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Movement-related phasic muscle activation. III. The duration of phasic agonist activity initiating movement

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Abstract To test the hypothesis that phasic muscle activation is related to the acceleration-deceleration characteristics of the resulting movement, we examined the relation between the duration of the acceleratory phase of a variety of movement types and the duration of the phasic muscle activity producing the acceleration (the initial agonist burst, AG1). Movements of five types were studied: (1) step-tracking movements of different amplitudes (10–90 deg) and durations (200–800 ms), (2) movements of the same amplitude (40 deg) and duration (600 ms) varying only in their symmetry ratio (SR, ratio of acceleration to deceleration durations), (3) movements in which acceleration duration was changed while acceleration magnitude was held constant, (4) oscillatory movements of different frequencies and peak amplitudes, (5) step-tracking movements against different inertial loads. Subjects made movements about the elbow joint in the horizontal plane. Surface electromyographic (EMG) activity was recorded from the biceps and the lateral head of the triceps muscles. Under all movement conditions tested and with acceleration duration ranging from 100 to 500 ms, acceleration duration varied linearly with the duration of AG1. Correlation coefficients for the linear regression lines ranged from 0.8 to 0.99. The slope of the best fit linear regression lines ranged from 0.5 to 1.6 and tended to be higher for extensions than flexions. The variations in slope may arise from differing mechanical properties of the biceps and triceps muscles, as well as from active forces produced in the antagonist. AG1 duration was unchanged by inertial loading when subjects kept acceleration duration constant. If subjects responded to an increase in inertial load with an increase in acceleration duration, there was a corresponding increase in AG1 duration. The data demonstrate a general relation between one characteristic of muscle activation (AG1 duration) and the resulting movement. The linear form of the relation is invariant across movement amplitude (range 10–90 deg), speed, duration (range 200–800 ms) and temporal profile (SR range 0.3–2.7), and is also independent of movement type (step, oscillatory). Such a general and simple relation between EMG and movement suggests that, at least to a first approximation, the nervous system can rather simply determine the muscle activation patterns needed to produce movements with desired characteristics.

Key words Movement · EMG · Acceleration Burst duration · Human

Introduction

This paper is the third in a series of studies on the relation between phasic muscle activation and voluntary movement in humans (Brown and Cooke 1990; Cooke and Brown 1990). The aim of these studies has been to determine what movement characteristics the motor system considers when planning or programming the motor commands required for a desired movement. We have approached this fundamental question by studying the relation between muscle activity (EMG) and the resulting movement. The EMG is reflective of the muscle forces involved in the movement and must therefore reflect the final commands responsible for movement generation. A finding of general or invariant EMG–movement relations would then suggest common or general rules used by the CNS in formulating movement commands.

What movement characteristics might the central nervous system consider when formulating the motor commands for a desired movement? In many simple, single-joint movements, muscle activation occurs in a typical 'triphasic' pattern (Brown and Cooke 1981; Hal-
An initial burst of agonist activity (AG1) is followed sequentially by a burst in the antagonist (ANT) and a second, less well defined agonist burst (AG2) (Hallett et al. 1975). We have recently shown that the antagonist burst consists of two separable parts, ANT1 and ANT2 (Cooke and Brown 1990). In trying to determine the function of the components of the triphasic pattern, most investigators have concentrated on the relations between the characteristics of the EMG pattern and such movement properties as amplitude, duration or speed. For instance, AG1 duration and magnitude increase with both movement amplitude and speed (Benecke et al. 1985; Berardelli et al. 1984; Brown and Cooke 1981, 1984; Hallett and Marsden 1979; Hoffman and Strick 1990; Mustard and Lee 1987). ANT magnitude has also been described as varying with movement amplitude (e.g., Brown and Cooke 1981; Hoffman and Strick 1990; Marsden et al. 1983; Mustard and Lee 1987; Wadman et al. 1979), although whether the relation is proportional or inverse is still unclear. The time of occurrence of ANT also varies with movement duration, appearing to be linked to the time of peak movement velocity (Hoffman and Strick 1990; Lestienne 1979; Sherwood et al. 1988; Wadman et al. 1979).

The function of the triphasic bursts has also been studied through altering the load being moved by the subject. Thus, for example, AG1 duration may increase with inertial load in the situation in which the subject is free to choose his own movement characteristics (movement strategy) (Angel 1974; Benecke et al. 1985; Berardelli et al. 1984). If, however, total movement duration is held constant, AG1 duration does not change with inertial load (Sherwood et al. 1988). Both AG1 and ANT magnitudes increase with increasing inertial load (Lestienne 1979; Karst and Hasan 1987; but see also Cooke and Brown 1992).

In part, the dependence of the EMG on such movement characteristics as amplitude and speed was investigated because these movement properties appeared intuitively to be important. Until recently they were also the only movement characteristics which could be readily manipulated by the investigator. The development of the technique of phase plane tracking (Cooke and Brown 1986) provided us with a method for training normal humans to make movements having different temporal structures. Step-tracking movements (the most commonly studied movements) normally have a typically bell-shaped velocity profile (Nelson 1983; Ostry et al. 1987). The observation that the form of the velocity profile is invariant under transformations of movement amplitude and duration suggested that such movements belong to an equivalence class. That is, a common organizing principle may underlie the production of all such movements; the triphasic EMG pattern being, perhaps, indicative of a common motor program. However, using the phase plane-tracking technique to alter the shape of the velocity profile, we demonstrated that (1) a triphasic EMG pattern is used to produce movements not belonging to the same equivalence class and (2) striking changes in the characteristics of the triphasic EMG pattern occurred independent of any changes in movement amplitude, duration, or speed (Brown and Cooke 1990). This and our subsequent study on the EMG activity associated with movements made at constant velocity (Cooke and Brown 1990) led us to postulate that the properties of the various components of the triphasic pattern might best be related to the acceleration and deceleration properties of the desired movement (Brown and Cooke 1990). The same hypothesis may be arrived at by remembering that the EMG must, in some way, reflect the force being exerted by the muscle. If acceleration provides a measure of force (as is likely at least to a first approximation) then EMG should relate to acceleration. Such a relation has been suggested from the study of Wallace (1989) who found a strong correlation between EMG burst duration and the period of oscillatory forearm movements.

In the present study we have tested this hypothesis by determining the relation between AG1 duration and acceleration duration under a variety of movement conditions. Our aim was to determine whether the AG1-acceleration relation has an invariant form independent of the type of movement being made (e.g., step tracking, oscillatory) and of various manipulations in movement characteristics (e.g., amplitude, duration, temporal profile). We further hypothesized that the increase in AG1 duration which results from increasing the inertial load (Angel 1974; Berardelli et al. 1984; Benecke et al. 1985) should be associated with an increase in acceleration duration. If acceleration duration is held constant, AG1 duration should not change with inertial load.

We will present data showing that the form of the AG1-acceleration duration relation is very close to linear under all conditions tested and that manipulations such as loading—which alter acceleration duration—are associated with changed AG1 duration. Parts of the present data have been presented elsewhere in abstract form (Cooke and Brown 1989).

### Materials and methods

Experiments were performed on 14 subjects aged 21–50 years with no known history of neurological disorders. A minimum of three subjects performed each of the experimental conditions to be described. Presented data are representative of all subjects tested. Each subject was seated comfortably and grasped a vertical rod attached to a horizontal manipulandum handle. The subject's upper arm was abducted 90 deg and supported at the elbow directly beneath the pivot point of the handle. Several different movement tasks were employed requiring flexion and extension movements about the elbow in the horizontal plane. In all tasks, both target and handle positions were displayed on an oscilloscope positioned approximately 1 m in front of the subject.