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Postural forearm changes induced by predictable in time or voluntary triggered unloading in man

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Summary. Human subjects sitting in a chair were asked to maintain their right forearm in a horizontal position in half supination. The forearm was loaded with a constant weight of one kilogram. Vertical force at the wrist level, angular position of the elbow and EMG activity of biceps, brachio-radialis and triceps muscles were recorded. Unloading was tested under four different conditions, the first two having been used in a previous study (Hugon et al. 1982): (A) Voluntary unloading by the subject's other hand. An "anticipatory" deactivation of the load bearing forearm flexors is observed preventing the elbow rotation of that arm. (B) Unpredictable passive unloading. This results in an upward forearm rotation which provokes the classical "unloading reflex". Two new conditions were tested in the present paradigm: (C) Imposed unloading predictable in time (tone signal preceding unloading by a fixed interval). (D) Unloading being actively triggered when the subject presses a key. Under the two latter conditions, no anticipatory deactivation of the flexor supporting muscles preceding the onset of unloading as in situation A was observed. During the first 120 ms after the onset of unloading, the forearm rotation was the same as in situation B (unpredictable passive unloading). Thereafter, the rotation was smaller in some subjects, apparently due to an ameliorated reflex action. It is concluded that temporal information concerning the precise time of the unloading or the triggering of the load release by a voluntary movement (key press) was not by itself able to induce the anticipatory deactivation of the forearm flexors that was seen with a coordinated voluntary release of the load by the contralateral arm.

Key words: Posture – Unloading reflex – Voluntary movement – Anticipatory postural reaction

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Introduction

In many bimanual tasks, one hand has a rather postural role, for example holding an object, while the other hand is used to manipulate the object, lifting it from the postural hand or loading it on that hand. When lifting the object is performed, even when the object is heavy, the postural unloaded hand does not move upwards as would be expected from mechanical laws; the flexor muscles which resist the load do not act as springs provoking an upward movement after unloading. As previously shown (Hugon et al. 1982), an anticipatory deactivation of the flexor muscles prevents the upward rotation when the unloading is actively performed by the subject.

Two hypothesis may account for the mechanism by which the active movement of one arm is associated with a simultaneous deactivation of the flexor muscles of the other postural arm. First, a central timing command could simultaneously trigger the active lifting movement of the hand and the anticipatory deactivation of the flexors of the contralateral postural arm. Alternatively, an internal copy of the central command of the moving arm could be utilized as a command signal controlling the time and the intensity of the deactivation of the postural arm (Dufossé et al. 1984).

The aim of the present study was to investigate whether a timing command per se could provoke an anticipatory deactivation of the flexors of the postural arm, as observed during active unloading. The role of two factors which could give a timing cue was investigated: (1) Prediction of the unloading time by a preceding acoustic signal (external cue), (2) Prediction by means of the subject's own key pressing which release the load (internal cue).

It will be shown that neither of the two factors resulted in an anticipated deactivation of the flexors of the postural arm.

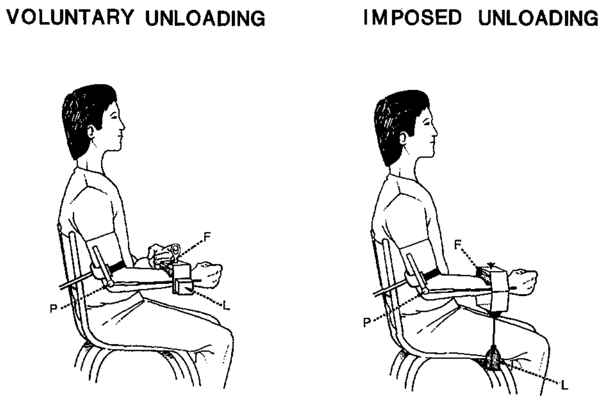

Fig. 1. Experimental condition under voluntary and imposed unloading. P: potentiometer measuring the elbow angle, L: 1 kg load, F: force platform measuring the load

Method

Six blindfolded healthy human subjects, 35–58 years old, were tested in the present series. The experimental paradigm is shown in Fig. 1. The subjects were confortably seated in a chair, with their right forearm positioned in a horizontal position at a right angle with the arm. The wrist was kept in half supination. The subjects were asked to maintain the forearm horizontal during the whole session, without any specific instruction for fast compensations. With this instruction, an anticipatory deactivation of the flexors of the postural arm is observed in situation A. A one kilogramme load (L) was supported by the forearm at the wrist level by a strain gauge equipped platform, measuring the vertical force exerted (F). The elbow joint position was obtained by means of a potentiometer (P). Myographic activities were recorded in both forearms as described below.

Experimental paradigm

Four experimental conditions were compared:

A. Voluntary unloading. In response to a tone, subjects were asked to lift the load with their left hand from the platform supported by the right forearm.

B. Imposed unloading. The load attached to the bracelet by means of an electromagnet, was dropped at unpredictable times with pseudorandom inter-trial intervals from 8 to 12 s.

C. Imposed unloading at predictable times with the same device as in B. A tone of 500 ms duration was followed with a further constant 500 ms delay by the switch-off of the magnet.

D. Unloading triggered by the subject. Same device as in B. The subject himself switched off the electromagnet by pressing a button with the left thumb.

Each subject underwent one to three sessions; in each session the four conditions were tested. Each condition was tested twice by series of 20–25 trials, with pseudo-random intertrial intervals of 8–12 s. Possible training effects were investigated by repeating, up to five times, the series of trials in conditions C and D, in addition to the initial and final set of the four experimental conditions.

Recordings and data analysis

Bipolar surface EMG recordings were obtained from the biceps, the brachio-radialis and the triceps of the postural right arm. In addition, the biceps of the left arm was also recorded in condition A. EMG were amplified, filtered with a 80 Hz – 10 KHz bandpass, stored on analog tape and, in parallel, rectified and integrated with a 10 ms time constant (leaky integrator) for further digital processing.

For each trial, vertical force, elbow angular position and integrated EMG activities were sampled with a 4 ms bin width. Averaging of signals (n = 20) was performed, the onset of unloading being used as a time reference. Examination of individual trials and of average traces over a series of trials were made. Latencies and amplitudes were measured from averaged signals.

Results

Voluntary (condition A) and unpredictable imposed unloading (condition B) serve to illustrate the two extreme control situations. Figure 2 shows the averaged curves obtained from one subject (MD), during these two conditions.

Voluntary unloading (condition A, Fig. 2A) was accompanied by a very stable forearm position, the elbow position being approximately constant. A decrease of the biceps EMG activity of the postural forearm preceded the force change by about 25 ms. The same pattern of activity was also found in the brachio-radialis. This decreased EMG activity was observed concomitantly with increased EMG activity of the contralateral biceps in the left weight lifting arm.

By contrast, imposed unpredictable unloading (condition B, Fig. 2B) was followed by an upward angular displacement of the weight bearing forearm. Elbow flexion started 16 ms after the onset of unloading and reached a maximum amplitude of 10° 200 ms later. A decreased biceps EMG activity was observed at a latency of 28 ms and was sometimes followed by an excitation. Increased activity in the antagonist triceps occurred later (latency 40 ms) at such a time when the forearm movement had stretched the muscle. The results are in agreement with those previously found by Hugon et al. (1982), obtained with a slightly different technique.

Figure 2C and D illustrates the results obtained in two predictable conditions, for the same subject as in Fig. 2A and B (condition C: tone preceding the load release by a fixed interval, condition D: release of the load triggered by the subject). In both conditions, the prediction of unloading time and the subject-triggered load release, the upward arm rotation and the myographic responses were similar to those obtained in condition B during an imposed unpredictable unloading. However, Fig. 3 shows a statistically significant moderate to marked reduction of the maximum upward arm deflection with 3 subjects in condition C (from 58 to 84% of the control value B). A careful analysis of the slope of the curves of the

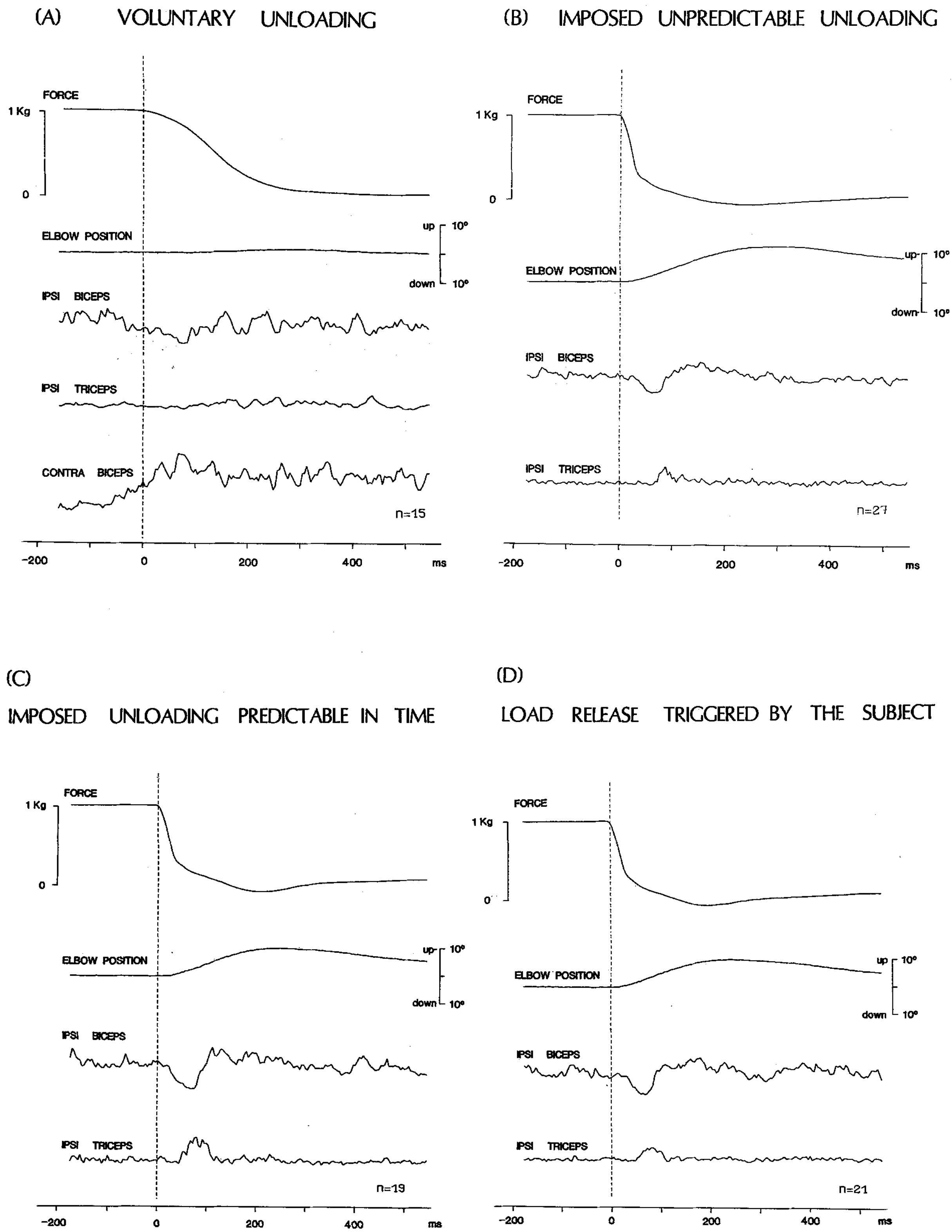

Fig. 2A–D. Comparison between the four experimental conditions. Notice in **A** the anticipatory deactivation of biceps of the postural arm and the lack of marked change in elbow position; notice in **B** the change of elbow position up to 10° and the unloading reflex EMG changes. Bottom: imposed unloading predictable in time (**C**) and release of the load triggered by the subject (**D**). In both cases, results are similar to those in condition B. No anticipatory deactivation of the elbow flexors such as those seen in condition A can be seen

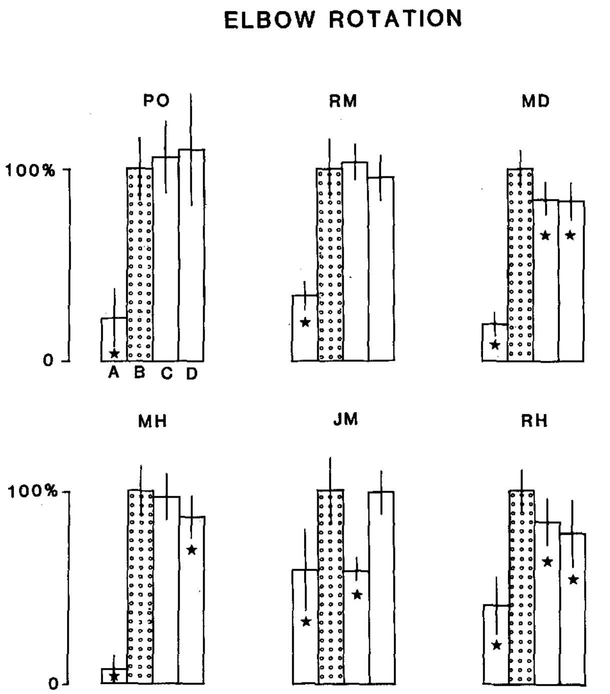

Fig. 3. Mean values (20 trials) and standard deviations of the maximal elbow rotation measured for six subjects in the four experimental conditions. Values are expressed as a percentage of the condition B (unpredictable imposed unloading), taken as a reference value. Stars indicate a statistically significant (1%) improvement in performance as compared with the control condition B

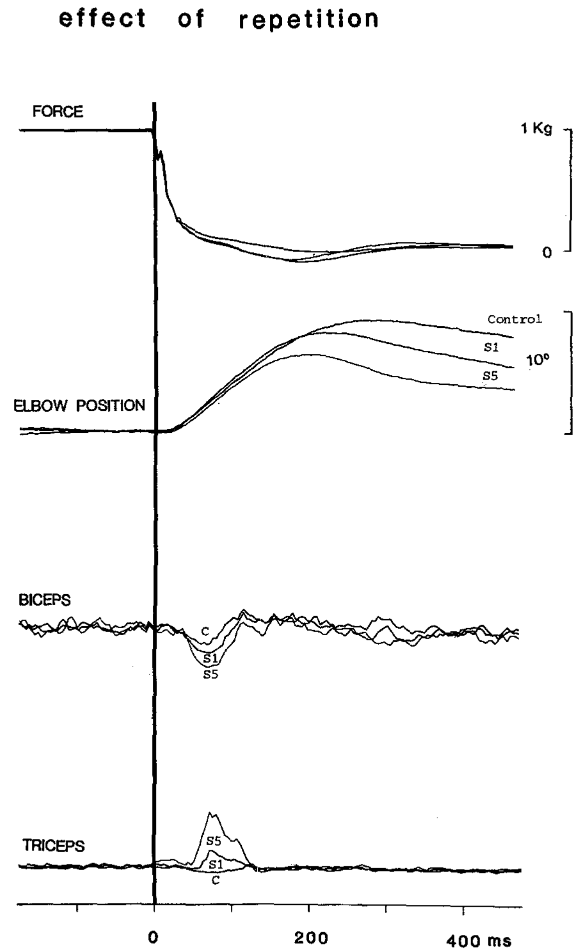

Fig. 4. Effect of repetition in condition C (imposed unloading predictable in time). The subject performed 5 series of 20 trials each, the first (S1), the last (S5) and the control condition B (unpredictable unloading) being superimposed. It can be seen that arm rotation is progressively reduced after 120 ms from the onset of force change, and this is associated with an increased reflex response in biceps and triceps

forearm position in Fig. 2C and D (see also Fig. 4) shows that they were approximately the same during the first 120–140 ms. Only after this delay did the amplitude of the arm position curve become smaller than that recorded in the unpredictable unloading condition.

The EMG analysis revealed no noticeable anticipatory deactivation of the biceps or the brachio-radialis of the postural arm.

Effect of repetition

These series were undertaken in order to test whether or not the repetition of conditions C and D could induce anticipatory postural changes as seen in voluntary active unloading (condition A).

Three subjects (MD, MH, RM) were trained in condition C, and three (JM, PO, RM) in condition D. They underwent up to 5 series of 20–25 trials within the same session, control series with the four conditions (presented in the order: B, C, D, A) being made before and after the training series.

None of the subjects showed any anticipatory deactivation of the biceps or brachio-radialis EMG activity of the postural forearm.

Figure 4 shows the results of the subject with improved performance in condition C. The slope of the forearm position curve after unloading remained roughly the same during the first 120 ms. There was an improvement after that delay from the first to the fifth series. Parallel with this improvement, an increase in both the unloading reflex in biceps and the stretch reflex in triceps was observed without any anticipatory change.

Among the three subjects in condition D with improved performance, one showed an increased unloading reflex in flexor, and increased stretch-reflex in triceps after unloading. In the two other subjects, improved performance appeared to be associated with the disappearance of a later rebound activation in the flexors. This late activation has been previously observed by Angel et al. (1965).

Discussion

The present experimental paradigm was designed to investigate the role of two factors possibly responsible for the coordination between voluntary movement and the associated anticipatory postural changes in a bimanual task.

It was seen that neither an external cue, such as a tone preceding unloading by a fixed interval, nor an internal cue, related to a voluntary key press triggering the unloading was used by the subject to induce adequate anticipatory postural adjustment. These cues only reduced the forarm's upward rotation, possibly by means of an improved reflex action.

The failure of both external and internal cues to induce the appropriate anticipatory control in our paradigm is at first glance surprising. Three considerations might explain this failure:

The time course of the magnet operated unloading is less than 20 ms. Any neuromyographic deactivation in the flexors of the postural arm is slower. Half-relaxation time has been measured in bundles of fibers of human biceps from 70 to 85 ms (Eberstein and Goodgold 1968). This time course should only allow a partial compensation of the brisk unloading. However, the mechanical effect of unloading observed on the arm position is rather delayed and slow, the maximum upward deflection being reached only after more than 200 ms. Thus, flexor deactivation should compensate the mechanical effect of the brisk magnet operated unloading, due to the forearm inertia acting as a low pass filter between the force change and the elbow position curve. This compensation would be optimal if the flexor deactivation starts before the imposed unloading. In fact, almost complete compensation can be obtained in situation D if the subject performs a voluntary inhibition of the flexors of the postural arm together with the key press.

A second cause of failure in generating an appropriate anticipatory control with an external cue might be the difficulty for the subject to predict the precise time of unloading after a warning tone. Standard error of 8–10% has been reported in the estimation of time intervals ranging from 500 ms to 1 s (Woodrow 1930). However, it would be surprising that this variability explains the total absence of any anticipatory changes over series of trials. The better correction observed in some subjects may be due to some spinal setting of the reflex machinery, resulting from supraspinal influence when the external cue is presented. However, the cue does not by itself induce an appropriate anticipatory coordination.

A third possibility is that the instruction given the subjects to maintain the arm position during the whole session is not constricting enough to build a new coordination when the unloading is provoked by pressing a button. However, the instruction is sufficient to allow the appearance of the anticipatory adjustment together with the voluntary movement in condition A.

Two other factors that could explain why these cues are not appropriate for the present coordination remain to be examined. A first hypothesis is that the coordination results from an "internal command collateral" of the voluntary command of the weight lifting arm. This internal command collateral, acting on the postural arm, would include a specific coding of the motor command parameters such as the force exerted. Acting on the postural arm, it would control the timing and intensity of the anticipatory flexor deactivation.

A second and not exclusive possibility is that coordination is only possible with a context dependent cue that is a command of the voluntary movement in an usual bimanual task situation. Conditions C and D are somewhat artificial in this respect. Matched adequate muscle action may depend upon a central image constructed from the instruction set, past sensorimotor experience and present postural context. However, making conditions C and D more familiar through repetition did not provoke the appearance of the coordination.

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