EYE MOVEMENTS INDUCED FROM THE SPINAL NERVES

Jun-Ichi SUZUKI and Setsuko TAKEMORI

INTRODUCTION

In the supine rabbit with the head fixed, twisting of the neck and body induces eye deviation in the direction of body twist. In the human also, neck twist induces eye movements, but since these movements are small and obscured by active spontaneous eye movements, they become more obvious when the responses induced by twisting the body on the pendular rotation chair with the head stationary are computer analyzed. In the present study, neck-induced eye movements were investigated in a quantitative fashion by applying electric pulse stimulation to the spinal nerves. Normally head rotation induces both vestibular and neck reflexes resulting in coordinated eye movement responses. Accordingly, some data indicating interaction between vestibulo-ocular and spinal-ocular reflexes are presented.

The experiment was performed on rabbits, as their scarcity of voluntary and involuntary eye movements would not interfere with the responses evoked by neck stimulation. Clinically, the study is related to neck reflexes, so-called cervical vertigo, and possible pathological nystagmus due to neck lesions.

METHOD

Seventeen white adult rabbits of 2.5–3.0 kg were used for the experiment under intravenous anesthesia using chloralose, 20–25 mg per kilogram and urethane, 0.1 g per kilogram. The head of the rabbit was tightly fixed by applying pointed bars at 4 points, at the infraorbital foramina and at the temporal bones on both sides. The body was held by two pointed bars fixed to the iliac bones. The head and the body were in nearly normal position, and extraneous movements were minimized. The brachial and ishadic nerves were also cut bilaterally to minimize movement artifacts. The spinal nerves and roots, which were exposed bilaterally at the cervical, thoracic, lumbar and sacral levels, were electrically stimulated by pulse trains applied through bipolar stainless steel electrodes. The pulse trains consisted of square waves of 0.1–0.3 msec duration and of 1.0–10 msec separation. The total number of pulses in a train varied up to 91. Eye muscle tension changes were isometrically recorded utilizing RCA-5734 in a bridge circuit. EMG of the eye muscles was recorded by bipolar electrodes. Lateral canal nerves were also electrically stimulated by the method previously reported.

From the Department of Otolaryngology, Teikyo University School of Medicine, Tokyo
This work was partly supported by NIH Research Grant #NB06585-03 and the Naito Science Foundation 1969.
Fig. 1. Superimposed tension changes in horizontal movers of the eyes induced by electric pulse trains applied to the first and second cervical nerves in the rabbit.

From A-E, the first spinal nerve on the right side (RC1N) was stimulated with pulse trains of 2.5 msec separation (in A-D). Tension curves are from the left medial rectus (LMR) and the left lateral rectus (LLR). Increase in tension is up and decrease, down. The number of pulses in a train for stimulation (shown by a horizontal bar) was 11 in A, 31 in B and 61 in C; namely, the length of trains was 25 msec in A, 75 msec in B, 150 msec in C. The length of train was 200 msec in D. The latency of tension changes of average responses is shown in D and E. Notice that tension decreases started during stimulation (D): the stimulus was on at ↓ and continued to the end of the picture. In E, a separation of pulses in a train was 1.0, 1.25, 1.6, 2.0, 2.5, 3.2, 4.0 msec. Trains with pulse separation of 1.0, 1.25, 1.6 and 2.0 msec induced the same tension increase but relaxation phases were different. Speed of tension changes was less in 2.5, much less in 3.2 and none in 4.0 msec pulse separations. Calibration: horizontal bars indicate 50 msec/cm in A-C, 20 msec/cm in D and E; vertical bars indicate 1/3 gm.

Equilibrium Res Suppl. 2
RESULTS

1) When spinal nerves or roots were stimulated, induced eye movements were always purely horizontal in the direction ipsilateral to the side of stimulation. Induced muscle tension and EMG activity was limited exclusively to the horizontal movers... the medial and the lateral recti. The responses were constant from the cervical nerves at C₁, C₂ (Fig. 1 A-E), less constant from C₃, but were not obtained from levels lower than C₄. Stimulation of the dorsal roots at the cervical level was more effective and always

![Fig. 2. Superimposed eye muscle tension changes in horizontal movers of the eyes from stimulation at the eighth thoracic level. Pulse trains were applied to the dorsal root on the right side in A, and on the left side in B. Traces in B show that the animal had quick return eye movements to the right in each trial towards the end of each trace. Calibration: 50 msec/cm and 1 gm. Stimulation frequency was 400 c/s total of 81 pulses.](image-url)
successful in inducing eye movements similar to those induced from nerve stimulation at high cervical levels. Responses were more reliably seen if the length of the trains was long. Short trains were not always effective in producing movements (Fig. 1 A-C). The latency of responses was long, and the responses were sometimes initiated after the stimulus had ceased depending on the stimulus train length. On the other hand, with a long train, the induced tension increase in the eye muscles showed gradual decline before termination of stimulation. Frequency of 300–1000 Hz was most effective in producing a steep rise in muscle tension and stimulating at frequencies below 400 Hz produced less steep increases (Fig. 1 E). Below 150 Hz no response was seen in most cases. Fusion frequency seems to be about 500 Hz. Responses were induced from the dorsal roots of the thoracic levels, although the effect was less intensive and less constant (Fig. 2). Responses

![Eye muscle tension changes and EMG superimposed in the eye and the neck muscles.](image)

Eye muscle tension curves are from the left medial rectus (LMR) in A, C and D, and from the left lateral rectus (LLR) in B (traces on the top in each of A-D). The vertical small shift of the tension curves indicates the stimulus on which was given to the first cervical nerve on the right. EMG was recorded in LMR in A, LLR in B, and the neck muscles on the level of C2-3 on the right (R•Neck) in C, and on the left (L•Neck) in D. Arrow indicates EMG change in C. Downward pulses are stimulus artifact. Calibration: 20 msec/cm in A, B, D, and 5 msec/cm in C: 50 µV for EMG.

*Equilibrium Res Suppl. 2*
were not reliably evoked by stimulation at the lumbar and sacral levels. More and more intense stimulation was necessary to obtain constant responses from lower spinal levels.

2) The latency for increase or decrease of eye muscle tension was 40-60 msec or more from the cervical nerves and dorsal roots (Fig. 1 D, E). Excitatory and inhibitory activities of the eye muscles, lateral and medial recti, were also demonstrated by showing changes in EMG (Fig. 3 A, B). Changes in EMG activities of cervical muscles on the ipsilateral and contralateral sides of stimulation were compared (Fig. 3 C, D).

3) The inhibitory effects of spinal nerve stimulation were also studied. One pulse train was given to evoke the control response. Then the conditioning train was followed at various intervals by the test pulse trains. Curves of inhibition are shown (Fig. 4). The effect on eye movements lasted for about three seconds in the case of double ipsilateral stimulation.

4) The inhibitory and excitatory effects of vestibular inputs on the neck-eye reflex were demonstrated and compared. Neck-induced muscle tension increases of medial rectus were depressed during electrical stimulation of lateral canal nerves on the contralateral side (Fig. 5 A-E). The effects of neck induced eye muscle tension (small b) were conditioned by a concomitant contralateral horizontal canal stimulation (small a). As

![Fig. 4. Recovery of self-inhibition of spinal-ocular reflex.](image)

The conditioning stimulus to the first cervical nerve on the right side was given at 0 sec. The amplitude of the tension increase of the left medial rectus was shown on the ordinate with 1/3 gm divisions. The test or the second stimulus was given at different delays from the conditioning stimulus. The maximum tension in each response was plotted. The small and large dots indicate 1 and 5 repetitions of the control trial respectively.

Equilibrium Res Suppl. 2
Fig. 5. Superimposed eye muscle tension changes due to lateral ampullary and cervical nerve stimulations.

The lateral ampullary nerve on the right side was stimulated with pulse trains of 91 pulses of 6.4 msec separation in A-C and E. The horizontal bars (a) indicate the duration of lateral canal nerve stimulation. The pulse trains were also given to the first cervical nerve as a test stimulus on the left side in A-D and on the right side in F and G. The horizontal bars (b) indicate the duration of cervical nerve stimulation. Pulses in a train in A-D, F and G were 41 pulses. Interactions between ampullary and cervical nerve stimulations on the contralateral (A-C) and the ipsilateral (F) sides were shown. D, E and G are control responses to the stimuli applied singly. D and E are lateral rectus. Calibration: 100 msec/cm and 1 gm.

the duration of the vestibular stimulation before onset of spinal stimulation became larger, inhibition increased. The tension changes from the neck, on the other hand, were initially inhibited and later facilitated during ipsilateral vestibular input (Fig. 5 E, F).

COMMENTS

The present experiment was successful mostly due to the introduction of intravenous anesthesia of chloralose urethane in combination. Actually, under chloralose the responses of eye movements appeared greater than in the unanesthetized state. The maintenance of the level of anesthesia of chloralose-urethane was not very critical and anesthesia was easily controlled during the experiment.

Hoshino observed eye movements after stimulation of spinal dorsal roots at all levels and proposed that these effects should be called "tonic spinal reflex" on the eyes instead of "tonic neck reflex". The present study demonstrated that the reflex was con-
stant from the cervical and thoracic levels. Although the responses could be evoked from the thoracic levels, the intensity of the stimulus had to be increased. Therefore, spread of the stimulus to the spinal cord from the bipolar electrodes placed to the dorsal roots could not be ruled out. The reflex appeared to be present but very inconstant from much lower levels such as the lumbar and sacral spinal cord. It was difficult to draw a decisive conclusion about whether or not the reflex exists from the low level spinal cord. However, since the reflex was present, even though it was not constant, at least from the thoracic levels, the reflex could be called "tonic spinal reflex" instead of "tonic neck reflex" on the eyes.

Inducing eye muscle responses was not successful from the spinal nerves at levels lower than C1. The spinal cord afferents responsible for the "tonic neck reflex" may actually branch very early and thus may not have been included in those fibers stimulated.

The latency of "tonic spinal reflex" on the eyes was very long, 40-60 msec or more. On the other hand, the latency of vestibulo-ocular reflex after electric pulse trains applied to the ampullary nerves was less than 10 msec in cats when eye muscle tension was measured. It should be noted here, however, that, in spite of the long latency, the induced eye movements were integrated to give horizontal deviation by activating exclusively the horizontal movers of the eyes.

Takemori et al. have shown in the rabbit that body rotation with the head fixed (activating neck receptors) from right to left produces eye movement to the left. On the other hand, rotation of the head from left to right activating the right horizontal canal and inhibiting the left horizontal canal produces eye movement to the left. Rather unexpectedly, these effects counteract each other, presumably to produce a more exact synchronization of eye position and visual image.

SUMMARY

Under general anesthesia of chloralose-urethane, electric pulse trains were applied to the spinal nerves and dorsal roots in seventeen white adult rabbits. The induced eye movements were horizontal, directed to the side of stimulation. Activation or inhibition of eye muscles by the stimulation was exclusively limited to the lateral and medial rectus muscles. Contraction or relaxation of these muscles occurred with a latency as long as 40-60 msec or more. The effect was constant and strong from the first and the second cervical nerves, not constant from the third and absent from the levels below the fourth. It was constant from cervical and thoracic dorsal roots but not certain from lumbar or sacral levels. Despite its unusually long latency, the highly selective linkage of the spinal sensory nerves to the horizontal movers of the eyes may indicate that the reflex is based on a well organized integration of the nervous system. The spinal neck reflex on the eyes was inhibited by the cupulo-ocular reflex when both reflexes caused the eyes to deviate in the same direction, but was augmented when the reflexes caused deviation in opposite directions. This shows that inputs from the vestibulum and from the neck sensory nerves counteract each other in driving the eyes in the horizontal direction.
J. SUZUKI and S. TAKEMORI

ACKNOWLEDGEMENT

We extend our thanks to Drs. M. Shimamura and S. Highstein for their help and criticism of our paper and to Mrs. Yamaoka for her technical assistance.

REFERENCES


(Received July 8, 1971)