dopa decarboxylase inhibitor. It has elevated cerebral serotonin, but an effective precursor of cerebral serotonin has failed to induce the full phenomenon described here. Since both L-dopa and melatonin appeared essential for turning and running, competition of neurotransmitters for neuronal receptors does not appear to offer an adequate explanation. We cannot interpret these findings at present in molecular or physiological terms. We can, however, determine their possible relevance to the involuntary movements induced by L-dopa in Parkinsonism.

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18. This work was supported primarily by the AEC and NIH. G.C.C. has also been receiving financial aid from Mrs. Katherine Rodgers Denckla.

22 March 1971

Eye-Head Coordination in Monkeys: Evidence for Centrally Patterned Organization

Abstract. *Eye-head coordination was investigated by recording from the neck and eye muscles in monkeys. The results show that (i) during eye-head turning, neural activity reaches the neck muscles before the eye muscles, and (ii) all agonist neck muscles are activated simultaneously regardless of the initial head position. Since overt movement of the eyes precedes that of the head, it was concluded that the central neural command initiates the eye-head sequence but does not specify its serial order. Furthermore, it was determined that the compensatory eye movement is not initiated centrally but instead is dependent upon reflex activation arising from movement of the head.*

Complex coordinated movements entail a temporally patterned sequence of motor and neuromuscular events. In order to better understand these sequences and their relation to each other, we have used behavioral and physiological methods to investigate the coordination of eye and head movement in monkeys. From earlier work on man (*1*) and from our observations of monkeys, we know that the appearance of a target in the visual field is usually followed by a saccadic eye movement directed toward the target, and then, after a latency of 25 to 40 msec (in monkeys), by a head movement in the same direction. Since the eyes move first and with a high velocity, their lines of sight typically reach the target and fixate it while the head is still moving toward it. For the duration of the head movement the eyes maintain their fixation by performing a rotational movement which is counter to that of the head and compensates for it—hence the name compensatory eye movement (*2*).

Thus, the act of directing the eyes and head to a target is composed of a fairly rigid pattern of events. A visual saccade carries the fovea near or to the image of the target. This is followed by a head movement in the same direction, which is accompanied by a compensatory eye movement.

We have taken advantage of this well-defined sequence of motor events to investigate, first, the spatial and temporal patterning of the neural command to the various muscles involved in eye-head turning. In a second set of experiments we sought to determine if the temporal sequence of saccade followed by compensatory eye movement is centrally programmed or, alternatively, if the compensatory movement is the result of a reflex activation induced by head turning. And, as a step toward eventually providing a quantitative description of the neural and behavioral aspects of eye-head coordination, we have paid close attention to the reliability of visually triggered eye-head movements.

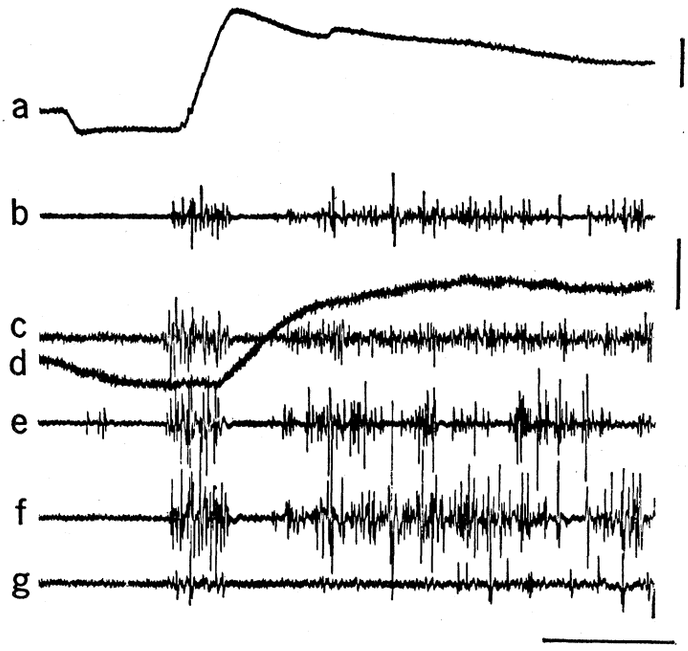
Four adult monkeys (*Macaca mulatta*) were used in these experiments. The animals were trained to turn correctly and to identify a 1-degree luminous target which appeared randomly at different horizontal positions in their field of vision. A lightweight apparatus was attached to the animal's head to record movements in the horizontal and vertical planes. Eye movements were recorded with silver–silver chloride pellet electrodes implanted in the orbital bone (*3*). Electromyographic (EMG) activity associated with horizontal eye movements was recorded from the lateral rectus muscle, along with the activity from the seven neck muscles involved in horizontal head rotation (trapezius, cleido-occipitalis, splenius capitis, longissimus capitis, complexus, obliquus capitis posterior, rectus capitis dorsalis major) (*4*). During the recording sessions the monkey's trunk was restrained.

The results show that, after the onset of the target light, the first event to take place is invariably a synchronous burst of EMG activity in all agonist neck muscles, which is usually followed by a 20- to 30-msec pause (Fig. 1). Concurrently, EMG activity is suppressed in all the antagonists, and, as Fig. 2 shows, both these events occur with a latency of approximately 160 msec.

That the bursts appeared simultaneously in all the agonists regardless of the initial head position of the animal is quite remarkable. We found, however, that the amplitude and duration of the bursts were dependent upon the starting position and the extent of the intended head movement.

The second EMG event to take place is an eye muscle burst, which always occurs approximately 20 msec after the beginning of neck muscle activity (Fig. 2).

Taken together, these EMG results indicate the spatiotemporal characteristics underlying sequentially ordered eye and head movement. The neural commands are, in fact, delivered simultaneously to all neck muscles and shortly thereafter also to the eye muscles. However, the overt sequence of movements that results from these commands does not reflect this order insofar as the head movement actually oc-



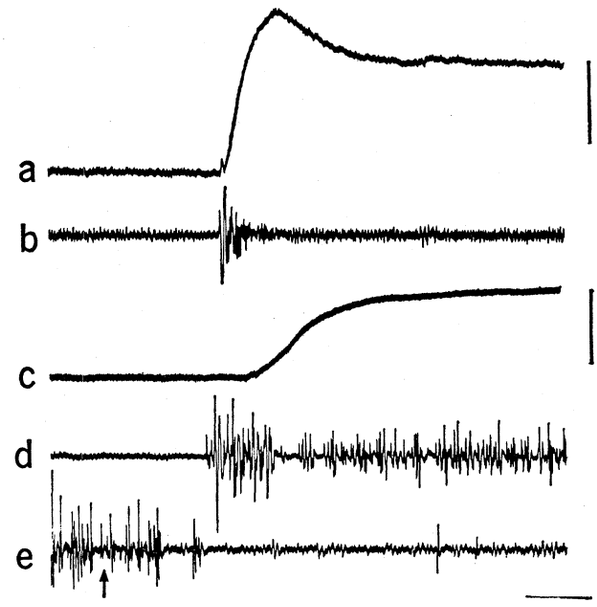


Fig. 1 (left). Electromyographic activity recorded from neck muscles during horizontal eye-head turning. Horizontal eye movements (*a*); obliquus capitis posterior (*b*); splenius capitis (*c*); horizontal head movement (*d*); rectus capitis dorsalis major (*e*); longissimus capitis (*f*); cleido-occipitalis (*g*). Time calibration, 200 msec; eye calibration, 10 degrees; head calibration, 10 degrees. Fig. 2 (right). Electromyographic activity recorded from left lateral rectus (*b*) and left (*d*) and right (*e*) splenii capitis during horizontal eye-head turning. Horizontal eye movements (*a*), horizontal head movements (*c*). Arrow represents onset of luminous target. Time calibration, 100 msec; eye calibration, 10 degrees; head calibration, 20 degrees.

curs *after* each saccade (20 to 40 msec). Peripheral factors such as the longer contraction time of the neck muscles, as well as the inertial properties of the head, are responsible for this delay. Thus, the central command initiates these movements but does not by itself specify their serial order.

Compensatory eye movements have been studied by several workers (*2, 5*), and, although it is generally agreed that these eye movements are influenced critically by visual, vestibular, and proprioceptive feedback loops, the suggestion has been made that they are initiated centrally (*6*). We devised a direct test of this hypothesis by developing a head holder that permitted free horizontal and vertical movements but could also be used to stop these movements quickly with an electrically activated brake.

After the animals had adapted to this new apparatus, the records of eye and head movement displayed the same temporal characteristics as those obtained with the lightweight head holder.

Figure 3A illustrates the normal sequence of a visual saccade followed by a head movement and then a compensatory eye movement. Even when we left the animal in darkness by turning off the target light before the saccade had been completed, the compensatory eye movement was still present. On randomly selected trials the presentation of the target was followed, after a delay of about 300 msec, by the application of the brake. As Fig. 3B shows, this resulted in an abrupt stopping of the head just after it had begun to move. It is clear that under these conditions a compensatory eye movement does not follow the saccade. The same result was obtained when visual factors were excluded by turning off the target before the saccade was completed. These findings indicate that the central command is only indirectly responsible for the compensatory eye movement insofar as it initiates the head movement. The head movement, in turn, provides by way of vestibular and neck proprioceptors the reflex excitation necessary for the compensatory eye movement to take place. Visual factors can, however, modify the course of the compensatory eye movement, but we did not investigate their role.

A preliminary quantitative analysis of the manner in which the angular distance between any two fixation points is covered by eye and head movements indicates that this motor sequence is repeated without marked variation. Again and again the ratio between eye and head displacement for different movements is surprisingly constant. In addition, the peak values of the angular velocity of the head for a given amplitude of movement show a consistency that is remarkably similar to that which has been demonstrated for saccadic eye movements (*7*).

It should be pointed out that the timing and characteristics of eye-head coordination just described are observed only when the position at which the visual target is presented to the animal

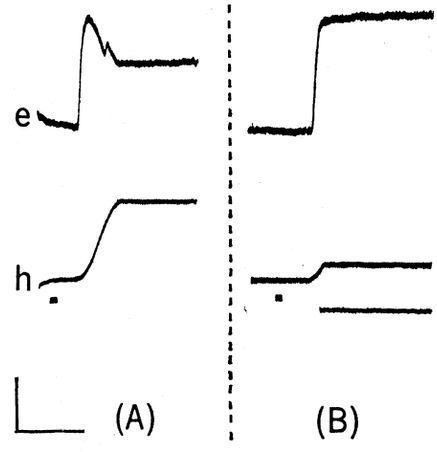


Fig. 3. (A) Typical coordinated eye (*e*) and head (*h*) response to sudden appearance of a target. (B) Presentation of the same target is followed by application of the brake (horizontal bar). Note lack of compensatory eye movement. Dots represent onset of luminous target. Calibration: horizontal bar equals 500 msec; vertical bar, 15 degrees.

is randomly varied. Nonrandom target presentation, with the animal displaying a behavior that suggests an ability to predict target position, reveals a different mode of eye-head coordination. Under these conditions the head moves before the target is presented. A saccade follows the head movement by up to 150 msec; therefore, the sequence of eye movements during head turning is characterized first by a compensatory movement, then a saccade, and then a second compensatory eye movement. Thus, there are clearly different strategies of eye-head turning available to the animal.

Finally, we believe that knowledge about the coactivation of the oculomotor and neck motor system could be helpful to the eye-movement physiologist since it would be very easy to misinterpret single unit data if the tight coupling between these two systems were not taken into account. Although artificially restraining the head may eliminate the overt manifestation of movement, it will not prevent the delivery of neural activity to the neck muscles. On the other hand, the possibility of bringing under control different strategies of eye-head coordination may be a useful tool for differentiating between the discharge of central neurons related to head movements and those concerned with movements of the eye.

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8. Research supported by NIH grant 1-R01-NA09343-01. We thank J. Graham for technical assistance.
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26 April 1971

Electroshock Effects on Brain Protein Synthesis: Relation to Brain Seizures and Retrograde Amnesia

Abstract. *The effects of electroshock on brain seizure activity and brain protein synthesis were studied in male mice. A significant but short-lasting inhibition of brain protein synthesis and an increase in the amount of free leucine were produced by electroshock at intensities above the brain seizure threshold. Electroshock at intensities below the brain seizure threshold did not affect brain protein synthesis.*

It is well known that electrical stimulation of the brain can impair memory for experiences that occur shortly prior to the brain stimulation (*1*). Much is known about the conditions under which correlate with the effects of ES type of memory impairment, which is referred to as retrograde amnesia (RA). For example, the degree of RA produced by ES varies directly with the current intensity and inversely with the time between the experience and the ES treatment (*2, 3*). However, although these effects have been studied for over two decades, little is known about the bases of the effects.

It is generally assumed that ES causes RA by interfering with the neurobiological processes involved in memory storage. But, what kind of interference is essential for the occurrence of RA? In recent research we have found that the passage of current through the brain is not a sufficient condition for producing RA. In order for ES current to produce RA, the current must be administered at intensities at or above the threshold for producing brain seizures (*3, 4*). For example, current levels which produce brain seizures and RA in normal mice do not affect memory in mice in which the brain seizures are prevented by light anesthetization with diethyl ether just prior to the ES treatment (*4*). In general, brain seizures are a highly reliable correlate of RA in animals given ES after training.

Seizures provide an electrophysiological sign of neurobiological disturbance. If it is assumed that memory storage involves neurochemical processes, it should be possible to find effects of ES on brain neurochemistry which correlate with the effects of ES on brain seizures and memory. The findings of many studies suggest that memory storage requires protein synthesis. Drugs such as cycloheximide, which impair protein synthesis, are reported to produce RA (*5*). In the experiment reported here we examined the effect of ES on brain protein synthesis. We wished to know whether or not ES inhibits protein synthesis and, if so, whether the degree of inhibition varies with ES current. The findings indicate that ES at intensities below the threshold for brain seizures and for RA does not significantly affect protein synthesis. However, at intensities above that necessary for producing seizures and RA, ES has a short-lasting but significant inhibitory effect on brain protein synthesis.

Male Swiss-Webster mice (*6*), housed individually in small cage pans, were used. They were approximately 80 days old when killed for the determinations of protein synthesis. The mice were first implanted with bilateral cortical electrodes (*7*) and used in studies of ES (administered through transcorneal electrodes) effects on brain seizures and RA (*3, 4*). After approximately 3 weeks the mice were used to study the effect of ES on brain protein synthesis. The experimental conditions used for ES administration were based on the findings of previous behavioral and electrophysiological studies.

To examine the effect of ES on brain protein synthesis at various times after treatment, we administered a 4-minute pulse of L-[1-^{14}C]leucine at varying intervals after the ES treatment. The use of a short labeling pulse enabled us to measure the time-dependent effects of ES on the rate of protein synthesis. Animals were injected in a tail vein with 4 μc of L-[1-^{14}C]leucine (30 mc/mmole, New England Nuclear). All animals were killed 4 minutes after the injection of the isotope to measure protein synthesis. For the measurement designated "immediate" (Table 1), animals were injected 2 minutes prior to ES and killed 2 minutes after. For all other groups, times indicated represent the times between ES and the beginning of the 4-minute incorporation period.

The ES consisted of 60-hz constant current delivered for 200 msec through transcorneal electrodes. Two ES current levels were used: 12 ma and 30 ma. From the earlier studies (*3, 4*) we determined that, with the stimulus parameters used, 12 ma produced both