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DIRECTIONAL ERRORS OF MOVEMENTS AND THEIR CORRECTION IN A DISCRETE TRACKING TASK

Robert J. Jaeger
Gyan C. Agarwal
Gerald L. Gottlieb

College of Engineering
University of Illinois at Chicago Circle
Chicago, Illinois 60680

and

Rush Medical Center
Chicago, Illinois 60612

ABSTRACT

The human operator is prone to making errors in quick choice reaction time tasks. Many studies have shown that subjects can correct their own errors of movement more quickly than they can react to external stimuli. In the control of movements, three general categories of feedback have been defined as follows: 1) Knowledge of results, primarily visually mediated, 2) Proprioceptive or kinaesthetic such as from muscle spindles and joint receptors, and, 3) Corollary discharge or efference copy within the central nervous system.

Experiments were conducted on four normal human subjects to study the effects of these feedbacks on simple reaction time, choice reaction time, and error correction time. The movement used was plantarflexion and dorsiflexion of the ankle joint. The feedback loops were modified, 1) by changing the sign of the visual display to alter the subject's perception of results, and 2) by applying vibration at 100 Hz simultaneously to both the agonist and antagonist muscles of the ankle joint. The central processing was interfered with when the subjects were given moderate doses of alcohol (blood alcohol concentration levels of up to 0.07%).

Vibration and alcohol increase both the simple and choice reaction times. However, the error correction time is not influenced by either. This data reinforces the concept that there is a central pathway which can mediate error correcting responses.

INTRODUCTION

The human operator is prone to making errors in a quick choice reaction time (RT) task. The speed with which the operator can recognize errors and correct them is an important consideration in many industrial tasks. Many studies have shown that subjects can correct errors of movement more quickly

PAGE INTENTIONALLY

than they can react to external stimuli. (For a review of the literature see Schmidt, 1975, 1976; Angel, 1976; Schmidt & Gordon, 1977.)

In the control of movement by skeletal muscles, three general categories of feedback have been identified (Evarts, 1971). These feedbacks arise as follows: first, "knowledge of results" from the external environment is primarily visually mediated. Second, proprioception from internal receptors stimulated as a consequence of muscular contraction and joint rotation is primarily spindle and joint receptor mediated. Third, "efference copy" or "corollary discharge" (Von Holst, 1953) from structures and pathways within the central nervous system may operate before muscle contraction occurs.

Currently, the first and second categories of feedback are perhaps better understood than the third, although the role of efference copy in saccadic eye movements has received considerable attention (Robinson, 1971, 1976; Lehmann, 1971). These three categories of feedback may be anatomically interconnected, especially the proprioceptive and efference copy mechanisms (Oscarsson, 1970). It is postulated that the cerebellar anterior lobe is important for correcting errors in motor activity elicited from the cerebral cortex and carried out by command signals through pyramidal and extrapyramidal pathways.

Recent work of Angel and his colleagues (Angel & Higgins, 1969; Angel, 1976) has attempted to quantitatively approach efference copy by measuring RTs to correct movement errors and the accuracy of these corrections. It has also been noted (Poulton, 1974) that the many studies which have measured RTs for the correction of movements have found these times to range from essentially zero to in excess of 300 milliseconds.

Since a rather wide range of error correction times exists, it could be hypothesized that the three general categories of feedback each have their own range of operating times which together contribute to the overall wide range of these times. Under this hypothesis, if a sufficient number of measurements were made, a trimodal distribution might be found. The minimum duration for processing visual feedback from a movement appears to be over 190 msec (Keel & Posner, 1968). The kinaesthetic RT is of the order of 120 msec (Chernikoff & Taylor, 1952). This RT is of the same order as the time for "Functional Stretch Reflex" (Melville Jones & Watt, 1971; Evarts, 1973; Gottlieb & Agarwal, 1978). Dewhurst (1967) has reported values of kinaesthetic RT based on recordings of muscle activity in the biceps as short as 50 msec. However, he did not give any range for kinaesthetic RT or the mean value in his experiments.

The experiments of the present study were designed to enable comparison of correction times measured under normal conditions with those measured under conditions in which the proprioceptive mechanisms was interfered with. It was possible to do this by applying vibration to the tendons of the muscles involved. (Hagbarth & Eklund, 1966; Goodwin, McCloskey & Matthews, 1972; McCloskey, 1973; Craske, 1977). In some experiments, central processing was interfered with when the subjects were given moderate doses of alcohol (blood alcohol concentration (BAC) levels of up to 0.07%). Alcohol produces a depressive effect on the CNS much as a general anesthetic does and the degree of depression appears to be dose related (Wallgren & Barry, 1970.)

METHODS

Four subjects were used in the present study. Two of the subjects (GCA and GLG) had extensive previous experience with the experimental apparatus as subjects in other tracking type experiments, while the other two subjects had no such experience. Parts of these experiments were also done on several other subjects.

A schematic of the experimental apparatus is shown in Figure 1. (This apparatus has been used in several studies, for details see Agarwal & Gottlieb, 1977).

The subject sat in an adjustable height chair facing an oscilloscope display positioned at a slight angle in front of him, His right foot was strapped to a one degree of freedom foot pedal (rotation in plantar-dorsal directions) with velcro straps. Self adhesive surface electrodes were positioned over the soleus and anterior tibial muscles to record the electromyograms (EMGs) of these muscles. A ground electrode was placed on the thigh just proximal to the knee. The EMGs were full wave rectified and filtered before recording on the digital tape at a sampling rate of 500 per sec.

The oscilloscope display consisted of two dots. The first was the target dot which was under the control of the computer. It was defocussed to approximately 2 mm diameter. This dot assumed only one of three positions at any instant of time, either in the center of the screen or ±4.0 cm vertically away from the center. The second dot was the response dot which was under the control of the subject. It was focused to a sharp point approximately 0.5 mm in diameter. The subject could vary the position of the dot continuously along the vertical axis of the oscilloscope. The crucial part of the experiment was the "polarity" of the subjects' control of the response dot. This polarity was under the control of the computer. Normal or positive polarity meant that when the subject moved the pedal down (up) the response dot also moved down (up). Inverted or negative polarity meant that when the subject moved the pedan down (up), the response dot moved up (down). The purpose of this provision for polarity reversal was do decouple the proprioceptive feedback from the visual feedback and induce the subject to make errors in movement. The use of polarity reversal has been previously described by Gibbs (1965) and Angel and Higgins (1969).

The target dot was controlled by the computer as follows. The experiment began with the target dot in the center. After a random delay of 3 to 5 sec, the target dot stepped randomly up or down. The new position was maintained for a random period of 3 to 5 sec and then returned to center. Ten initial trials stepping out and returning to zero were performed at normal polarity. Following these ten initial trials, the computer reversed the polarity of the response dot. A random number (8 to 12) trials were performed at the reversed polarity, after which, the polarity again reversed for the next group of trials. The response immediately following a polarity reversal was always discarded, since it could be expected to contain a higher proportion of visually mediated error corrections than other responses.

This scheme of target dot movement also provided the opportunity to study simple and choice RTs, since the majority of responses were correct. When the target dot moved from the center, it moved randomly up or down, forcing the subject to choose before reacting. When the target dot next moved, it always

returned to zero, allowing the subject to make a simple reaction.

The subjects were instructed to make the response dot follow the movement of the target dot as quickly as possible with as much accuracy as possible, but to favor a fast response.

In the vibration experiments, two Hagbarth type vibrators (TVR vibrator - model #TMT-18, Heiwa Electronic Industrial Comp., Japan) were attached to the distal tendons of soleus and anterior tibial muscles (just above the ankle joint) with surgical tape. The vibrators were operated at 100 Hz continuously during the tracking task.

In the alcohol experiments, the subjects were given alcohol proportional to the body weight such that the ultimate BAC was in the range of 0.06 to 0.07%. The BAC was measured using a Mark II Intoximeter (Gas Chromatography Unit by Intoximeters, Inc.).

The measurement of the RTs were done off line by displaying the individual responses on a four channel oscilloscope using a cursor to indicate the time measurement after the input. The accuracy of these measurements is equal to the sampling interval, i.e., 2 msec. The RTs measured are indicated in Figures 2 and 3.

The statistical analysis included means and variances of the sample data and the t-test of equality of the means of two samples whose variances are assumed to be unequal (Sokal & Rohlf, 1969, Chapter 13).

RESULTS

Data were collected on separate days for each subject and for each experimental paradigm. The first day experiment was always under normal conditions. Typical responses are shown in Figure 2 for a correct response in a choice RT and for error response in Figure 3. The four traces are the angular rotation (θ), EMGs of the anterior tibial (AT) and gastrocnemius-soleus (GS) muscles and the angular velocity ($\dot{\theta}$). The angular velocity was obtained by digital differentiation of angular rotation. The simple and choice RTs (SRT & CRT), the error reaction time (ERT), and the error correction time (ECT) were measured using both the EMG and velocity data. In the following tables only the EMG related measurements are reported. The final conclusions would have been exactly the same using the velocity data.

Table I shows the simple and choice reaction times under normal conditions with positive and negative polarity movements. With the exception of subject GA, and GG's SRT, the RTs for the other three subjects with positive and negative polarity were not significantly different. In general there was a slight increase in the RTs with negative polarity. Since the RT differences with alcohol and vibration were more significant, the positive and negative polarity data was lumped together.

Table II shows SRTs for all subjects in three paradigm conditions. Note that in general, alcohol as well as vibration increased the SRT. This is also true for CRT shown in Table III. The t-test comparisons are made between the normal and altered conditions. In Table II, six out of eight t-test values are significant at $P < 0.01$ level. In Table III, seven out of eight t-test values are significant at $P < 0.01$ level.

Table IV shows the error reaction times in the three paradigm conditions.

Most errors occured in the choice reaction condition. There was a significantly larger number of errors with negative polarity than with positive polarity feedback. The error rates for the two conditions ranged between 16% and 33%. In these data, four out of eight t-test values show significant differences at $P < 0.01$ level.

Table V compares the data from Tables III and IV for choice RT and error RT under normal conditions. Note that error RTs are larger than the choice RTs and only one out of four t-test values show significant differences at $P < 0.01$ level.

Table VI shows the error correction times for the four subjects under our three paradigms. The error correction time is significantly less than the choice or error RT. None of the eight t-test values between normal and altered conditions show significance at $P < 0.01$ level.

Table VII shows the error rates for individual experiments as well as combined error rates for all subjects. The vibration input did not influence the error rates. Alcohol tended to increase the error rates in three out of four subjects but the t-test values do not indicate any significance. For $n = 4$ the t-test values are not very meaningful.

DISCUSSION

The paradigm of incompatible display has been used by Gibbs (1965), Angel & Higgins (1969), and Angel (1976). There is a clear increase in the SRT as well as CRT with negative polarity display (Table I). This increase was significant at $P < 0.01$ level for subjects GA and GG whose RTs were fastest. The significance of positive and negative polarity disappeared with increased RT of subject RJ and FM.

Vibration and alcohol increases both the SRT and CRT for correct movements as compared to the normal condition (Tables II and III). Carpenter (1962) has reviewed the literature on the effects of alcohol on psychological processes and concluded that in most studies, RT is lengthened at relatively low blood alcohol levels. Vibration of a tendon in humans causes a predictable increase in the contractile activity of the agonist, caused by autogenous reflex excitation of the alpha motoneuron (Hagbarth & Eklund, 1966). This leads to involuntary movements and illusion of movements (Goodwin et al 1972; McCloskey, 1973; Craske, 1977). In our experiments, vibrators were attached to both agonist-antagonist tendons and subjects reported numbness in the vibrated ankle joint. The significant increase in the SRT and CRT with vibration could indicate that large irrelevant position signals from the vibrated joint delays processing of visual information and command selection.

Tables IV and V show that the choice reaction time and the error reaction time (initial movement in the wrong direction) are not significantly different under normal conditions. This agrees with Gibbs (1965) findings that the response latencies of correct and incorrect responses were virtually equal on equiprobable steps. Although the response latencies for the four subjects are significantly different, there is no correlation between the response latencies and the errors of subjects (see Table VII), i.e., the subjects who responded most rapidly did not make the most errors (Gibbs, 1965). The ERT in most cases is longer than the CRT, suggesting that there was no temporal anticipa-

tion of the target (A paradigm which has been used by Schmidt and Gordon (1977) in their study).

The surprising result of this study is that whereas the SRT and CRT are influenced (increased) by vibration and alcohol, the error correction times are not significantly affected as given in Table VI. The average error correction time is shorter than the CRT for individual subjects. This is in agreement with findings by Gibbs (1965), Rabbitt (1966), and Angel and Higgins (1969), Megaw (1972), and Angel (1976).

The histograms of error correction times for the four subjects under three paradigm conditions are shown in Figure 4. For subjects GA and GG who had the most experience in tracking studies, most errors are corrected in less than 250 msec, i.e., less than their normal choice reaction times. For subject RJ a significant number of ECTs are larger than 250 msec. For subject FM, his RTs were the slowest and larger percentage of ECTs are above 250 msec.

The conclusion of Higgins & Angel (1970) and Angel (1976) that the origin of feedback from error responses is central rather than kinaesthetic is reinforced by the invariance of ECTs with vibration on the limb. The vibration increases the SRTs and CRTs which implies an influence of the peripheral input in motor command decision making.

Alcohol which is known to produce a depressive effect on the CNS also increases the SRTs and CRTs but does not significantly influence the ECTs with BAC levels of 0.07% or less used in these experiments.

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TABLE 1: Effect of Display Polarity on Simple and Choice Reaction Times

SUBJ	Positive Polarity MEAN	SD	N	t	NEGATIVE POLARITY MEAN	SD	N
			Simple Reaction Times				
GA	216	32	113	-3.99*	248	78	110
GG	222	51	129	-2.52*	240	71	164
RJ	270	76	130	-1.42	283	78	156
FM	359	75	133	0.59	354	69	161
			Choice Reaction Times				
GA	235	57	98	-2.79*	272	102	73
GG	256	42	111	-2.00	271	70	122
RJ	268	80	83	-1.12	282	84	90
FM	338	76	112	-1.46	359	69	112

*P < 0.01

TABLE II: Simple Reaction Times

SUBJ	VIBRATION MEAN	SD	N	t	NORMAL MEAN	SD	N	t	ALCOHOL MEAN	SD	N
GA	246	45	150	-5.99*	219	39	233	-4.48*	235	42	297
RJ	316	92	156	-4.50*	277	77	286	-7.75*	333	96	269
FM	371	78	274	0.58	375	86	294	-5.68*	420	98	256
GG	311	84	164	-10.46*	232	64	293	-1.24	240	54	290

TABLE III: Choice Reaction Times

SUBJ	VIBRATION MEAN	SD	N	t	NORMAL MEAN	SD	N	t	ALCOHOL MEAN	SD	N
GA	317	111	131	-5.58*	253	80	171	-0.64	258	59	152
RJ	333	83	98	-5.27*	277	86	173	-8.25*	355	88	166
FM	409	96	211	-7.43*	348	73	224	-11.28*	443	100	212
GG	330	85	136	-6.98*	272	61	233	-3.34*	288	61	230

TABLE IV: Error Reaction Times

SUBJ	VIBRATION MEAN	SD	N	t	NORMAL MEAN	SD	N	t	ALCOHOL MEAN	SD	N
GA	274	60	19	-1.03	257	62	47	-0.56	263	59	104
RJ	342	65	55	-2.90*	311	55	80	-3.57*	343	69	111
FM	387	75	59	-1.83	363	72	68	-5.72*	443	70	41
GG	332	84	32	-2.42*	289	63	42	-0.08	290	60	45

TABLE V: Comparison of CRTS with ERTS under Normal Conditions

SUBJ	CHOICE REACTION TIMES MEAN	SD	N	t	ERROR REACTION TIMES MEAN	SD	N
GA	253	80	171	-0.37	257	62	47
RJ	277	86	173	-3.79*	311	55	80
FM	348	73	224	-1.50	363	72	68
GG	272	61	233	-1.62	289	63	42

TABLE VI: Error Correction Times

SUBJ	VIBRATION MEAN	SD	N	t	NORMAL MEAN	SD	N	t	ALCOHOL MEAN	SD	N
GA	137	69	19	0.32	143	72	47	0.67	135	59	104
RJ	194	101	55	-1.71	166	81	80	-1.62	186	88	111
FM	259	72	59	2.18	293	103	68	2.23	251	90	41
GG	170	84	32	-0.05	169	72	42	-0.68	150	74	45

TABLE VII: Rate of Errors in Percent

SUBJ	VIBRATION	NORMAL	ALCOHOL
GA	0.063	0.107	0.188
RJ	0.178	0.148	0.203
FM	0.110	0.116	0.081
GG	0.096	0.074	0.080

	VIBRATION	t	NORMAL	t	ALCOHOL
MEAN	0.112	-0.04	0.111	-0.74	0.138
SD	0.048		0.030		0.067
N	4		4		4

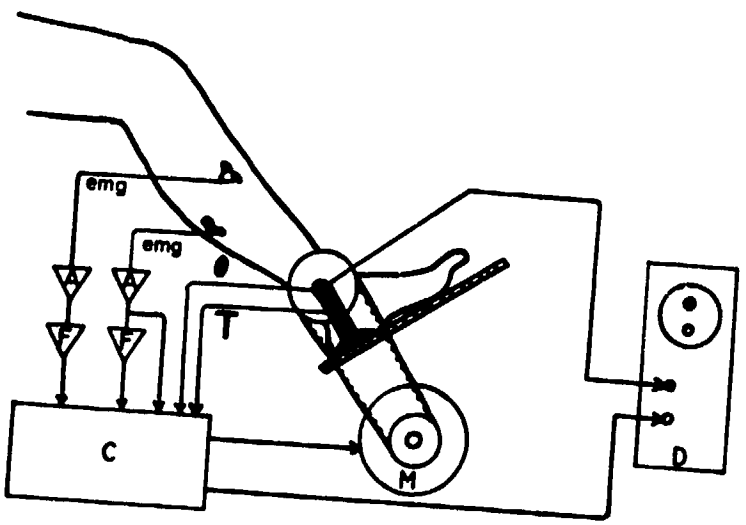

Figure 1

A schematic of the experimental apparatus. Electromyograms (EMGs) are measured using disk surface electrodes placed over the bellies of the gastrocnemius-soleus and anterior tibial muscles, EMG amplifiers (A) are differential amplifiers (bandwidth 60-600 Hz), filters (F) are third order averaging (10 msec averaging time), display oscilloscope (D) is a dual-beam Tektronix 502, digital computer (C) is a General Automation SPC016/65. The torque motor (M) and the torque measurements (τ) were not used in these experiments. The angular rotation (θ) is measured by a continuous transformer-type transducer, this signal is fed into the computer on an A/D input channel multiplied by +1 or -1 and outputed on D/A channel. This channel is operated independent of the data channels at a rate of 1 KHz.

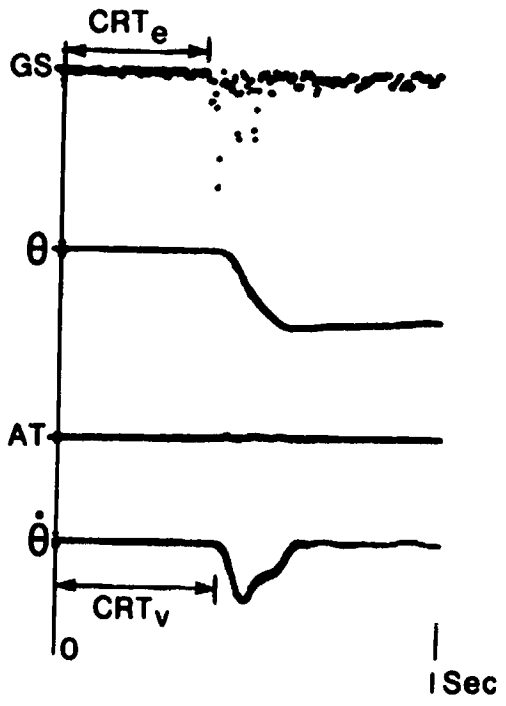

Figure 2

Typical response in a choice reaction with a display gain of +1 and a movement from central position to plantarflexion of the ankle joint. The choice reaction time (CRT) is measured from the jump of the target to the first EMG burst in gastrocnemius-soleus (GS) muscle. There is no EMG activity in the anterior tibial (AT) muscle. Total display time is 1 sec.

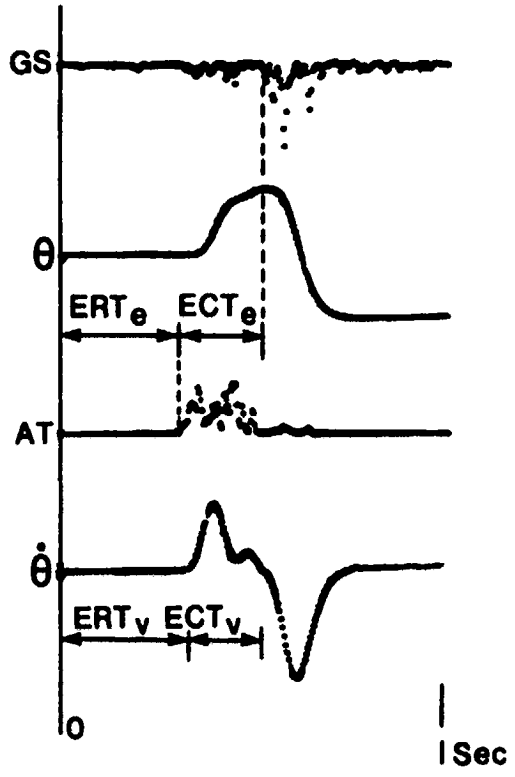

Figure 3

Typical response in error movement and subsequent correction. The display polarity is again +1. The error reaction time (ERT) and error correction time (ECT) are measured from the initial burst in the antagonist and agonist muscle EMGs. Total display time is 1 sec.

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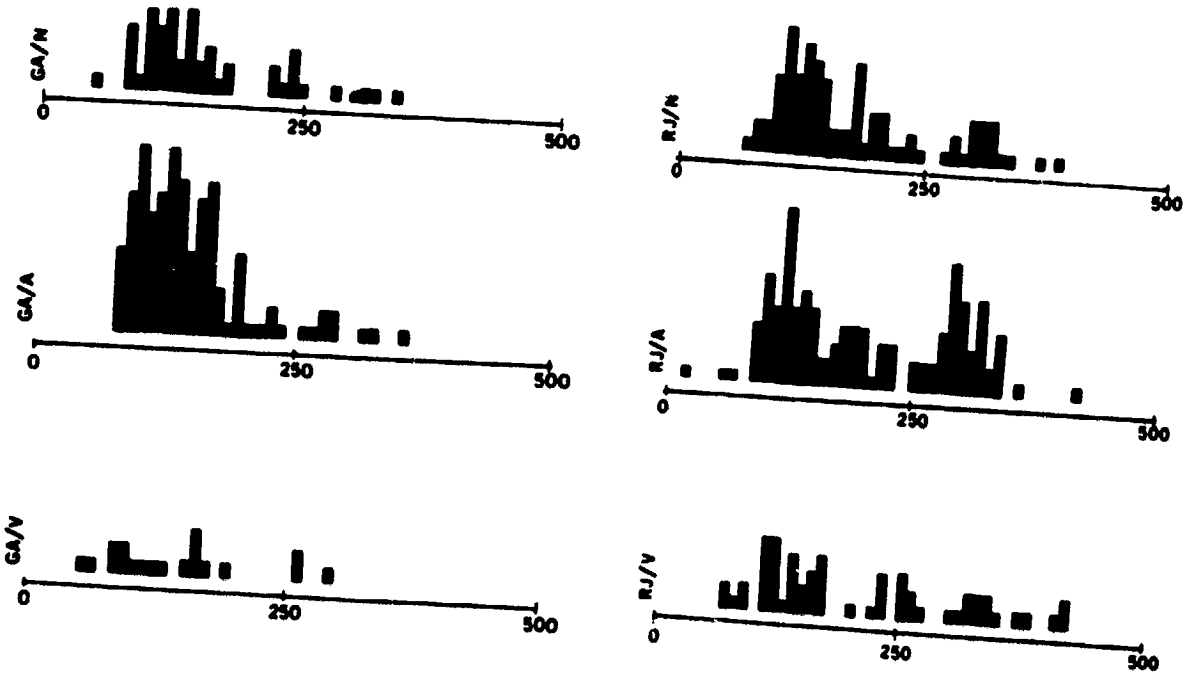

Figure 4

Histograms of the error correction times (ECTs) for the four subjects under normal (N), alcohol (A) and vibration (V) input paradigms. The time interval on abcissa is 500 msec. (continued on next page)

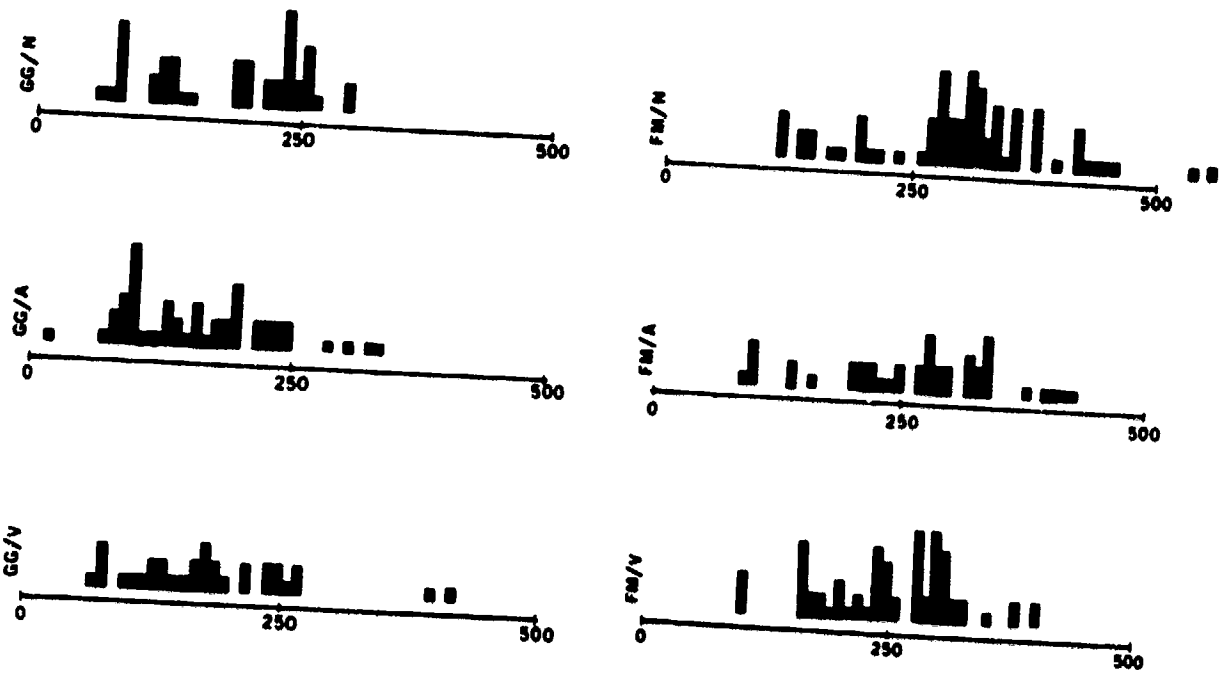

Figure 4 (continued)