagonistic muscles, the so-called three-burst pattern. Now detailed data on correlation of the bursts of EMG activity in the three-burst pattern with the inertial loading, amplitude, velocity, and duration of ballistic movements have been collected [11-18]. These data show that under conditions of these movements the first EMG burst generated by the agonists probably controls the parameters of the movement to a target. The second burst generated by the antagonists interacts at a definite stage with the above agonist activity, which results in achievement of the equilibrium at a predetermined value of the joint angle. Yet, it was mentioned above that these results relate only to rather fast movements connected with the presence of significant alternating moments of inertia. At the same time, the functional role of dynamic phases of motor commands controlling relatively slow targeted transitions of a joint to new equilibrium positions is studied to a much lesser extent.

In our present testings in humans, we studied modifications of EMG activity of the flexor muscles of the elbow joint at slow targeted transitions of the arm from one position to another. We studied a wide range of the changes of the joint angles under conditions when significant alternating inertial moments were absent. We paid main attention to the functional roles of dynamic and stationary phases of motor commands in this class of movements. Single-joint movements in the elbow joint of humans were studied under the influence of a steady external loading against the torque developed by the flexors, i.e., under conditions similar to those used earlier in several studies [5, 10, 19]. In this case, both movements of the arm and transition to an equilibrium position were provided exclusively by the agonists’ activity, and the function of antagonists was substituted by the influence of a steady external loading. If in this case we choose some rather slow movement velocity and use a non-inertial external loading, the alternating inertial moment can be reduced to a minimum value that could be neglected. The above-described experimental situation, in which movements are controlled exclusively by agonists, looked to us preferable because it is rather simpler than other situations.

METHODS

In the course of the experiments, tested persons were sitting near a horizontal plate, situated at the level of the arm-pit. The shoulder was fixed to this plate, and the angle between the shoulder axis and the tangent to the breast surface was equal to 90°. The arm was fixed to a light manipulandum (the inertial moment of 0.07 Nm·sec²/rad), which could rotate within the horizontal plane for 110°. The integral inertial moment of the manipulandum and the arm could be evaluated approximately as 0.16-0.17 Nm·sec²/rad. The axis of the elbow joint for the flexion-extension movements coincided with the axle of the manipulandum coupled to a servocontrolled mechanostimulator. The latter functioned in a force control mode that allowed us to apply various external non-inertial steady loadings to the arm, directed against the flexing torque. The time constant of a transition process of the mechanostimulator and proper compliance of the device did not exceed 60 msec and 50 N/mm, respectively. The mechanostimulator was provided with a force transducer (a system of tenoresistors) and an angle transducer (a precision potentiometer or a capacitance transducer), which made it possible to record with sufficient accuracy the changes of the external loading and joint angle. With the use of standard bipolar surface electrodes, we recorded EMG activity from three elbow flexors: two heads of the m. biceps brachii (cap. longum and cap. breve) and m. brachioradialis, as well from one elbow extensor, m. triceps brachii (cap. longum). After amplification, EMG were full-wave rectified, filtered (the filter band-pass of 50-500 Hz), and smoothed.

Performance of the motor task proposed to the tested individuals was indicated as a movement of the light indicator point on the monitor screen. Its position along the Y axis reflected flexion or extension of the elbow measured by the joint angle transducer. The indicator point had to follow another light point, a target. The people were instructed to follow this visual target, approximately reproducing its velocity, and to stop at the place of its fixation.

Two limitations were put on the movement performance. First, the people should not introduce voluntary corrections in the velocity of the indicator point movement, established after leaving an equilibrium state, including the cases when this velocity somewhat differed from the target velocity. Second, joint rotation should be stopped near a target-indicated position without post-corrections of this position with additional flexion or extension. When the subject strictly followed these limitations, we were able to obtain simple conjoint