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THÈSES CANADIENNES SUR MICROFICHE

NAME OF AUTHOR/*NOM DE L'AUTEUR* DANIELLE A. SCIARRETTA

TITLE OF THESIS/*TITRE DE LA THÈSE* THE EFFECTS OF INSTRUCTIONS ON MOTONEURON EXCITABILITY AND THE GAIN OF REFLEXES

UNIVERSITY/*UNIVERSITÉ* SIMON FRASER UNIVERSITY

DEGREE FOR WHICH THESIS WAS PRESENTED/ *GRADE POUR LEQUEL CETTE THÈSE FUT PRÉSENTÉE* M.Sc. (KINES)

YEAR THIS DEGREE CONFERRED/*ANNÉE D'OBTENTION DE CE GRADE* 1984

NAME OF SUPERVISOR/*NOM DU DIRECTEUR DE THÈSE* DR. PARVEEN BAWA

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THE EFFECTS OF INSTRUCTIONS ON MOTONEURON EXCITABILITY AND THE GAIN OF REFLEXES

by

Danielle A. Sciarretta

B.A., Simon Fraser University, 1977

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
in the Department
of
Kinesiology

SIMON FRASER UNIVERSITY

March 2, 1984

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Author:

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DANIELLE A SCIARRETTA

(name)

APRIL 16, 1986

(date)

APPROVAL

Name: Danielle A. Sciarretta

Degree: Master of Science (Kinesiology)

Title of Thesis: The Effect of Instructions on Motoneuron Excitability and the Gain of Reflexes

Examining Committee:

Chairman: Dr. Igor Mekjavic

Dr. P. Bawa
Senior Supervisor

Dr. J. Dickinson

Dr. T. Calvert
External Examiner
Faculty of Interdisciplinary Studies
Simon Fraser University

Date Approved: March 13, 1984

ABSTRACT

The object of this thesis was to examine instruction dependent modulation of amplitude of the short and long latency components of the stretch reflex in human wrist flexors. Two experiments were performed using repeated trials and four levels of perturbations. Background muscle activation was controlled using a constant biasing pre-load.

In Experiment I, the effect of instructions to "compensate", "let go", or "assist" the imposed perturbation was examined in one group of subjects under two separate conditions of instruction: 1) mixed instructions and 2) non-mixed instructions. In Experiment II the effect of "compensate" and "let go" instructions was compared for two age groups, one much older than the other (Group 1 age range= 21-30; Group 2 age range= 50-69). The relationship between modulating ability and voluntary kinesthetic reaction time was examined in both experiments.

In Experiment I, when instructions were not mixed, instruction dependent changes were seen in muscle background activity. Modulation of the amplitudes of both the short and the long latency components of the stretch reflex were also observed. Modulation of the short latency reflex component was dependent on the direction of change of background activity whereas that of the long latency component was independent of the changes in background. In the mixed instruction paradigm, no changes occurred in the background and hence no modulation of short latency reflex amplitude was observed. However, modulation of the long latency reflex component was still observed, just as in the non-mixed instructions paradigm.

In Experiment II, similar amplitude modulation was observed in the two age groups for both reflex components. The only statistically sigificant age group difference was the presence of modulation of background in the younger group only.

From both experiments no strong relationship emerged between ability to modulate reflex amplitude and kinesthetic reaction time.

The data gathered here support the existence of separate neural pathways for the short and long latency components of the stretch reflex, and indicate that there are little, if any, age related modifications in these neural pathways up to the sixth decade of life.

ACKNOWLEDGMENTS

I would like to extend many thanks to Dr. Nory Ison, for generous assistance in the statistical analysis of the data; and to Dr. John Dickinson, for support in the early stages of writing this thesis.

Dr. P. Bawa and her laboratory facilities were instrumental in the gathering and analyzing of the data. This work was supported by BCHCRF and NSERC grants to Dr. Bawa.

Lastly, the financial support of an NSERC Sholarship to the author also is gratefully acknowledged.

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CHAPTER I

INTRODUCTION

Motor reflexes consist of specific muscular responses to specific sites and types of stimulation. Responses are generally related to their stimulus in a strongly stereotypical manner, demonstrating fixed input-output relationships (Henneman, 1980).

The response of a muscle to stretch consists of a reflex contraction initiated by EMG activity starting from 8 to 37 msec from the start of stretch, depending on the muscle (Marsden, Merton and Morton, 1973a). This reflex constraction has traditionally been termed "tendon jerk" if elicited by a tap to the tendon, and "stretch reflex" if elicited by relatively slow rates of stretch (Marsden, Merton and Morton, 1973a). Afferent inputs mediating the reflex contraction originate predominantly from muscle spindles. Both spindle primaries (type Ia) and secondaries (type II) are involved, with their relative importance being determined by input characteristics such as velocity of stretch (Matthews and Stein, 1969) and duration (Henneman, 1980).

The stretch reflex has been the subject of intense investigation since the turn of the century and the time of Sherrington. Following his conceptualization of the stretch reflex as a prolonged tendon jerk in 1924, the same neural mechanism became accepted for both responses (Marsden, Merton and Morton, 1973b). Consequently, until recently, the stretch reflex was considered to be simple and spinal, mediated by a neural circuit involving one or more synapses between afferent and efferent limbs of the loop. This appealingly simple conceptualization of the stretch reflex was later challenged by the work of Hammond in the mid 1950's.

While testing the load compensation hypothesis of stretch reflex function, Hammond (1954, 1956, 1960) described, in human biceps, the occurrence of two separate components of reflex EMG activity. The first component, at a latency of 18 or 20 msec, seemed to correspond to the well established spinal reflex arc. The second component of activity followed a period of EMG quiessence and began at about 50 msec. That an altogether separate and different neural mechanism was likely to be responsible for the second component was immediately suggested by the dissociation of the two components in response to prior instructions. It was observed that instructions to "let go when pulled" could effectively suppress all activity starting at 50 msec, while the initial response, referred to as the "tendon jerk response" by the author, was not at all affected (Hammond, 1954 and 1956).

Since the latency of the second EMG component was much less than that for voluntary activity (later than 100 msec) yet much longer than any required by monosynaptic transmission, it was suggested that an altogether different neural circuit mediated the second component. A longer loop, one involving higher centres controlling alpha and gamma routes to the muscles, and possibly the cerebellum, was proposed to be operating simultaneously with the shorter, spinal pathway (Hammond, 1960).

Shortly thereafter the sensorimotor cortex began to replace the cerebellum as the most likely site of afferent-efferent linkage for long loops. The documentation of direct projections of Ia afferents to area 3a, in the baboon (Phillips, 1969), provided anatomical evidence for the circuitry of the hypothesized loops, and also placed them within an evolutionary context. It was suggested by Phillips that long loop (and modifiable) stretch reflexes might be replacing the more primitive, stereotyped, spinal loops in higher primates. Ascending the evolutionary scale, direct cortico-motoneuronal projections are present in macaques (Brown, Milner-Brown, Ball and Girvin, 1978), better developed in baboons (Phillips, 1969) and most dense in man (Brown et al, 1978).

Proprioceptive afferent linkage to motor cortex has been well established in primates. Open loop investigations established firing rates of both pre- and post-central neurons as responsive to mechanical perturbations of hand position in monkeys, and to be timed appropriately to contribute to long latency muscular activity beginning at 35 msec (Evarts, 1973; Evarts and Tanji, 1974). Pyramidal tract neurons (identified by antidromic stimulation at the medullary level) responded to stretch of the arm with a latency of 24 msec, non-pyramidal neurons responded at 14 msec and post-central neurons even earlier (10 msec after start of the stretch). Subsequent closed loop investigations in awake macaques by Fetz and coworkers have supported and expanded these findings. Using spike triggered averaging, these authors showed that most precentral corticomotoneuronal cells whose output produced postspike facilitation of forelimb muscles responded to passive stretch of their target muscles (Fetz and Cheney, 1980; Fetz, Finocchio, Baker and Soso, 1980; Soso and Fetz, 1980). This relation between the sensory input to the corticomotoneuronal cells and their motor output confirmed that they participate in a negative feedback loop via the cortex.

In humans, indirect evidence for the transcortical nature of long stretch reflex loops has been gathered by a number of clinical investigations. Examining the effects of lesions of the central nervous system on the stretch reflex in humans, it has been repeatedly demonstrated that lesions in the spinal cord (dorsal columns), medial lemniscus, internal capsule, and sensorimotor cortex, all result in a selective impairment of exclusively longer latency muscle activity (Adam, Marsden, Merton and Morton, 1976; Conrad and Aschoff, 1977; Marsden, Merton and Morton, 1977 and 1978; Chan, Melvill Jones, Kearney and Watt, 1979). Similar results have been obtained in more accurately and experimentally lesioned monkeys (Lee and Tatton, 1975; Lenz, Tatton and Tasker, 1983).

In comparing latency between tendon jerk responses and later activity for different muscles, it has been shown that this time interval increases as distance between motoneuron pool and brain increases (Marsden, Merton and Morton 1973 (a)) and 1976 (b); Chan et al, 1979). This has been interpreted as more indirect evidence for the existence of long loops, despite some exceptions to the pattern. In humans, long latency activity for flexor pollicis brevis was not the same as for flexor pollicis longus (Marsden et al, 1976). In the squirrel monkey, long latency activity in short head of biceps brachii was later than that in flexor carpi ulnaris and flexor digitorum profundus (Lenz et al, 1983a).

The importance of a transcerebellar route for the modulation of supraspinal reflexes has been suggested by others beside Hammond (Milner-Brown, Stein and Lee, 1975). In an elegant study of afferent-efferent linkages in the forelimb motor cortex of cats, the importance of cerebellar facilitation of cortical Ia response has been shown (Murphy, Wong and Kwan, 1975). Cerebellar cooling, particularly of dentate, drastically reduced the motor cortex response to Ia input, particularly that of the second component, starting 22 msec following stretch.

Whether a supraspinal pathway is essential for longer latency muscular activity has been questioned by a number of investigators. Results have been obtained indicating that participation of higher centres is not required for prolonged EMG activity. Spinal and decerebrate cats still showed multiple peaks of EMG (Ghez and Shinoda, 1978). All neural activity, background as well as subsequent responses, was equally reduced in the limbs of both spinal cats and monkeys (Tracey, Walmsley and Brinkman, 1980). Extensive cerebral and cerebellar lesions and cooling in monkeys did not affect late responses differentially from background or from earlier activity (Miller and Brooks, 1981).

An alternative viewpoint to the long loop hypothesis has recently been advanced, following observation of multiple bursts of spindle Ia afferent activity in passively extended human wrists (Hagbarth, Hagglund, Wallin and Young, 1981). Mechanical oscillations of the musculotendinous system have been proposed as responsible for the repeated bursts of afferent activity and the subsequent multiple EMG peaks, independently of longer circuits (Eklund, Hagbarth, Hagglund and Wallin, 1982a). Also supporting this "resonance hypothesis" is the observation in 'spinal' cats of two bursts of Ia activity corresponding to two EMG peaks (Tracey et al, 1980).

To recapitulate, evidence exists in favour both of a supraspinal, cortical or cerebellar, mediated long latency response to stretch, and of an exclusively spinal interpretation. One avenue of clarification of this issue is through examination of the effects of instruction on the components of EMG activity. If the long latency and the short latency components can, as first suggested by Hammond, be dissociated in response to instructions, separate pathways would be indicated. On the other hand similarity of response at both latencies would support the contention that both responses may be mediated by the same pathways. In the literature, four, possibly five, neural mechanisms have been proposed whereby modulation of reflex responsiveness could occur.

Firstly, increased reflex activity could be mediated by increased alpha-gamma drive. Enhanced alpha motoneuron activity would be manifested as increased muscular background activity and could result in larger reflex activity at both short and long latency. This has repeatedly been observed to occur when levels of biasing preload to a muscle are manipulated (Evarts and Granit, 1976; Gotlieb and Agarwal, 1979; Eklund et al, 1982; Jaeger et al, 1982). The increased gamma activity accompanying the increased alpha activity would similarly enhance responsiveness at all latencies.

Secondly, altered fusimotor activity alone has been proposed as another mechanism for changed reflex responsiveness. This would be manifested as an altered threshold for reflex response possibly unaccompanied by any change in background activity. Both components would then be affected similarly. Such a mechanism was proposed by Iles (1977) to account for increased responses in his pretibial muscle after instructions to 'resist' a perturbation; by Evarts and Fromm (1978) to account for the high sensitivity of pre-central neurons to small disturbances; and by Dufresne, Soechting and Terzuolo (1980) to account for changes in reflex excitability during sinusoidal movements. No change in fusimotor sensitivity was observed, however, during preparation for a voluntary contraction in human pretibial muscles (Burke, McKeon, Skuse and Westerman, 1980).

Thirdly, spinal reflex excitability could be centrally altered by subthreshold facilitation or disfacilitation of the motoneuron pool. No measurable EMG changes would be obvious prior to the response in this case also and both components would be affected similarly. That stretch reflex amplitude can be conditioned independently of background activity and muscle length has been suggested in monkeys (Braitman, Wolpaw and Kieffer, 1982). Further, monkey precentral neurons show instruction dependent changes in activity without concomitant EMG changes, prior to a perturbation (Evarts and Tanji, 1974; Tanji and Evarts, 1976). Subthreshold facilitation of the motoneuron pool has also been suggested by Eklund and co-workers (1982 (b)) for altered instruction-dependent responses, and also by Gottlieb and Agarwal (1979) and Jaeger and co-workers (1982a,b).

Fourthly, assuming the existence of a separate long loop for the long latency response, it could be possible to pre-set the gain of this loop separately. This was the mechanism originally proposed by Hammond (1960) and also by Colebatch and co-workers (1979). In this eventuality no change would be seen in prior background activity nor in the first component of a reflex response.

Lastly, an integrative perspective proposes that modulation of longer latency components of EMG activity can be achieved by altering reactivity at both the spinal and the supraspinal loop levels. Within this perspective, "transcortical reflexes" in an intact animal are interpreted as the product of both segmental and suprasegmental inputs to the motoneuron pool "organized for close cooperation" (Evarts and Fromm, 1981). It has been suggested that utilization of each loop, spinal and supraspinal, would be reweighed each time in order to be the "most appropriate to each set of circumstances" (Grimm and Nashner, 1978), particularly for modulation of muscular activity with instruction (Milner-Brown et al, 1975; Miller and Brooks, 1981).

The existing literature on the effects of instruction on stretch reflex modulation does not provide a definitive answer to whether the two components can be dissociated. Claims of both have been made since Hammond. Evidence supporting dissociation of the two components has been gathered but interpretations for this phenonmenon have varied widely.

Instructions to "resist" or to "let go" to forced extension of the elbow, in a paradigm very similar to Hammond's, resulted in the same enhancement or suppression of EMG activity occurring between 40 and 70 msec after stretch (Colebatch, Gandevia, McCloskey and Potter, 1979). Equivalent instructions, "pull" and "let go", to perturbations of the distal joint of the thumb resulted in amplitude modulation of the late portion, component B, of the late reflex acitivity if the thumb was held stationary (Marsden, Merton, Morton, Adam and Hallett, 1978), but in an absence of amplitude modulation when the thumb was moving

(Marsden, Merton and Morton, 1976a).

Comparing "resist" and "let go" instructions to perturbation of wrist flexors also demonstrated that late peaks are more easily modified by prior instruction than are initial EMG peaks (Eklund et al, 1982b). However, observations that in a train of short-latency responses those closest to the volitional response were most affected by instruction led these authors to conclude that spinal pre-setting was responsible for the phenomenon, and not long loops.

Literature also exists proclaiming that both the short and the long latency reflex activities are modified by prior instruction. It is worth noting at this point that Hammond himself also observed an occasional suppression of the "tendon jerk" response at the elbow following instructions to "let go" (Hammond, 1960).

Comparison of "compensate" and "passive" instructions on human wrist responses indicated that all EMG peaks were affected by the instructions (Lee and Tatton, 1975). Similar results were obtained comparing "compensate" and "let go" (Lee and Tatton, 1978). Although late EMG peaks (M2, M3) occurring from 55 to 85 msec were most markedly affected by instructions, the earlier activity (M1) at a latency of 30-35 msec was also modulated, to a smaller degree.

Also at the wrist a series of four different instructions, "do not react", "react to target", "react maximally", and "assist", were shown to affect magnitude of both early, "myotatic", activity occurring between 30 and 60 msec and "late-myotatic" activity spanning 60 to 120 msec from the stretch (Jaeger et al, 1982). Biceps and triceps also have demonstrated modulation of short-latency activity with a range of instructions (Thomas, Brown and Lucier, 1977).

Results of a similar nature have been obtained for lower limb muscles using "resist" and "let go" on human tibialis anterior (Iles, 1977), and "resist", "do not resist" and "assist" on soleus and gastrocnemious as well (Gottlieb and Agarwal, 1979).

Modulation of short latency acivity with instructions has also been documented in nonhuman primates (Evarts and Tanji, 1976) and in cats (Ghez and Shinoda, 1978).

At the level of the motor cortex, instruction induced changes in activity in monkey pre-central neurons occurred within 200 to 500 msec of instruction onset and prior to any perturbation, pre-setting spinal cord reflex excitability (Evarts and Tanji, 1974). Further, the level of pyramidal tract neuron activity following perturbations to the elbow also was modulated depending upon instructions to "pull" or to "push" (Evarts and Tanji, 1976).

Lastly, investigations directed specifically to examining the effect of mixing and non-mixing different instructions have shown, on human biceps, that randomization of instructions ("pronate" and "supinate") minimizes their effect on the short latency response (Evarts and Granit, 1976). Elimination of changes in tendon jerk amplitude was subsequently determined to be the result of concomitantly abolished changes in background discharge prior to the perturbation (Evarts and Vaughn, 1978).

In summary, there are two important considerations when instruction effects on reflex amplitude are examined. One, given the previously mentioned dependence of reflex response magnitude on levels of motoneuron pool excitability, it is essential to control background facilitation of the motoneuron pool prior to stretch, as mentioned by Iles (1977). Two, quantification of the reflex responses is also necessary. Failure to do this renders comparisons and conclusions tenuous.

Some of the studies mentioned above suffer from these methodological inadequacies. Instruction effects were examined under a condition of no biasing preload by Gottlieb and Agarwal (1979). And no quantification of results was performed by Hammond (1954 to 1960), Marsden and coworkers (1976 and 1978), Colebatch and coworkers (1979, for the short latency component), and Eklund and coworkers (1982).

Relationships between ability to modulate the gain of the stretch reflex pathways and other variables related to movement performance have not been explored before. While a great deal is known about voluntary reaction time and its relationship to aging, no information exists on how either of these two variables are related to gain modulating ability.

Kinesthetic reaction time, the time required to react voluntarily to a kinesthetic stimulus, can be very fast, in the order of 70-80 msec in human biceps (Evarts and Vaughn, 1978; Colebatch et al, 1979), and of 85 msec in flexor pollicis longus (Marsden et al, 1978). Voluntary reaction time to auditory or visual stimuli are all much longer, generally beyond 100 msec (Hammond, 1960; Evarts and Vaughn, 1978; Lee and Tatton, 1978). Since stretch reflex activity can preceed voluntary contraction by intervals of 25-40 msec in monkeys or even longer in man, it has been suggested that the very short kinesthetic reaction time may be rendered possible by some facilitatory effects of the prior reflex activity on the motoneuron pool (Ghez and Shinoda, 1978).

In functional investigations of stretch reflex activity it has been demonstrated that the long latency response magnitude in the human thumb can compensate up to 50% error in position due to a disturbance (Marsden, Merton, Morton, Rothwell and Traub, 1981) and that the magnitude of long latency activity and of voluntary activity are inversely related (Marsden, Rothwell and Traub, 1979). It is possible, therefore, that ability to modulate the reflex response might be related to short kinesthetic reaction time if both are aspects of the same neuromuscular functioning.

The general decrease in reaction time seen with age (Suci, Davidoff and Surwillo, 1960; Salthouse, 1979; Evarts, Teravainen and Calne, 1981) might thus be accompanied by a loss of ability to modulate the gain of reflex pathways.

Alternatively, the general reduction in physiological plasticity seen with age (Welford and Birren, 1965; Brown, 1972; Campbell, McComas and Petitio, 1973; Grimby, Danneskiold-Samsoe, Hvid and Saltin, 1982) might be directly reflected in or be responsible for a reduced ability to modulate reflex responses. The plasticity of the long latency response in particular has been well documented. Developmentally, it reaches adult form only around the age of 8-10 years (Bawa, 1981). It is highly susceptible to learning. Training is required to produce modulation or response in the flexor hallucis longus (Marsden, Merton and Morton, 1976b). Practice improves modulation performance in a variety of human muscles (Hammond, 1960; Conrad and Aschoff, 1977; Marsden, Merton and Morton, 1976b). Long latency activity is also highly dependent on its context. For example, despite similar anaesthesia of the thumb, long latency activity of the thumb flexor was reduced only when the muscle was perturbed while acting as a prime mover. The response was not affected when the muscle was acting posturally (Marsden, Merton and Morton, 1976c). Lastly, no long latency response was elicited by very small perturbations (+/- 1% of maximal force) unless these were mixed with large perturbations (Marsden, Merton and Morton, 1979).

This thesis was undertaken to explore the instruction-dependent amplitude modulation of the two components of the stretch reflex in human wrist flexors while giving particular attention to the methodological issues mentioned above. A variety of instructions were examined both mixed together and separately.

Additionally, the relationship between the ability to modulate the components, particularly longer latency activity, and kinesthetic voluntary reaction time was examined. This was also tested with different age groups to evaluate possible age related differences of both phenomena.

CHAPTER II

METHODS

Subjects

A total of thirty-eight subjects of both sexes, ranging in age from 21 to 69 years, were recruited from the university community. All subjects were right handed and were randomly assigned to three groups on the basis of instruction paradigm and age.

One group of fifteen subjects (8 male, 7 female), 23 to 30 years old, was tested under two separate conditions of instruction: 1) mixed instructions and 2) non-mixed instructions.

The other two groups were tested with a reduced mixed instructions paradigm only. Of these, one group consisted of ten subjects (8 male, 2 female) 21 to 30 years of age. The other consisted of thirteen subjects (9 male, 4 female) 50 to 69 years old.

Apparatus

Perturbations extending the wrist were administered by a vertical handle attached to the shaft of a precision torque motor (Aeroflex Laboratories TQ 82W, type C). The motor was driven by square pulses, 250 msec in duration, with a servoamplifier. Four different pulse magnitudes were used: 0.9, 1.8, 2.7 and 3.6 volts. These were each superimposed on a constant biasing preload of 0.4 volts. Calibrations of torque magnitude with the handle positioned at 10 cm from the shaft of the motor established 4.0 volts to correspnd to 10,000 gm cm.

A padded horizontal platform level with the handle supported the subject's arm during testing, reducing muscular activity other than for the wrist musculature. In positioning the arm for testing the axis of rotation of the wrist was aligned with the axis of rotation of the motor and stabilized with padded side grips. These gripped the forearm just proximally to the wrist and did not in any way impede either flexion or extension of the joint. The distance of the handle from the shaft of the motor was adjusted for each subject, a range of 7 to 10 cm so that the handle could be held comfortably in the palm of the hand with the fingers relaxed.

Angular wrist position was monitored by a potentiometer (Bourns Inc.) coupled to the shaft of the torque motor. Position feedback was provided to the subject by means of a Tektronix oscilloscope.

Tension at the handle was measured by two pairs of strain gauges (Micromeasurements type EA-13-250MQ-350) connected to a Vishay 2310 bridge circuit.

EMG Recording

In all subjects surface EMG was recorded for wrist flexors using Ag-AgCl electrodes placed 3-5 cm apart on the medial half of the forearm, over the flexor carpi radialis muscle. Extensor EMG was also recorded for those subjects involved in Experiment I. Grounding was through a strap positioned on the distal forearm. For recording, the EMG signals were first bandpass filtered (30Hz - 3KHz by Grass P15-AC preamplifiers) and then further amplified.

All signals, along with torque pulses, light pulses (see Instructions), tension and position records, were recorded on an 8 channel FM tape recorder for off-line analysis.

Instructions

Three different instructions were used to tell subjects how to respond to a forthcoming mechanically produced wrist extension. These were: "compensate", "let go" or "assist" and were clearly defined to the subjects. Specifically, "compensate"= react as quickly as possible to the perturbation by flexing the wrist ; "let go"= actively relax, let the wrist be extended without resisting; "assist"= aid the perturbation by actively extending the wrist.

Instructions were usually given by means of a light-box. On the box both the colour and the position of the light served as cues to the response required to be made subsequently to the perturbation. Facing the subject from left to right the lights were: red=compensate=flex; yellow=let go; green=assist= extend. When only two instructions were used the middle yellow light was covered by black tape and the green light was now used to signify let go. Square pulses of different amplitudes were used for labelling each light instruction for the purpose of recording and subsequent analysis.

The three instructions were given as one of the following paradigms.

A. 3-Choice Simple Reaction Time Paradigm:

All three instructions were used, mixed pseudo randomly.

B. 2-Choice Simple Reaction Time Paradigm:

"Compensate" and "let go" instructions only were used, again mixed pseudo randomly.

C. 1-Choice Simple Reaction Time Paradigm:

No light box was used. Each instruction was tested separately by asking the subject to repeatedly respond the same way to all the pseudo.randomly presented four loads.

These particular labels have been chosen in order to facilitate discussion of the different paradigms by referring specifically to the number of instructions used within each one. In all cases the subject was instructed on how to react to the perturbation well in advance of actually having to respond. The specific reaction times measured were therefore 'simple' in nature.

The whole study was devided into two main experiments. Experiment I included paradigms A and C. Experiment II consisted of paradigm B only. These two experiments are explained below.

Experiment I

This experiment included 15 subjects in the age group 20-30 years. The purpose of this experiment was dual: one, to investigate gain modulation of stretch reflex pathways with a range of instructions; two, to determine how this modulation is affected by the manner in which the instructions are given.

The two conditions of instruction consisted of one, intermixing the instructions (3-Choice Simple Reaction Time Paradigm) and two, testing each instruction separately (1-Choice Simple Reaction Time Paradigm).

Paradigm A: 3-Choice Simple Reaction Time

In this condition the three instructions (compensate, let go and assist) were given in random order, following a preprepared sequence which was used for all subjects. The time interval between each perturbation was such as to reduce the subject's preparatory time to a few seconds, at the most, thus preventing the establishment of a single and constant preparatory set. In addition, short sequences of five or six uninstructed wrist extensions were pseudo randomly intermixed with the instructed perturbations. These attempted to evaluate reflex magnitude to perturbations which were unexpected and to which the subject was not required to prepare a response.

Each of the four types of response: compensate, let go, assist and 'no-instruction', were paired with the four sizes of perturbation (0.9 V, 1.8 V, 2.7 V and 3.6 V) and tested repeatedly. Each possible instruction-load pair, 16 in total, was presented more than twenty times.

Paradigm C: 1-Choice Simple Reaction Time

In contrast to the first condition here each of the three instructions (compensate, let go, assist) was tested separately, in three single-instruction simple reaction time sets.

For each of these sets the one required response was given verbally at the beginning of the set and thereafter not given again. More than twenty repetitions of each instruction-load pair, 4 per set, were given.

The order in which the three instruction sets were given varied from one subject to the next. Each sequence of sets began with the preceding one's second instruction. For example: if subject A's sequence was 1. compensate 2. letgo 3. assist then subject B's sequence became 1. letgo 2. assist 3. compensate.

Lastly, the order in which the two conditions of mixed and non-mixed instructions were tested also alternated between consecutive subjects.

Experiment II

Paradigm B: 2-Choice Simple Reaction Time

This testing paradigm used a reduced condition of randomly mixed instructions to investigate possible age related changes in reflex gain modulating ability. Compensate and let go instructions only were used (along with the uninstructed loads) since these have been the two conventionally used to assess reflex modulation ability (Hammond, 1954). Two different groups of subjects of widely separate age ranges, 21-30 and 50-69 were tested. Again, four magnitudes of perturbation were used and all possible instruction-load pairs, 12 in total, were presented more than twenty times, in pseudorandom order, according to a predrawn list. The effect of testing the instructions separately was not investigated in these two groups. This less time consuming paradigm facilitated the recruitment of older subjects.

Procedure

Throughout the experimental session the subject sat with the right arm positioned as described above, facing both the instruction light-box and the positional feedback oscilloscope. Prior to testing the meaning of the instructions was carefully described, as were the significance of both the colour and the position of each light. In addition, it was requested that the handle attached to the torque motor be repositioned, after each trial, at a constant starting place (roughly 10 degrees flexion), by using the horizontal line on the scope for feedback.

All subjects were given practice to familiarize them with the equipment, with position and EMG feedback and the instructions. Inappropriate responses were corrected verbally by the experimenter. Practice was continued until the subjects felt comfortable with the tasks. Testing was then commenced.

Just prior to the start of the mixed instructions data gathering sessions subjects were informed that there would be occasional unexpected and uninstructed wrist extensions intermixed with the others. It was explained that these were part of the experimental design and that no specific responses were expected to be made to these perturbations.

For all trials a variable time delay of 0.5 to 2.0 seconds separated load onset from light onset. This variable time delay served the dual purpose of allowing the subjects sufficient time to prepare to respond appropriately while preventing a possible anticipatory response. The instruction-light remained lit throughout this interval.

Data Analysis

All data recorded from approximately twenty trials of each instruction-load pair were averaged on an LSI-11 microcomputer with a sampling rate of 1000/sec. Square pulses representing the different loads and lights were separated by multilevel logic circuitry. The outputs of this circuitry were fed to an AND gate to obtain trigger pulses for various load-instruction combinations. These pulses triggered the computer where four A/D channels simultaneously averaged flexors and extensors EMG, handle position and tension.

EMG Processing

Prior to averaging, EMG records were rectified, to eliminate cancelling of positive and negative activity, and amplified to 0-5 volts. In addition, flexor EMG was delayed by 40-50 msec to allow the evaluation of background activity. Position and tension records were amplified to ± 5 volts maximum.

Flexor reflex activity for each instruction-load combination was calculated for the background (BG), short latency (SL) and long latency (LL) components separately. The two components were identified by visual inspection of the averaged records and quantified according to previously used procedures (Bawa, 1981). Calculations were as follows:

$A_x(t)_i$ = averaged area under peak x, of duration t_i for condition i (over 20 trials),

x = SL or LL,

i = instruction and load pair,

$B(t)_i$ = area for the background period t prior to reflex activity,

A'_{xi}/msec = A_{xi} / duration of peak, t_i, and

B_i/msec = B_i / t.

Background activity, B_i/msec, was then subtracted from A_{xi}/msec in order to determine a measure of exclusively reflex activity:

$(A_{xi})_p = A_{xi}$/msec - B_i/msec
= mean reflex activity per msec under peak x above background.

Lastly, the values for background, the short latency and the long latency reflex components obtained in this manner were then normalized with respect to the largest value calculated for each subject. This process of normalization is useful in permitting comparisons to be made between subjects in terms of proportional change in activity across instructions.

A similar process was used to obtain a measure of extensors background activity during the first 16 msec following administration of the perturbation. During this brief time interval the extensor activity would be as yet unaffected by the reflex flexor activity beginning at 20 msec or later.

Voluntary Reaction Time

Voluntary reaction times were calculated from the averaged flexors and extensors traces. In all cases of Experiment I reaction time was defined to be the time (in msec) when averaged voluntary EMG activity reached a value three times that of the averaged background (also in msec). In this manner values for reaction time were obtained for all four magnitudes of perturbations for compensate (flexors EMG) and assist (extensors EMG) instructions in both the mixed (3-Choice) and the non-mixed (1-Choice) instruction paradigms. These multiple evaluations of reaction time ensured that an accurate measure of the fastest reaction time was obtained for each subject.

In Experiment II (2-Choice Simple Reaction Time Paradigm), values of reaction time were derived from the largest perturbation for the compensate task only since this was established to be consistently the fastest, as judged from Experiment I.

Calculations for Degree of Amplitude Modulation

Experiment I: 3-Choice and 1-Choice Simple Reaction Time Paradigms

The effects of instructions, of the manner in which instruction were presented (mixed versus non-mixed) and of the magnitude of the perturbation were examined using one-way repeated measures analyses of variance. An already existing computer package called MANOVA was selected for use from within the SPSS (Statistical Package for the Social Sciences) program available at S.F.U. Significant effects (p = < .05 level) were pursued with subsequent MANOVAS to the point of pairwise comparisons. All the MANOVAS were performed for the normalized values of background, short latency and long latency components following an arc sine transformation of the data. This transformation is required for parametric analyses on values that are in the form of proportions (Kleinbaum and Kupper, 1978). Both results and discussion of the results will be made in terms of the original, untransformed, normalized data to facilitate interpretation.

The relationships between modulating ability, reaction time and age were computed with Pearson R correlations. Again using SPSS, correlations were calculated between amplitude modulation of each of the three EMG variables (background and the two reflex components) and reaction time and age. First, amplitude modulation was calculated for the background, the short and the long latency components as the difference between all possible pairs of instructions in their averaged normalized responses (averaged over the four sizes of perturbations). For example:

$$\begin{aligned} LL\ (\text{comp} - \text{let go}) = {} & (cLLw + cLLx + cLLy + cLLz)\ /\ 4\ - \\ & (lLLw + lLLx + lLLy + lLLz)\ /\ 4, \end{aligned}$$

c = "compensate"
l = "let go"
w,x,y,z = perturbation magnitude
(0.9, 1.8, 2.7, 3.6 V)

Six values of amplitude modulation were thus obtained for background, short and long latency components, each, in the mixed instructions condition.

Each of these values for the two reflex components (short and long latency) was then correlated with 1) the fastest reaction time measured for that subject, 2) the fastest reaction time measured during the mixed instructions condition (3-choice simple reaction time); and 3) the fastest reaction time achieved during the non-mixed condition (1-choice simple reaction time).

For background, only two of the values of modulating ability were correlated with RT since all other differences were small in magnitude clustering around zero. The two values of background modulating ability used were: one, the difference between compensate and let go instructions and two, between compensate and assist, both from the non-mixed instructions condition. In these correlations only the single fastest reaction time was used, this being the best index of the optimal responding capacity for each individual (see Results for the comparison of 1, 2 and 3 choice simple reaction times).

Aging effects on reaction time were evaluated by correlating age with the subjects' fastest averaged reaction time.

Lastly, in order to examine the effects of flexors background modulation on extensors background, correlations were performed between flexors and extensors normalized backgrounds for each of the instruction sets of the non-mixed instructions condition.

Experiment II: 2-Choice Simple Reaction Time Paradigm

MANOVAS similar to those described above were performed on the results of this testing paradigm. In these MANOVAS age was substituted for instruction method and used as a grouping factor within a split plot design.

Correlations were calculated between each of all possible values of modulating ability for both the short and the long latency component (three each) and RT (2-choice). These correlations were performed for the two age groups together and separately.

Lastly Student's T test were performed on all the fastest reaction times measured in both Experiment I and II (using SPSS). Paired comparisons were made between 1-choice, 2-choice and 3-choice simple reaction times.

CHAPTER III

RESULTS

The stretch reflex response of wrist flexors typically consisted of two EMG peaks between 25 and 95 msec after application of the perturbation. Figure 1 shows the averaged rectified flexor EMG activity recorded for one subject (D.S.(28)) in the 1-Choice Simple Reaction Time Paradigm. Each instruction trace represents the 200 msec that followed stretch, beginning at time 0, with the largest load, 3.6 V. Clearly, EMG activity for the three instructions begins to differ well in advance of 100 msec. Both reflex peaks, at short (23-47 msec) and at long (48-91 msec) latencies, appear to be of different amplitude for different instructions. The differences in EMG activity for "compensate" and "let go" instructions in particular is striking. Both background and short latency reflex

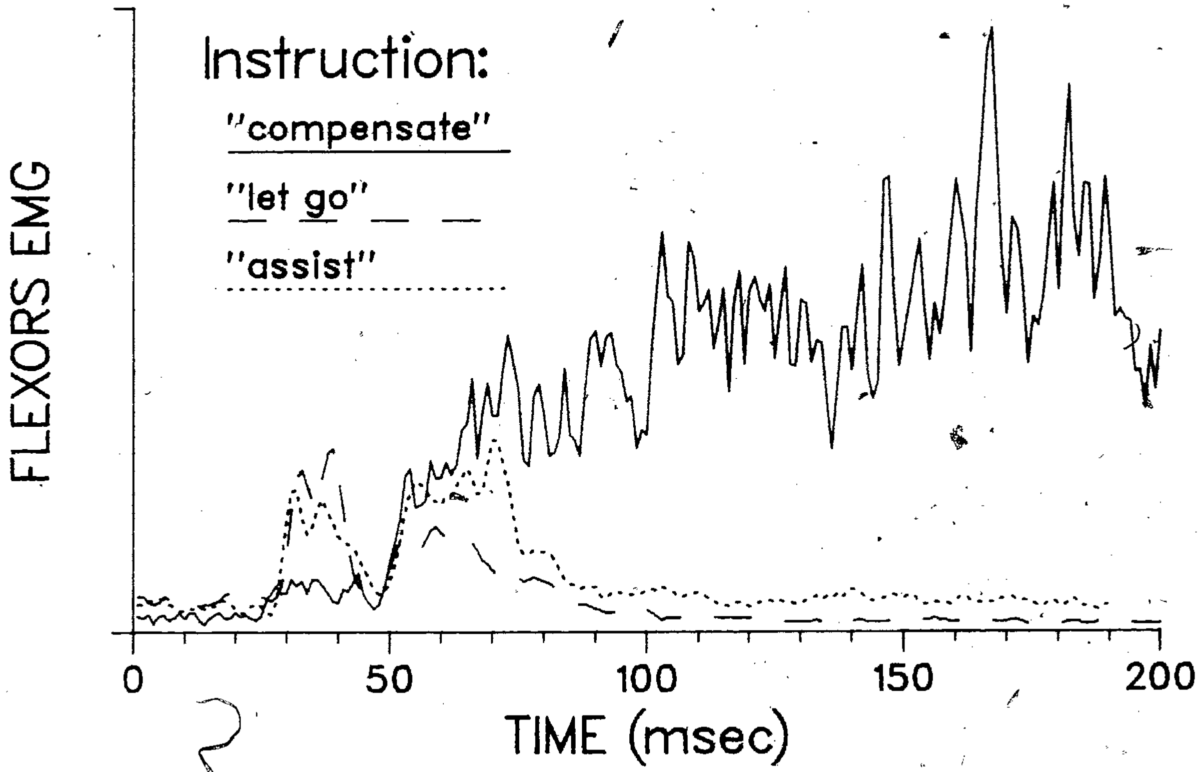

Figure 1. Normalized flexors EMG for 200 msec following perturbation (3.6 V), for one subject (D.S.), in the non-mixed instructions paradigm. EMG activity is shown in arbitrary units.

activity levels are smaller for "compensate" than for "let go" instructions. In contrast, long latency reflex activity for "compensate" is large, much larger than that for "let go".

The early instruction dependent modulation of flexors EMG was also reflected in the traces of torque handle tension and position. Tensions generated at the handle began to diverge from one another around 65-70 msec (Fig. 2), which is much earlier than the start of voluntary EMG activity occurring around 90 msec. These early deviations in tension must therefore be attributed to modulation of the amplitude of the reflex responses.

The position of the torque handle reflected later tension differences most clearly. Handle positions began differing greatly around 100-105 msec (Fig. 3) and are probably due to voluntary EMG activity.

For the sake of completeness a figure of extensors activity during the same period is also included (Fig. 4).

General Characteristics of Flexor Activity

The relative magnitude of the short and long latency reflex components varied greatly between conditions and instructions, as well as between subjects. Their latencies varied by as much as 15 msec across individuals, depending on their size, but were almost constant within individuals.

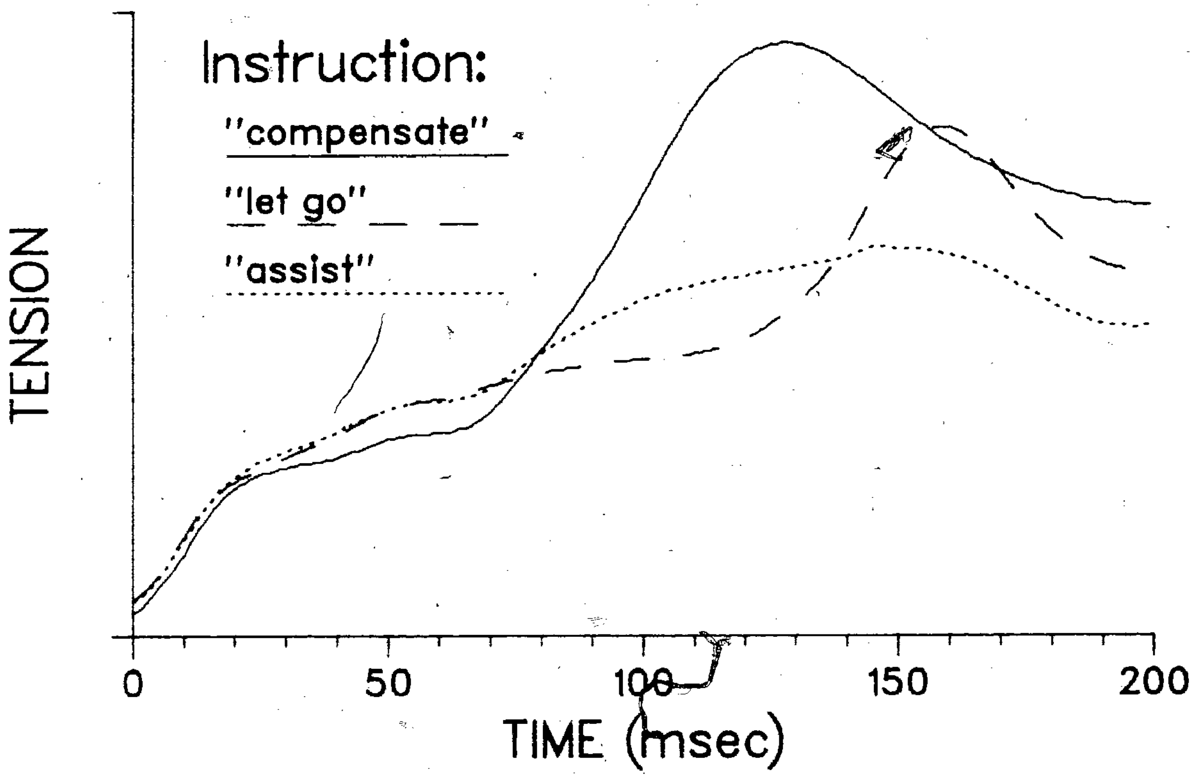

Figure 2. Tension measured at the torque motor handle for 200 msec following perturbation (3.6 V), for one subject (D.S.), in the non-mixed instructions paradigm. Tension is shown in arbitrary units.

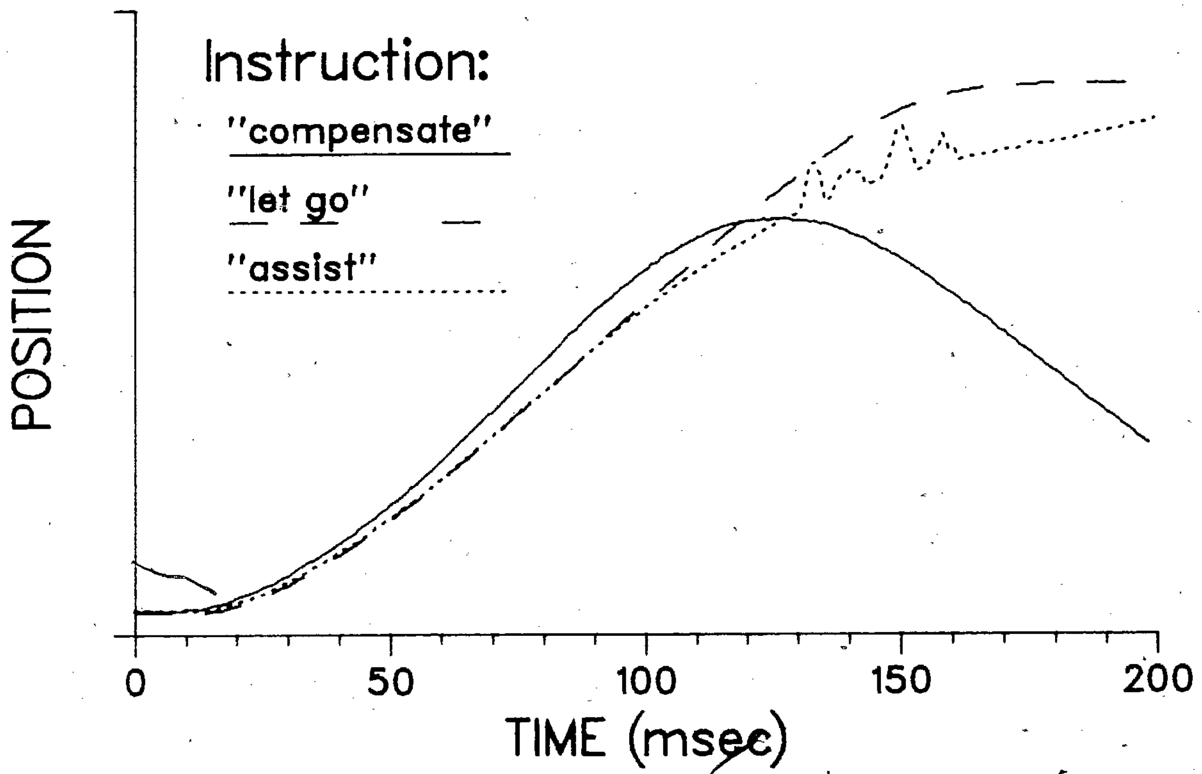

Figure 3. Torque motor handle position for 200 msec following perturbation (3.6 V), for one subject (D.S.), in the non-mixed instructions paradigm. Position is shown in arbitrary units.

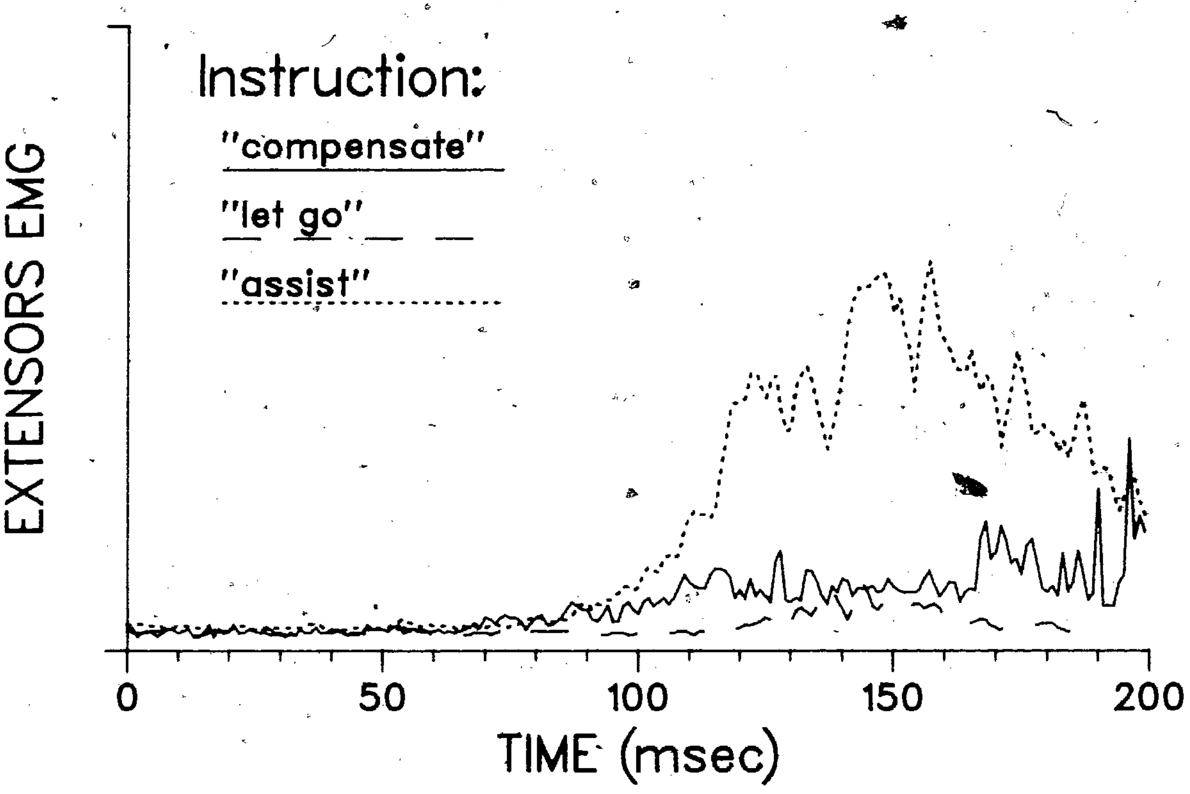

Figure 4. Normalized extensors EMG for 200 msec following perturbation (3.6 V), for one subject (D.S.), in the non-mixed instructions paradigm.

Result calculations were made using all the data collected, with the following exceptions.

In Experiment I data were unavailable for the smallest load (0.9 V) for one subject (R.L. (23)). This applied across all instructions and both conditions due to difficulties in separating that load from the next during the analysis. The Manova calculations performed were corrected for the missing data.

In Experiment II all the data collected from four older subjects were discarded, reducing the group's size to nine (6 male, 3 female). The data were not usable because following the "let go" instruction background EMG activity was nearly completely abolished in the wrist flexors. Failure by these individuals to maintain measurable background activity prior to the advent of the load rendered all quantification of reflex amplitude modulation (as defined in the calculations) impossible.

In both sets of experiments the no-instruction response data has been ignored because of the extreme variability in response among subjects. Some subjects compensated while others let go.

Subjects involved in Experiment I (N= 15, mean age= 25.9 ± 2.3 (standard deviation)) had short latency activity beginning at 29.1 msec on average, following the perturbation and lasting 27.1 msec. For this group long latency activity began at 56.3

msec and lasted 47.1 msec.

The younger subjects in Experiment II (N= 10, mean age= 25.6 ± 3.2) showed similar values of latency and duration, T-tests were not significant. Short latency activity began at 30.6 msec and had a mean duration of 29.2 msec while long latency activity began at 59.8 msec and lasted 47.7 msec.

Age group differences within Experiment II were minimal. The only significant difference between the younger and the older groups lay in the latency of the first component (p= .036). For the older subjects (N= 9, mean age= 56.6 ± 6.5) short latency activity began at an average 34.9 msec. The remaining variables were not significantly different between the two age groups. Mean values for the older subjects were: duration of the first component= 28.2 msec, latency of the second component= 63.1 msec, duration= 50.4 msec.

The degree of separation between reflex and voluntary EMG activity during "compensate" was widely diverse across subjects, independent of the group. In those cases where the end of long latency activity and voluntary EMG were continuous during "compensate", the end of the second component was established from flexor traces during the "let go" condition, for the most part, or from extensor traces during "assist", if necessary.

(1) Kinesthetic Voluntary Reaction Time

a) Experiment I: Reaction Times

Collapsing the two conditions of instruction together and using both flexors and extensors EMG traces to derive the fastest possible reaction time, the mean value for this group of subjects was 93.8 ± 11.1 msec. Examining reaction times within the mixed and non-mixed instructions conditions separately showed this value to be representative: 3-choice mean simple reaction time was 96.9 ± 9.4 msec; 1-choice mean simple reaction time= 94.7 ± 10.6 msec. Further, Students T-tests did not show any significant differences between 3-choice and 1-choice simple reaction times either. both when the reaction times No significances were obtained both when the reaction times derived from the averaged flexors and extensors EMG traces were used together, and when they were tested separately. For a table of reaction times see Appendix A, Tables 1 and 2.

Lastly, Pearson R correlations between each of the three reaction times (fastest, 3-choice simple, 1-choice simple) and age were not significant, in this group of subjects (r= -.05, r= -.11, r= .03, respectively).

b) Experiment II: Reaction Times

The mean reaction times (2-choice simple) for the two age groups were similar. In the younger population the mean value was 113.5 ± 21.0 msec. In the older population mean reaction time was only slightly longer, 118.4 ± 17.7 msec. Despite this similarity, however, significant age trends were present in these two groups. Pearson R correlations within the younger group showed a negative relationship between age and reaction time: r= -.72 (p= .009). In the older group the relationship was instead positive: r= .59 (p= .048) A correlation performed on the combined age and reaction time data from the two groups resulted in the cancelling out of the two opposite trends and in an absence of significance (r= .14).

T-test comparisons between all 2-choice simple reaction times and both the 1-choice and the 3-choice simple reaction times (from the flexors only) showed no significant differences.

(2) Amplitude Modulation

Independent of experimental conditions, large individual differences were observed in ability to modulate the amplitude of the two components of the stretch reflex. Figures 1 to 4 are examples of the four data traces recorded for a good modulator of reflex amplitude. Tables 1 to 4 in Appendix B give average differences in background, short and long latency reflex activity for all pairs of instructions for all subjects.

Different patterns of amplitude modulation emerged for the three EMG variables studied. The long latency reflex component was affected most by instructions irrespectively of instruction conditions and age groups. Short latency activity was affected less by instructions and was closely dependent on modulation of muscle background activity levels. Lastly, significant modulation of background activity occurred infrequently.

a) Experiment I: Amplitude Modulation

The extent of modulation observed when the three instructions were mixed and when they were not was markedly different. When mixed together instructions produced amplitude modulation only in the long latency reflex component. When instructions were tested separately modulation of background and of short latency reflex activity was also seen.

When present, instruction effects on EMG activity were superimposed on the otherwise fixed input-output characteristics of the system. Background modulation was unaffected by torque while instruction effects on the short and long latency components of the reflex were instead superimposed on the torque dependent increases.

3-Choice Simple Reaction Time Paradigm: Mixed Instructions Modulation

When the "compensate", "let go" and "assist" instructions were mixed no significant pair-wise differences were observed in either background or in short latency reflex activity. See Table 1 for MANOVA results and Fig. 5 for averaged background activity levels. Fig. 6 shows the averaged activity levels for the short latency reflex component. The slopes of the torque dependent increases in activity also were not different between instructions, indicating complete absence of gain modulation for short latency activity.

Substantial, instruction dependent modulation of long latency reflex activity was observed. All instructions produced significantly different levels of activity (p ranged from p=.005 to p < .001).

"Compensate" long latency reflex activity was by far the largest in amplitude (see Fig 7). "Assist" responses were intermediate in amplitude. Long latency reflex activity was smallest following instructions to "let go".

Comparing the "let go" values for the smallest and largest torques to those obtained for "compensate" reveals a four to six fold difference in long latency response amplitude with these instructions. In terms of the averaged responses the difference is comparable, slightly larger than four fold.

Unlike for short latency reflex activity, the rate of increase of long latency reflex activity across torques differed

TABLE 1: **EXPERIMENT I MANOVA RESULTS (p values)**

EFFECT	BACKGROUND ACTIVITY		SHORT LATENCY ACTIVITY		LONG LATENCY ACTIVITY	
set (mixed vs non-mixed)	.000		n.s.		n.s.	
instruction	0.0		.001		0.0	
load	n.s.		0.0		0.0	
set x instruction	.000		.000		.001	
set x load	n.s.		.033		n.s.	
instruction x load	n.s.		n.s.		.000	
set x instruction x load	n.s.		n.s.		n.s.	
	MIXED	NON	MIXED	NON	MIXED	NON
instruction within set	n.s.	.000	.008	.000	0.0	.000
compensate vs let go		.000	n.s.	.000	0.0	.000
compensate vs assist		.000	n.s.	.000	.000	.000
let go vs assist		.000	n.s.	n.s.	.005	n.s.

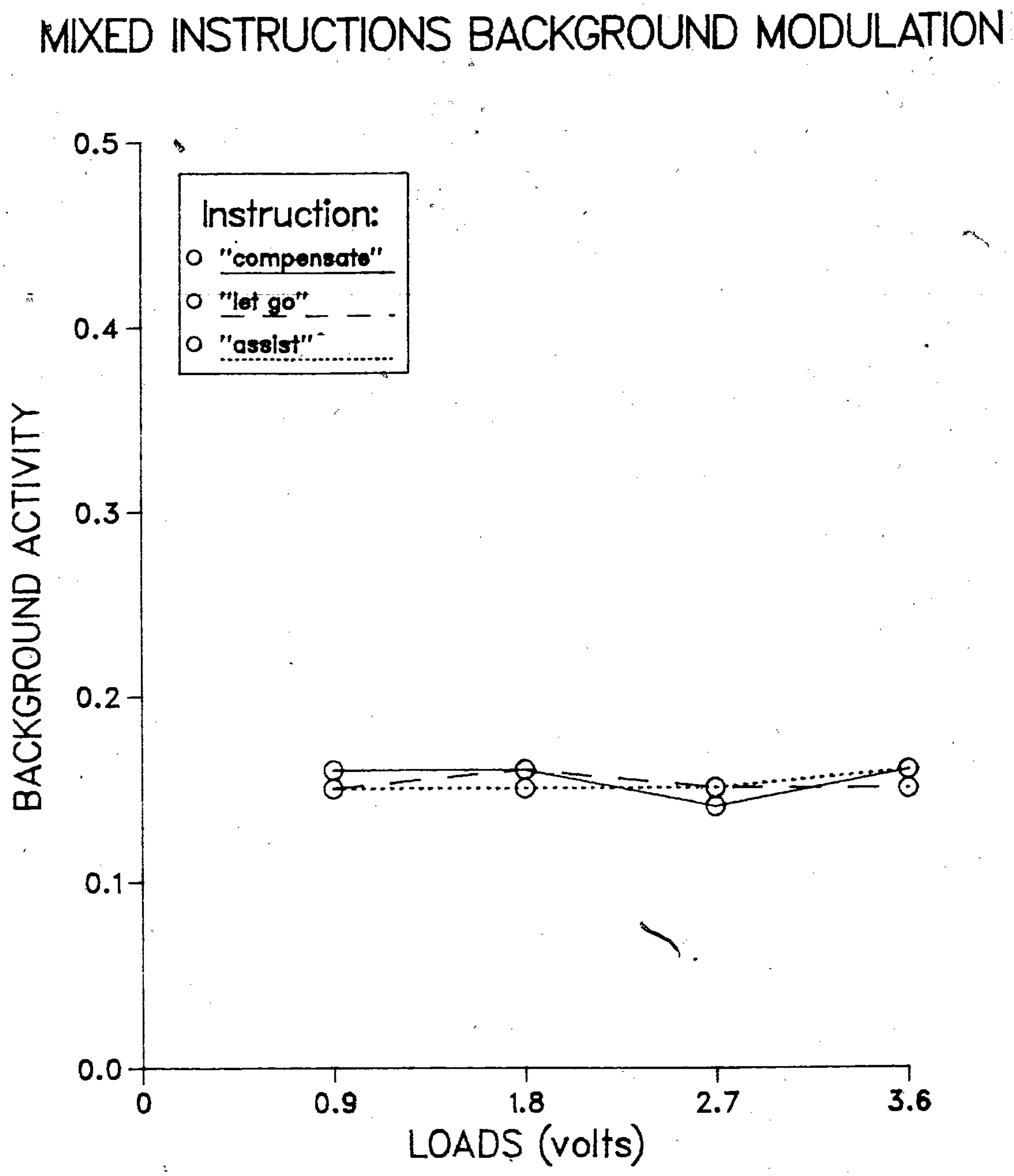

Figure 5. Averaged normalized background activity for the three instructions and four levels of perturbation in the Mixed Instructions Paradigm of Experiment I (N=15).

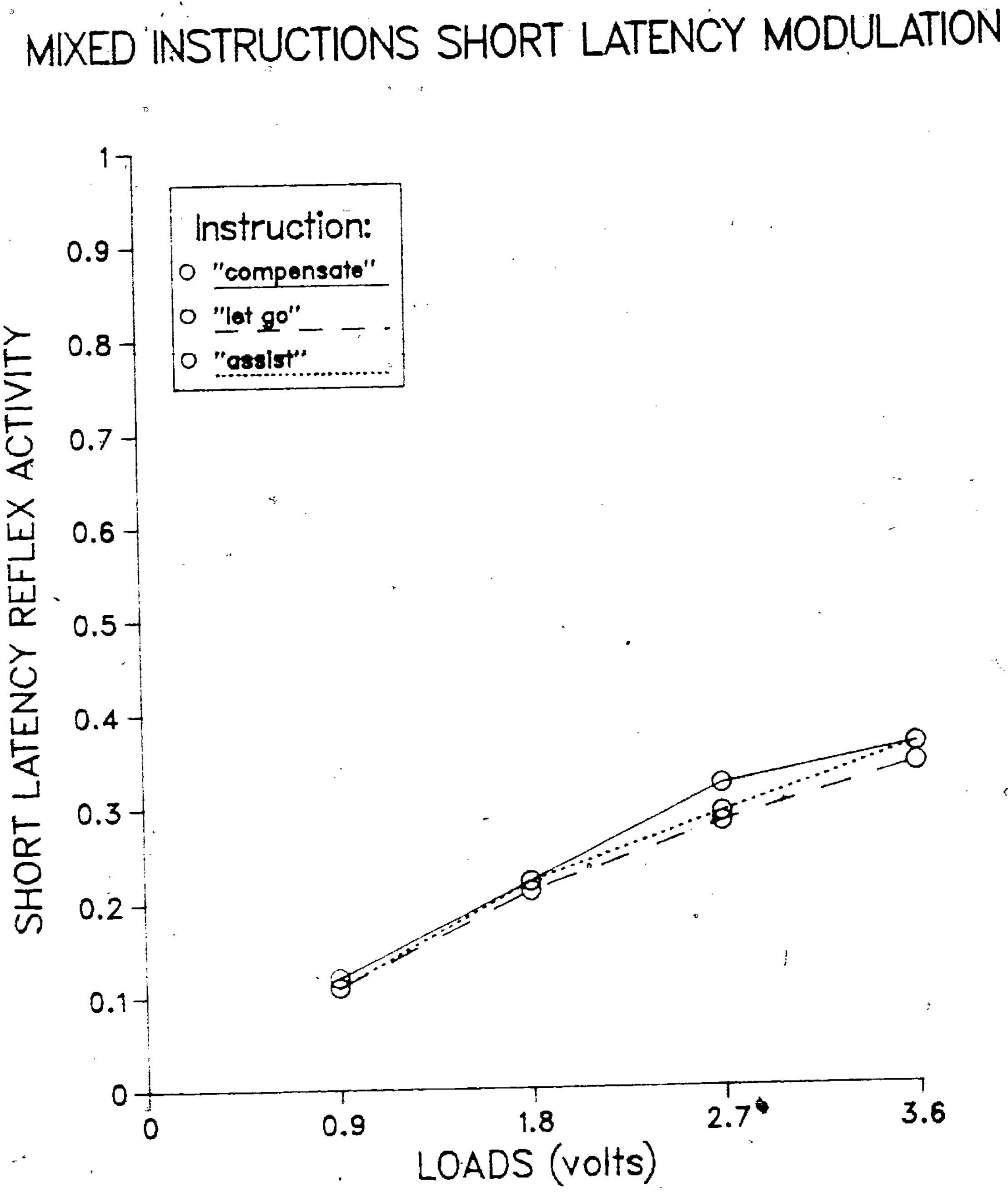

Figure 6. Averaged normalized short latency reflex activity for the three instructions and four levels of perturbation in the Mixed Instructions Paradigm of Experiment I (N=15).

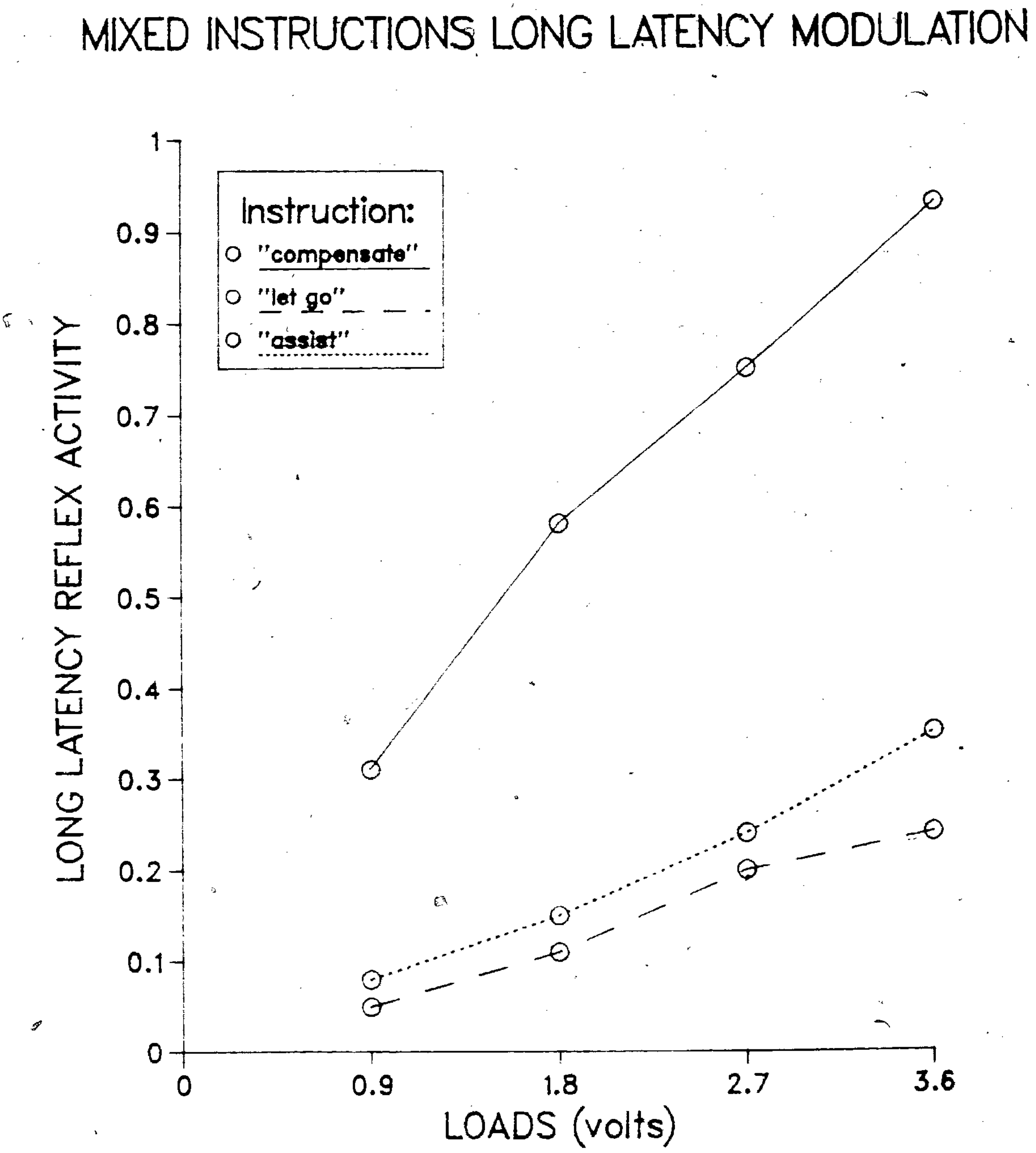

Figure 7. Averaged normalized long latency reflex activity for the three instructions and four levels of perturbation in the Mixed Instructions Paradigm of Experiment I (N=15).

between instructions. The load x instruction interaction was highly significant ($p < .001$) for this component. This indicates that changes in long latency reflex gain with instructions also modified the slope of its input-output relationship.

1-Choice Simple Reaction Time Paradigm: Non-mixed Instructions Modulation

In this paradigm, in which each instruction was tested separately, significant differences in mean amplitudes were obtained for all three EMG variables (see Table 1 for MANOVA results).

Background activity for each instruction differed from one another and although the differences were small, they were highly significant ($p < .001$). "Compensate" background levels were smallest (see Fig. 8). "Let go" levels of background were next. And "assist" background levels were the largest. Short latency reflex activity showed a similar, but not identical pattern (Fig. 9).

"Compensate" responses were still smallest and significantly different from the next largest "let go" responses ($p < .001$) and the larger still "assist" responses ($p < .001$). But unlike background, the "let go" and "assist" short latency reflex responses were not significantly different.

Like for background, short latency reflex amplitude differences between instructions were small in magnitude,

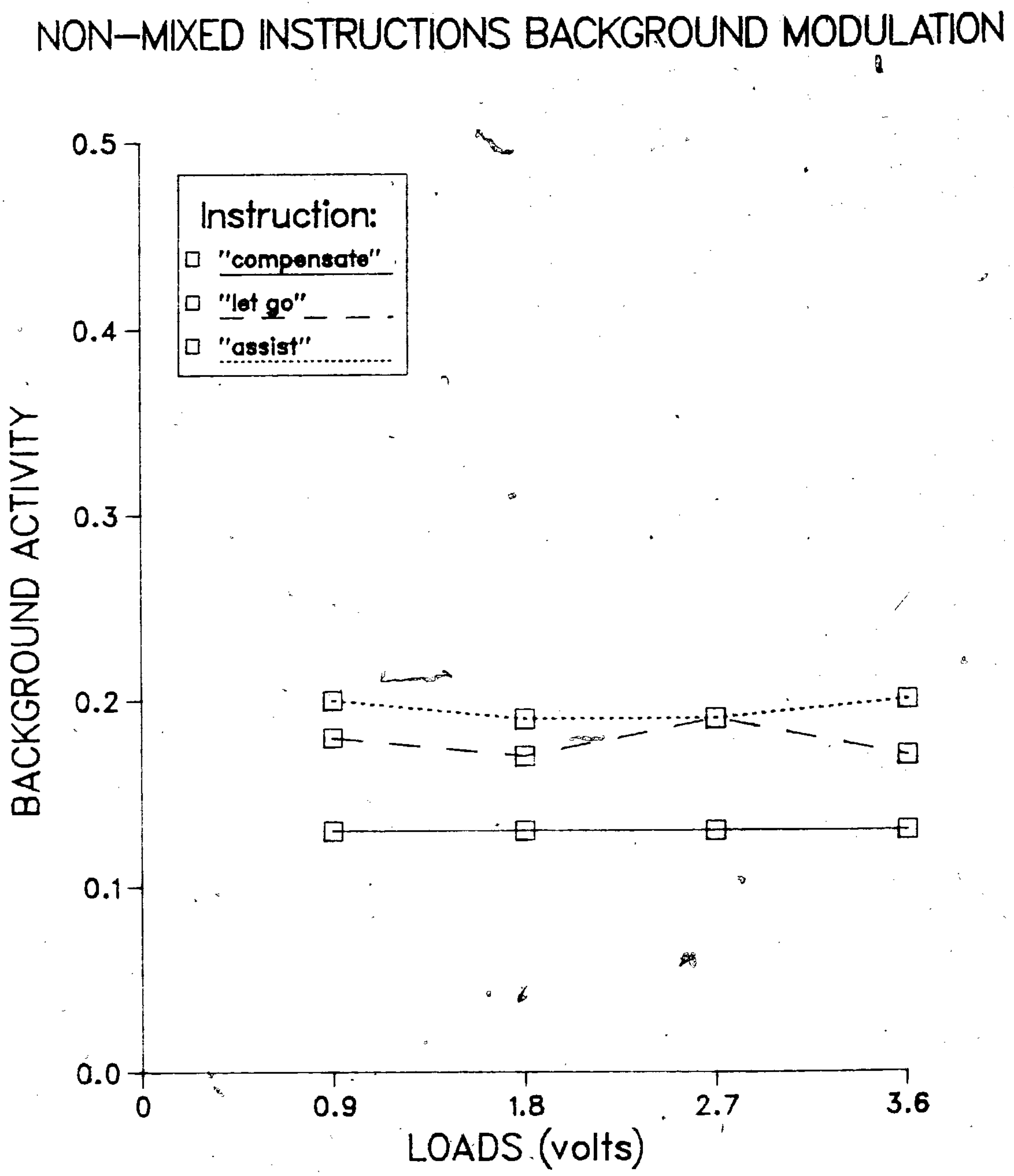

Figure 8. Averaged normalized background for the three instructions and four levels of perturbation in the Non-mixed Instructions Paradigm of Experiment I (N=15).

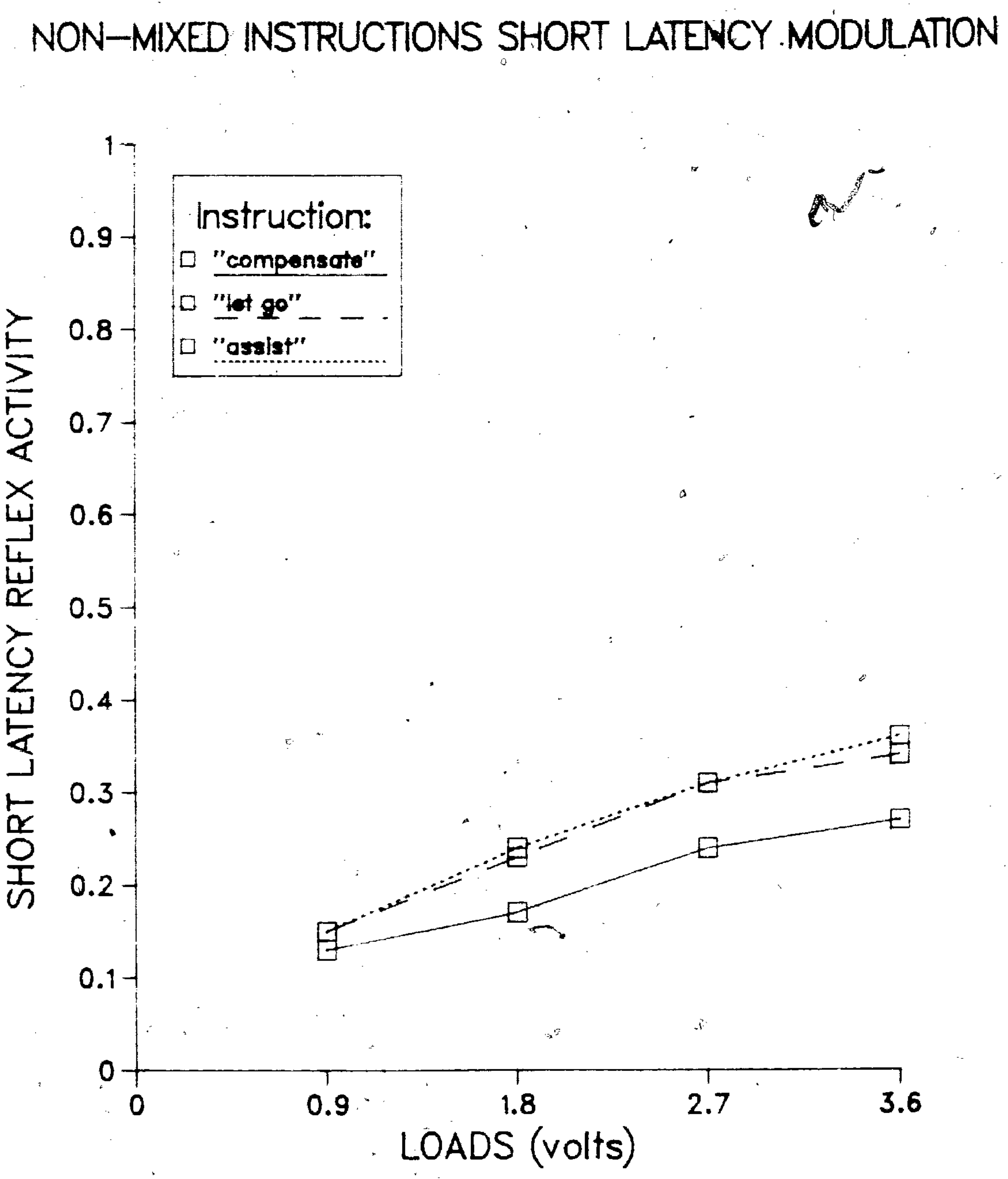

Figure 9. Averaged normalized short latency reflex activity for the three instructions and four levels of perturbation in the Non-mixed Instructions Paradigm of Experiment I (N=15).

despite being significant. No significant differences were obtained for the rate of increase of short latency responses across loads.

The direction of amplitude modulation of long latency reflex activity was different from that of the other two variables (Fig. 10). Long latency reflex amplitude for "compensate" was now the largest by far (p < .001), with the "let go" and "assist" responses (still not significantly different) being much smaller. The average amplitude difference between both "let go" and "assist" instructions and the "compensate" long latency reflex activity was three fold.

As in the mixed instructions condition, the load x instruction interaction for long latency reflex activity was significant (p < .001), indicating that gain differences between the response to "compensate" and the other two instructions were manifested in more than an amplitude difference alone.

In summary, differences in mean EMG amplitude modulation of background, short latency and long latency reflex activity were seen depending on whether the instructions were mixed or not. When instructions were mixed modulation was seen only at the level of the long latency reflex component. Modulation of this component of reflex activity was completely dissociated from both background and short latency reflex activities. When instructions were not mixed modulation was observed in short latency reflex activity and in background as well. However,

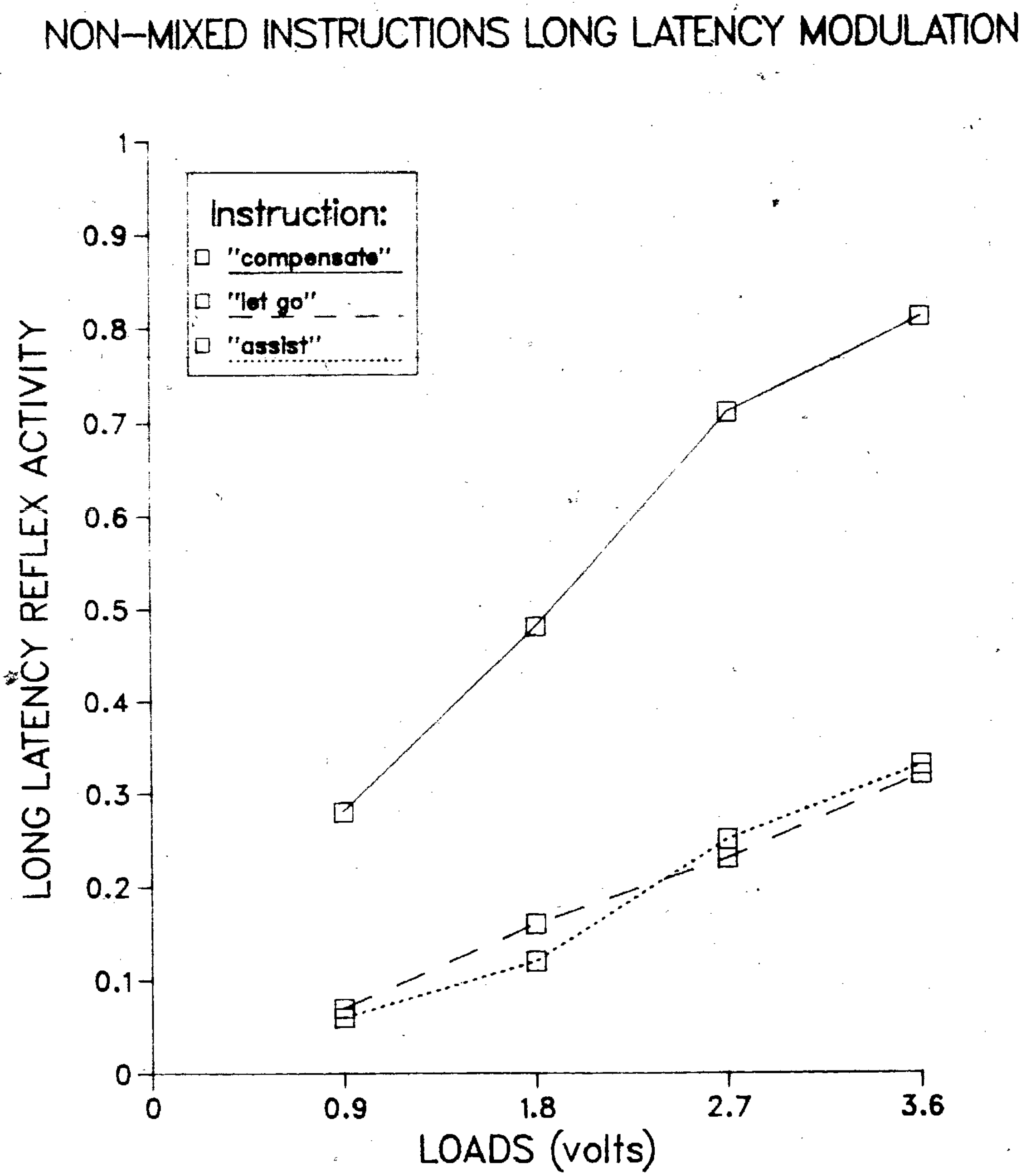

Figure 10. Averaged normalized long latency reflex activity for the three instructions and four levels of perturbation in the Non-mixed Instructions Paradigm of Experiment I (N=15).

while short latency reflex activity modulation corresponded closely to that occuring in background activity, the long latency reflex component showed a very different pattern. Schematically the relationships described above may be illustrated as follows, where: C= "compensate" response, L= "let go" and A= "assist".

	AVERAGE ACTIVITY		
		Stretch Reflex Response	
	BACKGROUND	SHORT LATENCY	LONG LATENCY
MIXED INSTRUCTIONS (3-Choice)	C = L = A	C = L = A	C >> A > L
NON-MIXED (1-Choice)	C < L < A	C < L = A	C >> L = A

b) Experiment II: Amplitude Modulation

In this 2-choice simple reaction time paradigm, in which only "compensate" and "let go" instructions were mixed, all three EMG variables (background, short and long latency reflex activities) were modulated in the same direction by the younger group. In the older group, results were similar except for an absence of modulation of background in these subjects (see Table 2 for MANOVA results).

In both age groups, amplitudes of both the short and long latency reflex components were larger following instructions to "compensate" than for "let go" ($p<.003$). As illustrated in Fig. 12, short latency reflex amplitude differences between "compensate" and "let go" responses in the younger group was small. In the older group the differences tended to be even smaller.

Although the average amplitude of short latency reflex activity was significantly different for the two instructions, the rate of rise of responses over loads was similar for both "compensate" and "let go". The load x instruction interaction was not significant.

As illustrated in Fig. 13, long latency reflex amplitude was modulated in the same direction as short latency amplitude, in both groups. Again, "compensate" activity was larger than "let go" activity. The differences in amplitude for the two instructions were very much larger for long latency than for short latency reflex activity in both age groups. For both groups the average amplitude differences represent a two to three fold modulation between "let go" and "compensate" long latency reflex activities.

In addition to amplitude differences between the two instructions, the rate of increase of long latency "compensate"

TABLE 2: **EXPERIMENT II MANOVA RESULTS (p values)**

EFFECT	**BACKGROUND ACTIVITY**		**SHORT LATENCY ACTIVITY**	**LONG LATENCY ACTIVITY**	
age	.049		n.s.	n.s.	
instruction	n.s.		.001	0.0	
load	n.s.		0.0	0.0	
age x instruction	.006		n.s.	.005	
age x load	n.s.		n.s.	n.s.	
instruction x load	n.s.		n.s.	.000	
age x instruction x load	n.s.		n.s.	n.s.	
	YOUNGER	**OLDER**			
age x instruction	.002	n.s.			
instruction:				**YOUNGER**	**OLDER**
compensate vs let go	.031		.002	.000	.000

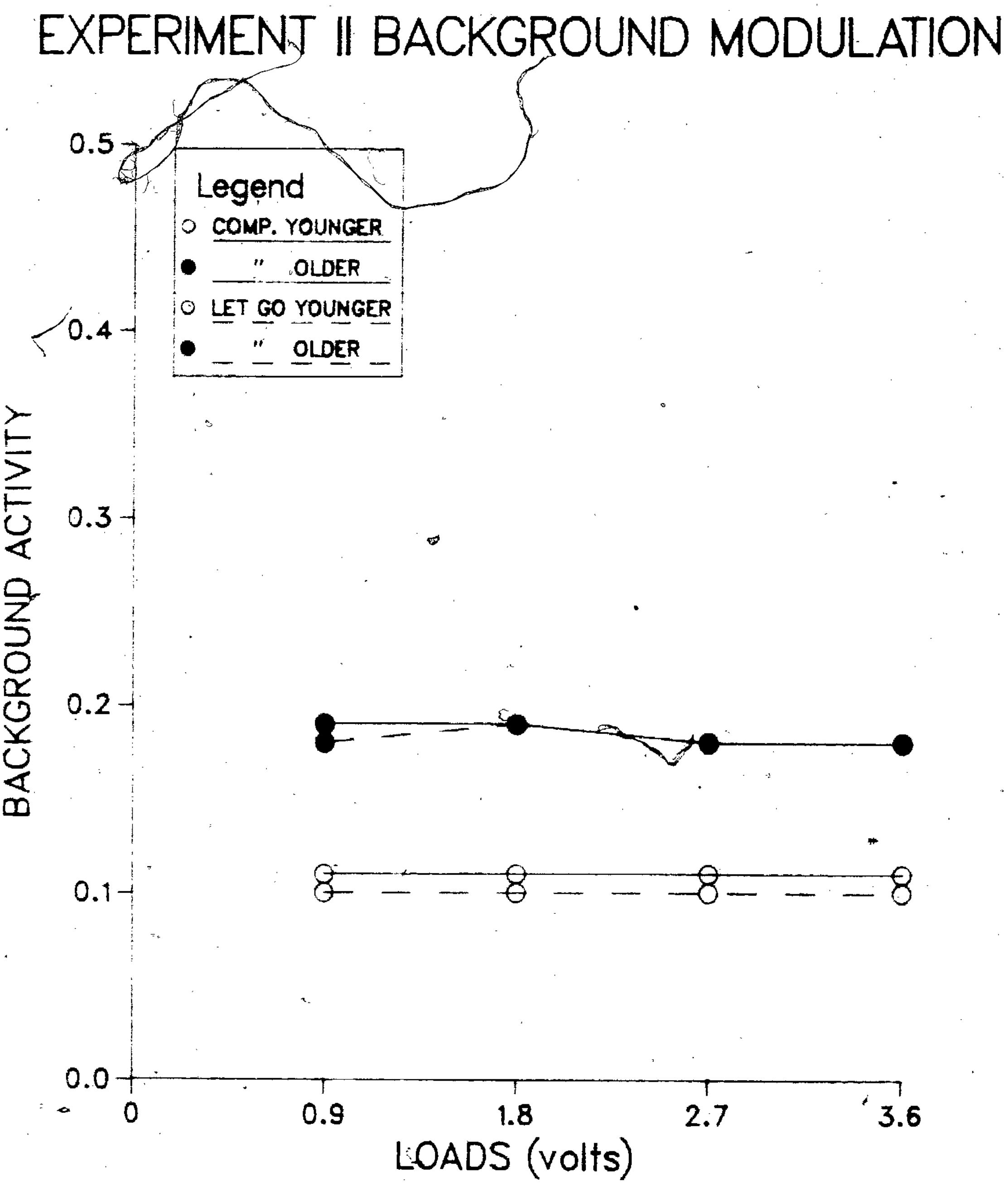

Figure 11. Averaged normalized background for the three instructions and four levels of perturbation in Experiment II (Younger group N=10, mean age=25.6; Older group N=9, mean age=56.6).

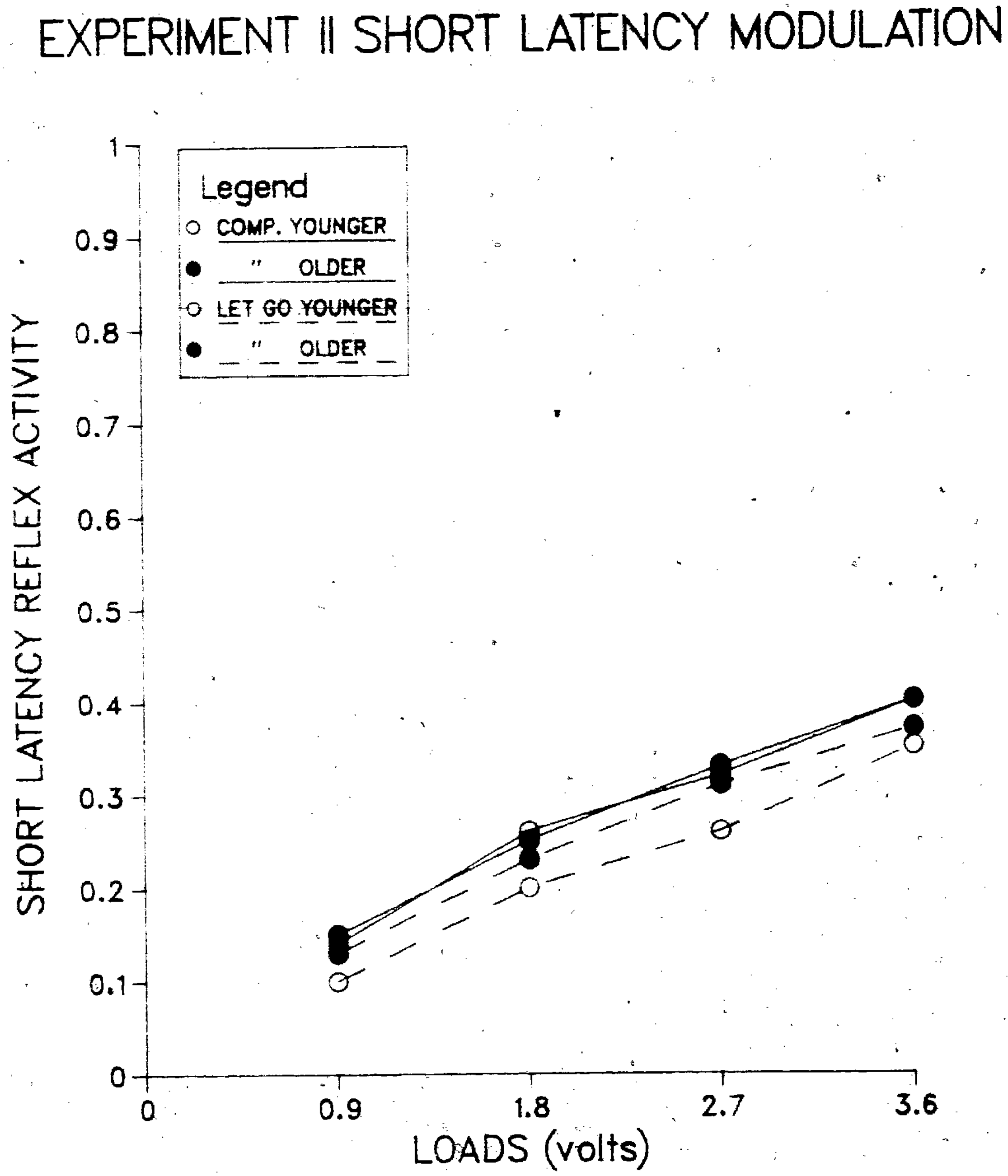

Figure 12. Averaged normalized short latency reflex activity for the three instructions and four levels of perturbation in Experiment II (Younger group N=10, mean age=25.6; Older group N=9, mean age=56.6).

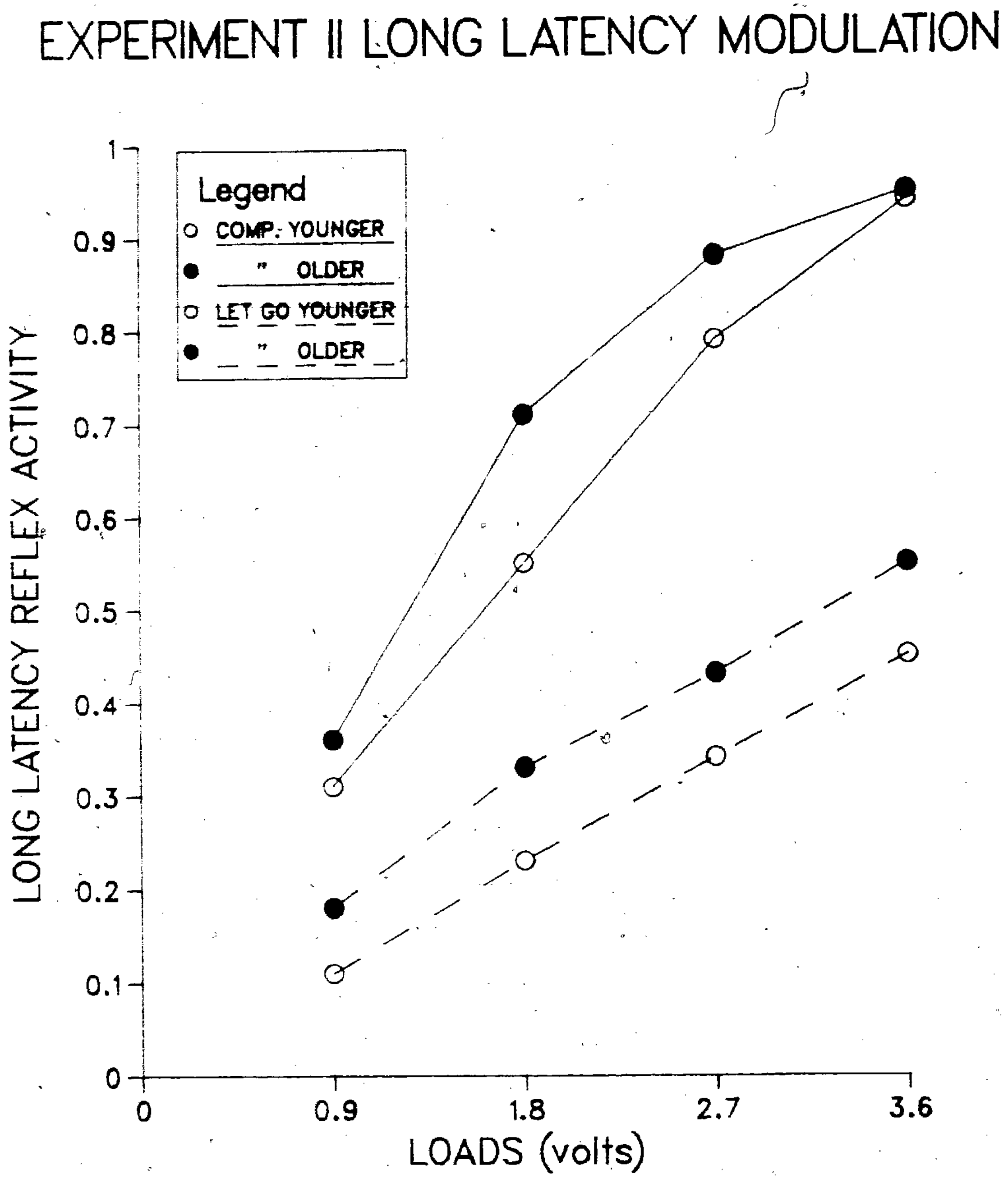

Figure 13. Averaged normalized long latency reflex activity for the three instructions and four levels of perturbation in Experiment II (Younger group N=10, mean age=25.6; Older group N=9, mean age=56.6).

responses across loads in both age groups was significantly different ($p < .006$), and larger, than that for "let go" responses. Again this is consistent with results of Experiment I indicating major gain differences at the level of the long latency reflex component with instructions.

It is only in modulation of background activity that age differences were manifested. While no modulation of background was observed in the older group, a very small but significant modulation ($p < .05$) was seen in the younger group. "Compensate" background activity was consistently slightly larger than "let go" activity , across all loads (see Fig. 11). The average background activity for the older subjects was nearly twice that for the younger group.

In summary, similar directions of modulation of background, short and long latency reflex activities were observed in the younger group. For all three variables "compensate" amplitude was larger than "let go" amplitude. In the older subjects similar modulation of both components was observed, as in the younger group, but with an absence of background modulation. Schematically:

AVERAGE ACTIVITY

		Stretch Reflex Response	
	BACKGROUND	SHORT LATENCY	LONG LATENCY
YOUNGER GROUP (X age=25.6)	C > L	C > L	C >> L
OLDER GROUP (X age=56.6)	C = L	C > L	C >> L

(3) Relationship of Amplitude Modulation To Voluntary Reaction Time

No strong relationships emerged between reflex components amplitude modulation and the various reaction time values used. Significant correlations were few and not consistent across conditions.

a) Experiment I: Amplitude Modulation versus Reaction Time

Correlations between modulation (averaged across loads) of background, short and long latency components and each of the three types of reaction times (fastest, 1-choice simple, 3-choice simple) for this paradigm revealed few significant relationships (See Appendix C, Table 1).

Within the non-mixed instructions condition there were no significant correlations between amplitude modulation of any of the three EMG variables and any of the three reaction times.

Within the mixed instruction condition one significant relationship was observed between reaction time and one type of modulation of the long latency component. This was modulation between the "let go" and the "assist" long latency response amplitudes. Correlations between this modulation and each of the three reaction times were all significant: with the fastest reaction time r= -.57 (p= .013), with 1-choice simple reaction time r= -.45 (p= .047), and with 3-choice simple reaction time r= -.70 (p= .002).

No significant relationships emerged for the "compensate" minus "let go" type of modulation of any EMG variable and reaction time, in either condition.

b) Experiment II: Amplitude Modulation versus Reaction Time

Correlations between average modulation of both the short and the long latency reflex components and reaction time (2-choice simple) revealed a few significant relationships for the long latency component of reflex activity (Appendix B, Table 4 and Appendix C, Table 2).

"Compensate" minus "let go" modulation of long latency activity was significantly related to reaction time in the younger group, r= -.63 (p= .026) and in the pooled data, r= -.57 (p= .006). This relationship did not quite reach significance in the older group (r= -.50, p= .083).

There was no significant relationship between short latency reflex activity amplitude modulation and reaction time in either the younger group alone, the older group alone, or in the pooled data.

Modulation of Background Activity of Flexors and Extensors

The individual correlations performed between flexors and extensors background levels of activity for each of the instructions in the non-mixed instructions condition in Experiment I revealed a general absence of significance (see Appendix D Table 1)

Significant results were obtained for only three out of the fourteen subjects (D.V.(27) missing), and only for one instruction. Following instruction to "compensate" two subjects

(D.S.(28) and B.C. (28)) showed a negative relationship between flexors and extensors levels of activity. Respectively these values were: $r = -.90$ ($p = .049$) and $r = -.91$ ($p = .044$), indicating that while flexors background activity was lowered during "compensate", extensors activity was reciprocally increased. The third subject (D.C.(23)) co-contracted in preparation to compensate, exhibiting instead a positive correlation between the two backgrounds of $r = .93$ ($p = .037$).

CHAPTER IV

DISCUSSION

The results of this study indicate that the amplitudes of the short and the long latency components of the stretch reflex can be differentially affected by intentions on how to voluntarily react to an anticipated limb perturbation. The two components can be dissociated in response to instructions. Amplitude modulation of the long latency component appears to be a consistent phenomenon, of large magnitude, and unaffected by changes in instruction conditions. In contrast, changes in short latency response amplitude appear to be generally of small magnitude, and highly dependent on changes in background muscle activity, which occur only in some circumstances.

The extent to which each component's amplitude can be modulated varies greatly among individuals. Gain modulation of reflex pathways appears to be a largely idiosynchratic characteristic and unrelated either to kinesthetic reaction time or age, up to the sixth decade of life.

Dissociation of Reflex Components

In Experiment I two kinds of dissociation of the short and long latency components were observed depending on whether instructions were mixed or not. When instructions were mixed the two components were dissociated in that the long latency component was modulated with instructions whereas no change whatever was observed in short latency response amplitude. When instructions were not mixed the two components were dissociated in terms of the kind of changes seen in each component's amplitude with the instructions. Strikingly different, in the latter paradigm, reflex activity following "compensate" was the smallest of the three instructions for the short latency component whereas it was the largest one for the long latency component. Further, the changes in short latency response magnitude in this condition paralleled similar changes in background activity while those of the long latency component were different from both.

Dissociation Characteristics

The type of dissociation seen in the mixed instructions paradigm is the one originally observed by Hammond (1954, 1956, 1960), and subsequently also reported by Marsden and co-workers (1978b) and Colebatch and co-workers (1979). Curiously, while Colebatch and co-workers also used randomized instructions, both Hammond and the Marsden group obtained their results while testing instructions in sets and not mixed. Presence of amplitude modulation of the long latency component with instructions in the absence of significant differences in short latency reflex activity lends some support to the notion that separately modulated neural pathways exist for the two components, as first suggested by Hammond in 1960.

The kind of dissociation of short and long latency response magnitude observed in this thesis, when instructions were not mixed, strongly emphasizes the dependence of short latency modulation on changes in the background activity. The background dependence of short latency modulation with instructions has been suggested previously for human biceps by Evarts and Granit (1976) and Evarts and Vaughn (1978). These authors also observed that modulation at a latency of 20 msec only occurred following changes in the tonic muscle activity which were present only with non-random instructions. However, in their paradigm, changes in amplitude were consistent for all three EMG variables. Background levels, as well as activity starting at both 20 msec and at 60-70 msec was greatest following instructions to "supinate" and least for "pronate". This contrasts the results of the present study where both background and short latency were smallest for "compensate" while only long latency activity was large for this instruction. A possible explanation for this discrepancy could be the different nature of the instructions used in the respective paradigms. In Evart's paradigm the perturbation was simply a trigger stimulus for a particular voluntary movement, supination or pronation of the arm. And the larger postural drive for supinate instructions may simply have been due to an early voluntary activation of the motoneuron pool while getting ready to move. In contrast, in the present paradigm the instructions called for a very specific response to be made quickly to the perturbation itself.

To return now to the absence of short latency modulation with sets of instructions reported by Hammond (1960) and Marsden and co-workers (1978b), these authors did not analyze their data for background so it is not possible to say whether background changes also were absent. If this was indeed the case, one must then conclude either that presenting instructions in sets does not always result in the establishment of background intentional sets or that intentional sets do not necessarily result in differential tonic muscle activity. Regardless, it's worth pointing out that absence of changes in background would not dramatically interfere with modulation of the long latency reflex component.

In this study one discrepancy was noted between background changes and short latency reflex amplitude in the non-mixed instructions paradigm. The significant amplitude differences in tonic discharge levels between "assist" and "let go" were not reproduced for short latency activity. Most probably the reason for this lack of correspondence may have been the small magnitude of the difference in the background for the two instructions. The normal stochastic variability in short latency response magnitude independent of background could be large enough to cover a small effect due to background modulation.

Pathways for Stretch Reflex Modulation

The results of the non-mixed instructions paradigm in particular give credance to the existence of separate neural pathways for the two components of the stretch reflex. The type of modulation seen with mixed instructions also is suggestive, but it is not conclusive. The results of the 3-choice paradigm can also be interpreted using constructs from the spinal resonance theory (Eklund et al, 1982).

For example, the exclusive modulation of long latency reflex activity without other measurable changes in background and short latency reflex activity could be produced if the effects of spinal pre-setting by higher centres on the multiple afferent bursts produced by the perturbation were altered by co-contraction of the antagonists. Facilitatory or disfacilitatory impulses from spinal pre-setting circuits would then summate variably with the facilitatory inputs to the motoneuron pool from the first burst of afferent activity and the inhibitory inputs from the activated antagonists. The degree of discharge of the motoneuron pool following the afferent volleys would then be determined by the summing of the new inputs with the pool's level of excitability at that moment. This level would have been determined by the degree of excitatory summation of the previous sub-threshold inputs, as influenced by instructions. Compensate instructions would presumably cause the largest facilitatory spinal pre-setting, while "assist" and "let go" effects could also be due to disfacilitation of pool responsiveness to later peripheral inputs.

The opposite directions of modulation seen in the non-mixed instructions paradigm cannot, however, be reconciled within an exclusively spinal interpretation. The similarity of short latency reflex activity to background levels can be easily understood as a function of instruction-induced altered alpha-gamma drive prior to the perturbation. The general positive relationship between a muscle's state of activation and reflex amplitude is widely acknowledged (Gottlieb and Agarwal, 1979a; Eklund et al., 1982; Jaeger et al., 1982a). However, modulation of the longer latency reflex response with sets of instructions was not in the same direction as background. An additional other pathway must be involved to permit such a complete reversal of gains of reflex responses from short to longer latencies.

A spinal polysynaptic pathway could theoretically mediate some portion of the long latency reflex response. Lesions of higher centres in non-human primates does not always selectively abolish long latency responses, suggesting that spinal circuits suffice even for longer latency responses (Tracey et al, 1980; Miller and Brooks, 1981). But interpretation of such results is difficult. Lesions involve drastic alterations in normal neural functions and it is possible that under these circumstances spinal pathways normally inhibited by or replaced by cortical ones are gated open. The weight of anatomical and physiological evidence instead tends to support the existence of a cortical pathway for longer latency reflex responses (Phillips, 1969; Evarts and Tanji, 1976; Fetz et al, 1980). Long latency reflex activity would thus be the result of contributions from cortical as well as continuing spinal inputs.

Voluntary Reaction Time versus Amplitude Modulation

The general absence of significant relationships between the variously labelled reaction times in Experiment I and reflex amplitude modulation indicates that kinesthetic reaction time neural processing is independent of the central processing leading to amplitude modulation of the long latency reflex.

The presence in the 3-choice instruction paradigm of only one significant relationship out of the possible types of modulation ("compensate" versus "let go"; "compensate" versus "assist"; and "assist" versus "let go") and kinesthetic reaction time, renders the existence of such a relationship questionable. It is more likely that although one of the types of reflex amplitude modulation was found to be significantly related to voluntary reaction time, the effect was without meaning. This conclusion is further strengthened by the absence of any significant equivalent relationships in the non-mixed instructions paradigm.

An alternate but unlikely explanation would be that the values of long latency reflex modulation involving "compensate" responses might have been contaminated by some overlapping voluntary activity, thereby obfuscating a (possibly) existing relationship between long latency reflex modulation and reaction time. The relationship between 'pure' reflex amplitude modulation and reaction time would then be masked by a variable degree of overlap from subject to subject. However, assuming a relationship between reflex modulation and reaction time to exist, the faster reacting subjects would then have the greatest degree of voluntary overlap of long latency reflex responses. This would enhance rather than reduce an inverse relationship between the two variables and would therefore result in significant relationships between <u>all</u> modulations and reaction time. Clearly this was not the case, indicating that the long latency reflex component was accurately separated from subsequent voluntary activity.

In conclusion, a relationship between reflex modulating ability and reaction time may exist, but the data gathered here are not conclusive.

Modulation of Agonist and Antagonist Backgrounds

The inverse modulation of background activity in the opposing muscle groups observed in two subjects during "compensate" in the 1-choice paradigm did not generally occur. Increasing extensor tone as a possible mechanism for decreasing flexor background appears to be uncommon. Further, it appears that most changes in tonic flexors' activity brought about by instructions were not sufficiently great to destabilize the joint and require compensatory adjustments in tonic activity of the extensors.

Effects of Aging

Aging, across the span of years compared in this study, does not appear to significantly alter ability to modulate stretch reflex activity with instructions. Identical modulation was seen at the level of short latency reflex activity in the two groups. Mean differences between "compensate" and "let go" instructions differed for the long latency reflex response for the two age groups, but not substantially. Mean modulation between "compensate" and "let go" long latency reflex responses was three fold in the younger group and only two fold in the older. Since the range of "compensate" long latency reflex amplitude across loads was nearly identical for the two age groups (Fig. 13), the difference in the magnitude of modulation of the second component was due to the larger "let go" response in the older group. Comparison of the two groups for short latency reflex responses and background levels (Figs. 12 and 11) reveals that the older group had consistently higher levels of activity for both instructions. It would appear, therefore, that the larger "let go" responses in this age group, particularly at longer latency reflex intervals, were probably due to the initially higher activity in the motoneuron pool. The older group had nearly twice the tonic activity of the younger subjects with the same pre-load. It's possible that this bias may have represented a larger proportion of total muscular loading capacity in the older subjects. This does not seem likely since it is known that muscle strength as well as muscle mass and number of motor units decreases with age only after the sixth decade of life (Brown, 1972; Campbell et al, 1973; Grimby et al, 1982). And the majority of the older subjects in this study were younger than 60. Alternatively, the possibility that the older subjects had higher tonic levels due to co-contraction of flexors and extensors while stabilizing handle position cannot be excluded.

It is interesting to note that comparable modulation of reflex activity was achieved in the two age groups with an absence of modulation of background in the older group. It seems likely that similar facilitation of motoneuron activity occured in both groups in preparation to "compensate", but that only in the younger group was it sufficient to produce a just measurable EMG change.

In summary, it appears that the neural plasticity required to modulate stretch reflex components is well retained at least until the 60s. The ability to effectively modulate responses appears to be highly idiosynchratic, in adulthood, and not necessarily related to age. Across both groups of subjects in Experiment II the subject who could modulate the reflex amplitude the least also happened to be the youngest subject, 21 years old.

In terms of other age related comparisons, it is possible that the 4.3 ms difference in the start of the short latency reflex component between the two age groups could have been a manifestation of the decreased conduction velocity already documented with age (Campbell et al, 1973). Given the small amplitude of the difference and the absence of a similar shift in the longer latency reflex and voluntary components this seems unlikely. More probably the difference was due to sampling differences.

The anticipated slowing of reaction time with age was observed in the older group of subjects. This is a well established phenomenon (Evarts et al, 1981; Suci et al, 1960), and independent of the larger emphasis placed on accuracy by older individuals in choice reaction time paradigms (Salthouse, 1979).

The large inverse relationship between age and reaction time obtained in the younger group was completely unexpected. Despite the high value of statistical significance for this relationship the results appear unlikely. No similar relationship was obtained in the larger sample of young subjects used in Experiment I. The significant results obtained from the younger group in Experiment II must be artifactual, probably due to the small number and age clustering of the subjects.

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APPENDIX A

EXPERIMENT I REACTION TIMES

APPENDIX A - Table 1: EXPERIMENT I FLEXORS REACTION TIMES

"compensate" Instruction

Subject	Age	MIXED INSTRUCTIONS loads 3.6 to .09					NON-MIXED INSTRUCTIONS loads 3.6 to .09				
D.S.	28	91	91	91	91	(msec)	91	91	91	91	(msec)
D.V.	27	101	101	101	101		101	101	101	101	
N.G.	24	111	111	111	111		111	111	111	111	
P.C.	26	105	105	105	105		102	111	111	111	
K.G.	25	96	96	96	96		96	96	96	96	
B.C.	28	107	107	107	107		106	106	106	106	
R.L.	23	154	154	154	154		154	154	154	154	
A.L.	30	150	161	149	149		152	148	141	145	
B.L.	28	96	96	96	96		96	96	96	96	
B.C.	23	91	91	91	91		91	91	91	91	
D.C.	23	104	104	104	104		104	104	104	104	
I.M.	26	121	121	121	121		121	121	121	121	
C.H.	25	137	137	137	137		152	162	138	141	
J.S.	25	100	100	100	100		100	100	100	100	
T.M.	29	164	164	166	168		178	185	190	188	

APPENDIX A - Table 2: EXPERIMENT I EXTENSORS REACTION TIMES

"assist" Instruction

Subject	Age	MIXED INSTRUCTIONS loads 3.6 to .09				NON-MIXED INSTRUCTIONS loads 3.6 to .09			
D.S.	28	82	83	84	111 (msec)	99	103	95	101 (msec)
D.V.	27	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
N.G.	24	102	96	86	109	78	93	82	90
P.C.	26	112	109	108	n/a	108	115	119	137
K.G.	25	96	91	95	97	95	90	94	100
B.C.	28	90	108	96	100	97	95	99	121
R.L.	23	109	113	116	116	101	105	106	n/a
A.L.	30	99	102	104	97	95	90	95	96
B.L.	28	101	110	109	108	112	117	111	128
B.C.	23	93	92	92	96	90	88	95	96
D.C.	23	131	n/a	n/a	n/a	119	116	115	136
I.M.	26	102	86	111	n/a	70	103	113	104
C.H.	25	112	111	114	116	110	109	114	n/a
J.S.	25	118	119	132	138	132	133	127	158
T.M.	29	108	107	115	127	106	111	112	134

APPENDIX B

MEAN EMG MODULATION

APPENDIX B - Table 1: EXPERIMENT I MEAN BACKGROUND ACTIVITY

		PARADIGM					
		MIXED INSTRUCTIONS			NON-MIXED INSTRUCTIONS		
Subject	Age	C-L	C-A	L-A	C-L	C-A	L-A
D.S.	28	-.01	.01	.02	-.09	-.07	.02
D.V.	27	-.04	-.04	.00	-.05	-.04	.01
N.G.	24	.00	-.01	-.01	-.07	-.04	.03
P.C.	26	.00	.00	.00	-.02	-.06	-.04
K.G.	25	.04	.02	-.02	-.02	-.04	-.02
B.C.	28	-.01	.01	.02	-.11	-.13	-.02
R.L.	23	.00	-.04	-.04	-.04	-.05	-.01
A.L.	30	.02	.01	.01	-.12	-.22	-.10
B.L.	28	.03	.02	-.01	-.01	-.02	-.01
B.C.	23	.00	.00	.00	.00	-.03	-.03
D.C.	23	-.02	.00	.02	-.09	-.10	-.01
I.M.	26	.00	.00	.00	.00	-.02	-.02
C.H.	25	-.01	.00	.01	-.07	-.04	.03
J.S.	25	.00	.00	.00	-.04	-.06	-.02
T.M.	29	.02	.02	.00	.00	-.03	-.03

where: C="compensate" L="let go" A="assist"

APPENDIX B - Table 2: **EXPERIMENT I MIXED INSTRUCTIONS PARADIGM**

MEAN REFLEX MODULATION

Subject	Age	SHORT LATENCY C-L	SHORT LATENCY C-A	SHORT LATENCY L-A	LONG LATENCY C-L	LONG LATENCY C-A	LONG LATENCY L-A
D.S.	28	.05	.05	.00	.58	.60	.02
D.V.	27	.11	.05	-.06	.55	.48	-.06
N.G.	24	.00	-.04	-.04	.29	.23	-.05
P.C.	26	.10	.05	-.05	.45	.40	-.05
K.G.	25	.02	.01	-.01	.58	.54	-.04
B.C.	28	.02	.00	-.02	.59	.61	.02
R.L.	23	.01	-.04	-.05	.66	.58	-.08
A.L.	30	-.02	.03	.05	.26	.21	-.05
B.L.	28	.08	.02	-.05	.44	.39	-.05
B.C.	23	.04	.03	-.01	.42	.41	-.01
D.C.	23	-.04	-.03	.01	.73	.62	-.10
I.M.	26	.05	.03	-.02	.72	.66	-.06
C.H.	25	.06	.03	-.03	.53	.44	-.09
J.S.	25	-.15	-.06	.09	.39	.27	-.12
T.M.	29	.01	.00	-.00	.38	.22	-.16

where: C="compensate" L="let go" A="assist"

APPENDIX B - Table 3: EXPERIMENT I NON-MIXED INSTRUCTIONS PARADIGM

MEAN REFLEX MODULATION

Subject	Age	SHORT LATENCY C-L	C-A	L-A	LONG LATENCY C-L	C-A	L-A
D.S.	28	-.11	-.11	.00	.69	.55	-.14
D.V.	27	-.12	-.09	.03	.22	.24	.03
N.G.	24	-.12	-.11	.01	.26	.53	.28
P.C.	26	.07	.00	-.07	.43	.26	-.17
K.G.	25	-.04	-.10	-.06	.27	.27	.00
B.C.	28	-.02	-.03	-.01	.39	.56	.17
R.L.	23	-.02	-.13	-.11	.62	.53	-.10
A.L.	30	-.05	-.11	-.06	.34	.40	.07
B.L.	28	.01	-.01	-.02	.61	.56	-.05
B.C.	23	.04	-.02	-.05	.25	.25	.00
D.C.	23	-.18	-.12	.05	.60	.58	-.02
I.M.	26	.02	.01	-.01	.36	.38	.03
C.H.	25	-.04	.03	.08	.25	.17	-.08
J.S.	25	-.29	-.14	.15	.45	.40	-.05
T.M.	29	.00	-.05	-.05	.08	.16	.09

where: C="compensate" L="let go" A="assist"

APPENDIX B - Table 4: EXPERIMENT II MEAN REFLEX MODULATION ("compensate" minus "let go")

AGE GROUP							
YOUNGER				OLDER			
Subject	Age	SHORT LATENCY	LONG LATENCY	Subject	Age	SHORT LATENCY	LONG LATENCY
G.A.	21	-.02	.02	Ba.	50	.01	.32
J.A.	24	.00	.21	Ma.	50	-.05	-.37
A.M.	24	.04	.18	Am.	51	-.02	.49
G.J.	24	.19	.51	Ki.	54	.14	.55
F.K.	24	.12	.54	Vo.	54	.08	.12
L.B.	24	.07	.18	Ly.	58	.05	.59
S.K.	25	.03	.51	He.	61	.01	.22
C.J.	30	.09	.48	Ca.	62	.02	.49
J.R.	30	-.01	.66	Wi.	69	.00	-.08
S.U.	30	.04	.25				

APPENDIX C

AMPLITUDE MODULATION CORRELATIONS

APPENDIX C - Table 1: EXPERIMENT I MODULATION CORRELATIONS (r values)

ii) MIXED-INSTRUCTIONS PARADIGM

VARIABLES:	AVERAGE REFLEX MODULATION					
	SHORT LATENCY			LONG LATENCY		
	C-L	C-A	L-A	C-L	C-A	L-A
REACTION TIME:						
fastest	-.05	-.12	.00	-.02	-.20	-.57*
1-choice	-.03	-.07	.01	.03	-.11	-.45*
3-choice	-.05	-.16	-.04	-.01	-.22	-.70*

iii) NON-MIXED INSTRUCTIONS PARADIGM

	BACKGROUND		SHORT LATENCY			LONG LATENCY		
	C-L	C-A	C-L	C-A	L-A	C-L	C-A	L-A
REACTION TIME:								
fastest	.01	.00	-.12	.00	.17	-.05	-.34	-.39
1-choice	-.10	-.05	-.15	-.03	.18	.05	-.26	-.43
3-choice	.07	.03	.01	.06	.04	-.11	-.38	-.35

where: C="compensate" L="let go" A="assist" * = $p < .05$

APPENDIX C - Table 2: EXPERIMENT II MODULATION CORRELATIONS (r values)

VARIABLES:	AVERAGE REFLEX MODULATION ("compensate" minus "let go")					
	YOUNGER GROUP		OLDER GROUP		COMBINED	
	SHORT LATENCY	LONG LATENCY	SHORT LATENCY	LONG LATENCY	SHORT LATENCY	LONG LATENCY
REACTION TIME (2-choice)	-.25	-.63*	.39	-.50	-.03	-.57*

where: * = p < .05

APPENDIX D

BACKGROUND CORRELATIONS

APPENDIX D: FLEXORS AND EXTENSORS BACKGROUND ACTIVITY CORRELATIONS

NON-MIXED INSTRUCTIONS:

Subject	Age	"COMPENSATE"		"LET GO"		"ASSIST"	
		r	sig.	r	sig.	r	sig.
D.S.	28	-.90*	.049	-.65	.224	-.79	.106
N.G.	24	.54	.230	.62	.19	.57	.215
P.C.	26	.79	.104	-.71	.144	-.64	.181
K.G.	25	.12	.438	-.81	.095	.29	.358
B.C.	28	-.91*	.044	-.38	.308	-.58	.212
R.L.	23	-.50	.333	.56	.309	-.78	.216
A.L.	30	-.87	.067	.75	.124	-.70	.151
B.L.	28	.06	.471	.57	.216	.79	.103
B.C.	23	-.66	.171	-.80	.102	.33	.335
D.C.	23	.93*	.037	.27	.363	n/a	n/a
I.M.	26	.82	.089	.65	.174	-.79	.106
C.H.	25	.03	.484	-.14	.428	.55	.225
J.S.	25	.53	.234	-.01	.494	.31	.343
T.M.	29	.57	.216	.36	.322	-.37	.313

where: * = $p < .05$

APPENDIX E

EXPERIMENT I NORMALIZED EMG VALUES

Appendix E : EXPERIMENT I NORMALIZED EMG VALUES

Subject D.S.

MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.15	.10	.10	.11	.09	.17	.29	.28	.48	.73	.90	1.00
"let go"	.11	.13	.13	.11	.08	.14	.16	.27	.13	.14	.24	.30
"assist"	.08	.10	.11	.13	.05	.13	.21	.24	.12	.14	.20	.26
none	.11	.12	.12	.12	.12	.21	.25	.33	.13	.31	.43	.67

NON-MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.08	.08	.08	.08	.08	.08	.17	.14	.75	.76	.94	.98
"let go"	.16	.18	.18	.14	.13	.16	.24	.37	.08	.14	.21	.23
"assist"	.15	.16	.15	.14	.11	.19	.29	.31	.11	.32	.34	.46

Subject D.V.

MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.22	.22	.08	.22	.05	.10	.52	.20	.18	.47	1.00	.88
"let go"	.21	.22	.21	.21	.04	.11	.12	.15	.02	.05	.09	.19
"assist"	.22	.21	.22	.22	.06	.08	.21	.31	.04	.09	.13	.34
none	.21	.21	.21	.20	.06	.11	.09	.24	.04	.16	.27	.50

NON-MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.19	.21	.20	.20	.25	.02	.06	.06	.15	.23	.44	.50
"let go"	.26	.26	.26	.22	.09	.20	.31	.27	.02	.07	.17	.20
"assist"	.23	.25	.24	.26	.14	.14	.22	.24	.02	.07	.11	.15

Subject M.G.

MIXED CONDITIONS PARADIGM

	BG				SL				LL			
loads (V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.11	.13	.09	.11	.11	.18	.20	.24	.24	.56	.50	.69
"let go"	.12	.10	.12	.11	.11	.17	.20	.23	.05	.14	.31	.34
"assist"	.10	.12	.11	.13	.10	.22	.22	.35	.14	.16	.24	.51
none	.12	.11	.11	.11	.11	.11	.13	.23	.05	.17	.23	.45

NON-MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads (V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.15	.13	.13	.11	.01	.11	.17	.10	.18	.51	.70	1.00
"let go"	.18	.19	.19	.22	.14	.17	.31	.25	.11	.25	.42	.56
"assist"	.17	18	.18	.17	.07	.16	.30	.29	.11	-.02	.00	.16

Subject P.C.

MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.14	.13	.13	.15	.15	.25	.28	.31	.33	.45	.60	1.00
"let go"	.12	.16	.13	.14	.09	.13	.18	.21	.11	.15	.14	.19
"assist"	.13	.15	.14	.13	.08	.21	.19	.32	.15	15	.17	.30
none	.12	.12	.12	.13	.05	.09	.16	.18	.07	.12	.22	.28

NON-MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.13	.12	.12	.12	.08	.15	.26	.31	.36	.50	.73	.79
"let go"	.13	.13	.13	.15	.04	.11	.17	.21	.12	.18	.18	.23
"assist"	.17	.18	.17	.20	.14	.15	.23	.28	.14	.19	.46	.56

Subject K.G.

MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.15	.12	.10	.14	.06	.15	.18	.32	.56	.63	.61	1.00
"let go"	.10	.09	.07	.09	.05	.18	.16	.25	.08	.10	.16	.13
"assist"	.12	.11	.12	.11	.04	.11	.23	.31	.08	.11	.26	.19
none	.11	.09	.09	.10	.08	.09	.21	.18	.20	.33	.47	.47

NON-MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.09	.08	.08	.08	.04	.07	.11	.16	.24	.35	.57	.53
"let go"	.09	.11	.10	.10	.10	.08	.19	.18	.04	.12	.21	.26
"assist"	.13	.14	.11	.13	.09	.20	.20	.31	.05	.11	.21	.26

Subject B.C. (28)

MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.35	.31	.31	.32	-.03	.10	.12	.16	.47	.74	.97	.98
"let go"	.35	.33	.32	.34	.03	.08	.10	.06	.10	.21	.22	.27
"assist"	.30	.27	.30	.36	.06	.19	.11	.01	.09	.21	.25	.15
none	.36	.33	.27	.32	.00	.01	.20	.08	.44	.72	.88	.87

NON-MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.28	.25	.24	.23	.03	.03	.07	.11	.44	.68	.86	1.00
"let go"	.38	.32	.39	.33	.02	.11	.10	.11	.28	.45	.27	.41
"assist"	.38	.37	.37	.42	.00	.13	.13	.11	.16	.22	.15	.20

Subject R.L.

MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	n.a.	.10	.11	.12	n.a.	.22	.29	.35	n.a.	.49	.81	.90
"let go"	.11	.11	.11	"	.20	.29	.33	"	.03	.09	.12	
"assist"	.13	.12	.19	"	.29	.33	.36	"	.08	.18	.20	
none	.09	.10	.11	"	.16	.20	.29	"	.28	.39	.59	

NON-MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	"	.09	.10	.10	n.a.	.14	.18	.24	n.a.	.53	.65	1.00
"let go"	"	.14	.16	.13	"	.15	.20	.27	"	.06	.10	.16
"assist"	"	.13	.15	.17	"	.22	.32	.42	"	.12	.21	.28

Subject A.L.

MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.31	.29	.37	.32	.11	.26	.37	.41	.18	.63	.71	1.00
"let go"	.30	.30	.32	.29	.08	.24	.46	.46	.04	.33	.57	.52
"assist"	.31	.34	.27	.30	.08	.18	.36	.41	.07	.44	.46	.70
none	.27	.28	.26	.27	.20	.15	.23	.42	.16	.46	.68	.78

NON-MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.22	.20	.26	.27	.16	.26	.25	.50	.24	.60	.74	.78
"let go"	.40	.36	.38	.32	.15	.31	.42	.47	-.01	.20	.33	.48
"assist"	.45	.39	.48	.53	.18	.45	.45	.52	.04	.13	.28	.30

Subject B.L.

MIXED INSTRUCTIONS PARADIGM

loads (V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.10	.14	.10	.09	.16	.26	.36	.39	.26	.37	.58	.66
"let go"	.09	.08	.08	.07	.12	.18	.27	.28	.01	.03	.04	.05
"assist"	.10	.09	.09	.09	.14	.29	.30	.34	.02	.07	.09	.13
none	.10	.12	.11	.09	.18	.24	.31	.29	.08	.22	.40	.36

NON-MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads (V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.10	.12	.10	.10	.13	.24	.39	.41	.36	.56	.82	1.00
"let go"	.11	.12	.15	.12	.20	.26	.28	.39	.01	.06	.08	.16
"assist"	.13	.13	.15	.14	.20	.31	.33	.38	.01	.06	.18	.26

Subject B.C. (23)

MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads (V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.05	.05	.05	.06	.08	.10	.09	.20	.27	.48	.42	1.00
"let go"	.04	.05	.05	.05	.06	.08	.08	.09	.09	.13	.12	.16
"assist"	.03	.05	.06	.06	.07	.08	.11	.10	.09	.10	.15	.20
none	.05	.07	.06	.07	.06	.08	.13	.12	.06	.11	.16	.19

NON-MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads (V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.01	.03	.03	.04	.08	.03	.06	.05	.24	.25	.38	.35
"let go"	.02	.03	.04	.04	.02	.02	.02	.03	.03	.03	.07	.10
"assist"	.06	.06	.07	.06	.05	.05	.10	.09	.02	.04	.08	.09

Subject D.C.

MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads (V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.14	.17	.17	.18	.32	.40	.35	.67	.46	.83	.75	1.00
"let go"	.19	.19	.16	.19	.29	.46	.49	.64	-.02	-.01	.06	.11
"assist"	.16	.18	.17	.16	.26	.41	.63	.56	.07	.04	.17	.27
none	.29	.29	.32	.30	.38	.57	.57	.64	-.03	.00	.11	.14

NON-MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads (V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.12	.17	.14	.14	.27	.33	.56	.61	.33	.59	.95	.88
"let go"	.22	.22	.26	.22	.38	.61	.72	.76	-.02	.04	.12	.22
"assist"	.24	.25	.27	.22	.32	.54	.68	.72	-.01	.02	.13	.31

Subject I.M.

MIXED INSTRUCTIONS PARADIGM

loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.10	.10	.10	.10	.08	.10	.18	.19	.44	.74	1.00	.96
"let go"	.08	.12	.10	.10	.05	.06	.13	.11	.02	.04	.12	.07
"assist"	.08	.12	.11	.11	.03	.08	.13	.18	.06	.13	.09	.22
none	.11	.10	.12	.11	.05	.06	.10	.08	.13	.28	.43	.50

NON-MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.08	.09	.10	.10	.07	.09	.09	.11	.20	.42	.53	.85
"let go"	.08	.08	.09	.09	.05	.06	.09	.08	.07	.12	.14	.24
"assist"	.09	.12	.11	.13	.07	.07	.10	.08	.05	.08	.12	.22

Subject C.H.

MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads (V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.16	.16	.18	.16	.37	.63	.84	.90	.08	.67	.76	.93
"let go"	.17	.18	.20	.15	.34	.53	.71	.91	-.03	.00	.20	.17
"assist"	.16	.16	.17	.16	.33	.60	.67	1.00	-.01	.07	.22	.41
none	.21	.22	.20	.28	.31	.47	.66	.74	-.01	.26	.33	.51

NON-MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads (V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.14	.14	.18	.15	.45	.68	.68	.83	.11	.49	.76	.80
"let go"	.24	.21	.23	.20	.46	.63	.80	.91	.05	.31	.36	.45
"assist"	.23	.16	.18	.18	.46	.51	.71	.83	.05	.19	.62	.63

Subject J.S.

MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions;												
"compensate"	.13	.15	.15	.15	.09	.20	.54	.48	.30	.56	.85	.91
"let go"	.14	.14	.13	.14	.13	.42	.60	.76	.03	.17	.37	.50
"assist"	.12	.14	.14	.16	.14	.25	.48	.69	.08	.28	.56	.63
none	.12	.11	.12	.10	.14	.33	.35	.31	.06	.27	.29	.40

NON-MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions;												
"compensate"	.14	.13	.14	.13	.13	.11	.23	.15	.21	.46	.98	1.00
"let go:	.16	.16	.18	.17	.26	.41	.57	.54	.05	.14	.27	.41
'assist"	.19	.20	.17	.19	.11	.23	.38	.46	.02	.16	.41	.48

Subject T.M.

MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.15	.16	.13	.12	.10	.18	.23	.31	.13	.39	.84	1.00
"let go"	.12	.13	.12	.11	.08	.19	.23	.30	.06	.09	.27	.41
"assist"	.12	.12	.13	.13	.10	.19	.23	.27	.09	.20	.48	.69
none	.12	.12	.11	.11	.07	.14	.22	.25	.09	.27	.49	.67

NON-MIXED INSTRUCTIONS PARADIGM

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.10	.11	.10	.10	.10	.17	.28	.28	.13	.33	.66	.67
"let go"	.10	.12	.09	.10	.11	.19	.28	.28	.08	.26	.51	.65
"assist:	.14	.12	.12	.13	.16	.26	.28	.34	.02	.16	.39	.57

APPENDIX F

EXPERIMENT II NORMALIZED EMG VALUES

Appendix F : EXPERIMENT II NORMALIZED EMG VALUES

Subject L.B.

YOUNGER GROUP

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.15	.15	.15	.15	.28	.26	.32	.38	.38	.82	.94	1.00
"let go"	.13	.16	.12	.13	.16	.24	.25	.32	.26	.44	.62	.76
none	.13	.12	.18	.15	.18	.31	.29	.34	.35	.59	.81	.97

Subject G.A.

YOUNGER GROUP

	BG				SL				LL			
loads (V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.24	.23	.25	.25	.33	.60	.72	1.00	.31	.49	.67	.64
"let go"	.28	.25	.23	.23	.27	.51	.75	1.00	.12	.41	.72	.80
none	.29	.29	.28	.29	.33	.48	.72	.97	.13	.44	.59	.73

Subject J.A.

YOUNGER GROUP

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.14	.14	.14	.14	.08	.17	.33	.39	.25	.47	.64	1.00
"let go"	.14	.14	.14	.14	.08	.22	.28	.39	.17	.28	.39	.67
none	.14	.14	.17	.14	.17	.19	.31	.42	.22	.47	.75	.89

Subject A.M.

YOUNGER GROUP

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.10	.09	.09	.09	.16	.38	.51	.49	.14	.43	1.00	.99
"let go"	.06	.09	.09	.07	.14	.33	.38	.55	.14	.38	.51	.81
none	.10	.12	.07	.12	.20	.28	.49	.43	.10	.43	.84	.87

Subject G.J.

YOUNGER GROUP

	BG				SL				LL			
loads (V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.04	.03	.04	.03	.17	.22	.39	.39	.23	.43	.71	1.00
"let go"	.04	.03	.03	.04	.03	.09	.16	.13	.01	.03	.18	.10
none	.04	.03	.04	.04	.00	.07	.07	.10	.06	.11	.20	.33

Subject F.K.

YOUNGER GROUP

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.04	.04	.03	.05	.10	.17	.32	.36	.43	.48	.75	1.00
"let go"	.03	.04	.03	.03	.04	.08	.17	.17	.06	.13	.17	.17
none	.04	.04	.04	.04	.05	.12	.22	.21	.33	.48	.56	.73

Subject S.K.

YOUNGER GROUP

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.15	.13	.15	.16	.10	.13	.10	.21	.37	.65	.79	1.00
"let go"	.11	.11	.11	.13	.06	.10	.13	.13	.11	.11	.23	.32
none	.15	.16	.16	.16	.10	.06	.16	.16	.23	.26	.37	.39

Subject C.J.

YOUNGER GROUP

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.07	.06	.08	.07	.08	.21	.33	.42	.32	.52	1.00	.80
"let go"	.06	.05	.06	.06	.05	.13	.13	.39	.11	.12	.15	.34
none	.07	.07	.06	.07	.05	.13	.19	.24	.18	.38	.48	.66

Subject J.R.

YOUNGER GROUP

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.08	.08	.08	.08	.03	.19	.08	.11	.37	.74	.94	1.00
"let go"	.06	.06	.06	.06	.03	.08	.16	.18	.03	.08	.11	.08
none	.10	.08	.08	.06	.03	.11	.19	.24	.23	.31	.39	.56

Subject S.U.

YOUNGER GROUP

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.10	.13	.10	.10	.05	.28	.15	.26	.26	.46	.49	1.00
"let go"	.10	.10	.13	.10	.10	.18	.21	.21	.10	.28	.36	.46
none	.13	.13	.13	.10	.08	.13	.15	.21	.18	.41	.69	.77

Subject Ba.

OLDER GROUP

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.10	.11	.10	.08	.06	.17	.25	.29	.33	.93	1.00	.72
"let go"	.08	.10	.08	.08	.08	.18	.20	.29	.17	.25	.34	.51
none	.08	.10	.08	.08	.10	.17	.22	.22	.18	.29	.35	.40

Subject Ma.

OLDER GROUP

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.35	.40	.38	.35	.03	.13	.20	.23	.20	.60	.75	1.00
"let go"	.35	.35	.38	.35	.13	.20	.20	.23	.10	.23	.28	.48
none	.15	.15	.15	.18	.08	.20	.20	.18	.15	.35	.63	.53

Subject Am.

OLDER GROUP

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.15	.18	.15	.18	.44	.45	.67	.76	.33	.84	1.00	.98
"let go"	.15	.15	.15	.15	.29	.58	.78	.75	.13	.30	.31	.45
none	.16	.15	.15	.16	.35	.38	.60	.69	.15	.47	.58	.55

Subject Ki.

	OLDER GROUP											
	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.21	.15	.15	.19	.15	.39	.42	.49	.40	.91	1.00	.87
"let go"	.17	.17	.19	.17	.09	.17	.28	.34	.08	.25	.34	.32
none	.19	.19	.17	.19	.08	.23	.34	.45	.11	.17	.31	.31

Subject Vo.

OLDER GROUP

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.08	.08	.08	.06	.19	.27	.29	.39	.39	.56	.73	1.00
"let go"	.06	.08	.06	.08	.11	.16	.27	.37	.31	.53	.58	.79
none	.10	.08	.08	.08	.10	.18	.31	.42	.37	.56	.69	.79

Subject Ly.

OLDER GROUP

	BG				SL				LL			
loads (V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.24	.24	.22	.22	.10	.20	.22	.26	.42	.68	.88	1.00
"let go"	.24	.26	.22	.24	.08	.18	.16	.16	.04	.12	.22	.24
none	.26	.34	.28	.24	.14	.20	.22	.24	.08	.18	.42	.70

Subject He.

OLDER GROUP

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.12	.10	.10	.10	.12	.21	.33	.42	.30	.54	.76	1.00
"let go"	.10	.12	.12	.10	.09	.16	.36	.45	.15	.34	.58	.67
none	.12	.12	.12	.12	.09	.16	.33	.46	.12	.46	.66	.88

Subject Ca.

OLDER GROUP

	BG				SL				LL			
loads(V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.16	.16	.20	.16	.10	.12	.12	.20	.57	.76	.95	1.00
"let go"	.18	.20	.18	.17	.04	.08	.18	.15	.11	.28	.46	.47
none	.17	.18	.18	.17	.09	.09	.12	.15	.20	.33	.45	.41

Subject Wi.

OLDER GROUP

	BG				SL				LL			
loads (V):	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6	0.9	1.8	2.7	3.6
Instructions:												
"compensate"	.27	.27	.27	.32	.18	.27	.45	.59	.27	.59	.82	.95
"let go"	.27	.27	.27	.27	.23	.32	.36	.59	.55	.64	.77	1.00
none	.27	.32	.36	.32	.27	.32	.36	.45	.18	.45	.64	.77