Anticipatory postural adjustment in the absence of normal peripheral feedback

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The responses to voluntary unloading (by the subject's contralateral arm) and imposed unloading (by the experimenter) of a 1 kg weight supported at the wrist were studied in normal volunteers (controls) and in a deafferented subject (patient). The patient had no touch, pressure or kinesthetic sensations in either of the arms, but the motor nerve fibers were unaffected. The reflex activity generated by imposed unloading in the controls was never observed in the patient. The displacement's amplitude of the unloaded forearm was 3x smaller with voluntary than with imposed unloading. In both the controls and the patient, the displacement was of similar amplitude and preceded by an anticipatory postural adjustment. It is concluded that this postural adjustment is of central origin since it can be generated in the absence of peripheral feedback.

The nature of the contribution of sensory inputs to the planning and execution of motor commands is an important issue. One way to explore it is to study motor output in the absence of peripheral feedback, putting the motor command system into an open loop condition. The present paper describes the anticipatory postural adjustments in a bimanual task studied in normal human subjects and in one patient deprived of proprioceptive and cutaneous peripheral afferents but with an intact peripheral motor system.

Movement of the limbs can displace the body's center of gravity and anticipatory postural adjustments are known to occur to reduce instability. For example, leg and trunk muscles are activated prior to a voluntary movement of the arm and this activity is specific to the muscles involved in the postural adjustment\textsuperscript{1,3,6}. Similar anticipatory postural adjustments occur between arms in bimanual tasks. When a subject uses his arm to suddenly remove a weight supported by the other hand, the unloaded limb shows very little displacement as compared to unloading performed by the experimenter. Hugon et al.\textsuperscript{7} have demonstrated that an anticipatory deactivation of the muscles supporting the weight is part of the postural compensation preventing the undesirable movement of the unloaded limb. The muscle activity in the 'postural' arm falls prior to the removal of the weight, at about the same time as the activation of the muscles in the contralateral 'lifting' arm used to remove the weight. However, the knowledge of the precise time of unloading is not sufficient to produce an anticipatory adjustment\textsuperscript{4}, nor is a voluntary movement that is not directly responsible for lifting the weight (i.e. in a condition where the contralateral hand is used only to trigger a mechanical system which unloads the limb). Thus, coordinated voluntary movements of the contralateral limb which directly remove the weight appear to be necessary for the appearance of an anticipatory postural adjustment. Some observations suggest that this postural response is impaired in patients with cortical lesions involving the supplementary motor area\textsuperscript{8}. However, it is not known if peripheral feedback, particularly that originating from the 'lifting' arm is necessary for the elaboration of the anticipatory postural response in the 'postural' arm.

To answer this question we studied unloading of the forearm in 5 normal subjects (aged 24-33) and in one functionally deafferented subject (aged 37). Briefly, this woman has suffered a permanent and specific loss of the large sensory myelinated fibers in her 4 limbs following a second episode of sensory polyneuropathy 3 years prior to her participation in this series of experiments. The resulting clinical picture was a loss of all sensory modalities except pain and temperature. The motor pathways remain intact. A more complete clinical

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description of patient G.L. can be found elsewhere. The deafferented and the control subjects were seated on an adjustable chair with the right shoulder in a neutral position and the elbow 90° flexed. The forearm was in a neutral position (zero supination-pronation) and a 1 kg weight was hanging from the right wrist (always the side to be unloaded). Right shoulder extension was prevented by a cushion at the triceps level. There were two unloading conditions: in the imposed unloading, the experimenter removed the weight by pulling a handle situated above the subject’s wrist and attached directly to the load; in the voluntary unloading condition, the subject responded to an auditory stimulus (50 ms, 800 Hz, 35 dB) by rapidly pulling the handle using a flexion movement of the contralateral left elbow. After one practice trial, 10 consecutive trials were recorded for each unloading condition. The experiments were performed without visual feedback. In the deafferented subject, trials with visual feedback were also recorded and yielded similar results.

Angular displacement of the right elbow was measured by a precision potentiometer. Raw and integrated EMG signals from the biceps and anconeus muscles on both sides were recorded from 500 ms before to 1500 ms after the unloading. The raw EMG was rectified and integrated by a circuit with a voltage reset threshold where each reset gave a pulse. The frequency of the pulses was thus proportional to the energy of the signal and an envelope was made from the frequency histogram. Other considerations as to the recording and treatment of data were presented elsewhere.

Figs. 1 and 2 show, for individual and averaged trials respectively, that the forearm angular displacement following unloading was of similar amplitude in a normal (A,B) and in the deafferented subject (C,D). Similar results were obtained in the other normal subjects. The average amplitude of the elbow rotation of the unloaded arm was about three times greater with imposed (A,C) unloading (controls: 16 ± 2°; deafferented: 16 ± 4°) than with voluntary (B,D) unloading (controls: 5 ± 2°; deafferented: 5 ± 3°). The deafferented subject showed a tendency to drift in flexion some 150 ms after the forearm had stabilized in its position following active unloading (D).

With imposed unloading in the normal subjects, the shortening right biceps muscle showed a decreased EMG activity within 50 ms (39 ± 18 ms) after the onset of elbow displacement (RB, Figs. 1A, 2A) while the activity increased in the lengthening right anconeus, less than 100 ms (72 ± 23 ms) after the onset of movement (RA, Figs. 1A, 2A). These short latency reflex responses were not seen in the deafferented subject (RB and RA, Figs. 1C, 2C). However, an increase in the EMG activity was often observed at longer latencies in the biceps (236 ± 58 ms) and in the anconeus (171 ± 29 ms) of the deafferented subject. This activity appears to be a voluntary response to the unloading since the deafferented subject mentioned that she was somehow aware of the unloading through a feeling in her head and neck.

With voluntary unloading, the EMG records confirmed the presence of an anticipatory postural adjustment in both the deafferented subject (RB, RA, Figs. 1D, 2D) and normals (RB, RA, Figs. 1B, 2B). This adjustment consisted of a decrease of activity in the right biceps and an increase in the right anconeus occurring, on the average, 70 ms prior to the onset of elbow displacement. At about the same time the contralateral left biceps and anconeus (LB, LA) were activated to remove the weight.

Fig. 1. Raw EMG (top 4 traces) and elbow angular displacement (lower trace) in a normal subject (A and B) and a deafferented subject (C and D) following an imposed (A and C) and a voluntary (B and D) unloading of a 1 kg weight supported at the right wrist. Right biceps (RB), right anconeus (RA), left biceps (LB) and left anconeus (LA) EMG activity is presented in a similar order in each of the 4 sections. The vertical lines represent the movement onset time.
Fig. 2. Envelope of integrated EMG and elbow displacement averaged over 10 consecutive trials. Each series of trace represents the same conditions, and the same normal and deafferented subject as in Fig. 1. The muscle activity and the movement are also presented in the same order.

Functionally deafferented patients tend to show much more tonic activity and cocontraction during postural holds. It is also evident here from traces C and D (Figs. 1 and 2). This difference in strategy could explain why, in the deafferented subject, the EMG postural responses tended to show more amplitude variation than in the normal subjects and also why the 'postural' arm tended to drift in flexion late in the task.

The results reported here confirm the previous observation by Hugon et al. that voluntary unloading in normal subjects produces an anticipatory postural adjustment to minimize displacement of the unloaded limb. This is characterized by a phasic decrease in the EMG activity of the unloaded muscle that occurs some 100 ms prior to unloading and at about the time that the contralateral muscles (responsible for removing the weight) are activated. Moreover, we observed that this postural adjustment involves not only a decrease in the activity of the muscle supporting the weight, but also an increase in the antagonists, thus further limiting the displacement.

The presence of such anticipatory postural adjustments
in a functionally deafferented subject indicates that
proprioceptive and cutaneous feedback from the 'active'
as well as from the 'postural' arm is not a necessary
condition for the generation of these postural reactions.
A central origin is also supported by the results of Viallet
et al.8 who found impairment of such postural reactions
in patients with cortical lesions involving the supplementary
motor area.

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