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Trajectory control in targeted force impulses

II. Pulse height control

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Summary. The present report examines the control strategy adopted by subjects to modulate the amplitude of transient force responses aimed to a target. Previous studies (Freund and Budingen 1978; Ghez and Vicario 1978) suggest that subjects modulate the rate of rise of force while maintaining force rise time at a near-constant value, independent of peak force. Such studies, however, have examined only the most rapid responses where force rise time could have been at a physiological limit. We now examine whether this control policy is dependent on an instruction to produce the fastest possible trajectories, or whether it is freely selected by subjects to maximize accuracy when rise time is unconstrained. We compared responses made by six subjects, under two task conditions: *1*. Fast, "make the force impulse as brief as possible"; and *2*. Accurate, "be as accurate as possible without regard to rise time". Subjects were trained to produce monotonic flexion force impulses at the elbow to match the amplitudes of visually presented target shifts. Targets of three different were presented in randomized order. Responses made under the Accurate condition were less variable at each target amplitude than those under the Fast condition. Under both conditions, the initial peaks of the first and second time derivatives of force, early measures of trajectory dynamics, were strongly predictive of the peak force achieved and were correlated with the required force (target amplitude). Therefore, response trajectories must have been largely preprogrammed, and, further, the degree to which the initial peak d^2F/dt^2 predicts the peak force achieved represents a measure of the contribution of a preplanned motor program to trajectory formation. Subjects showed two systematic differences in trajectories between conditions. First, in all subjects force rise time was greater in the Accurate condition than in the Fast condition. Second, while in the Fast condition there was a modest dependence of force rise time on peak force, in the Accurate condition this dependence disappeared. Thus, when subjects were attempting to be as accurate as possible, they more consistently regulated force rise time around a constant value. This pulse height control policy allows responses of different amplitudes to be produced by proportional scaling of a stereotyped waveform. We conclude that a pulse height control policy with regulation of force rise time is a strategy adopted by subjects to simplify accurate control of response amplitude.

Key words: Human subjects – Isometric – Trajectory control – Motor programs – Accuracy – Agonist-antagonist EMG pattern

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Introduction

On the basis of experiments performed almost a century ago, Woodworth (1899) postulated two phases in the control of targeted limb movements. The first phase was an "initial adjustment" which governed most of the limb's trajectory to the target, while the second phase of "current control" brought the limb to the target through a series of corrections. Woodworth believed that the initial adjustment was the expression of a plan that specified "...the innervation of different muscles one after the other... [and]...also a command to stop after a certain distance" (p. 55). He considered the corrections occurring during the phase of current control to be reactions to visual or kinesthetic stimuli arising from the movement itself. A similar view of the control of targeted movements is still widely held today (see Brooks 1979 for review). Simple limb movements to