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FINAL REPORT

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PROJECT NO: NAG 5-895 (April 15 1987-1988)

PRINCIPLE INVESTIGATOR: Jane E. Clark

Sally J. Phillips
(Co-investigator)

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(NASA-CR-182901) THE EFFICACY OF USING HUMAN MYOELECTRIC SIGNALS TO CONTROL THE LIMBS OF ROBOTS IN SPACE Final Report, 15 Apr. 1987-1988 (Maryland Univ.) 289 p
CSCL 05H G3/54
N88-25155
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Acknowledgments

Greatful appreciation is extended to Jody Jensen and Pam Russell for their hard work and expertise in all phases of this project. Their efforts were essential to the timely completion of this project.

Data collection also was facilitated by Linda Clarke and Terri Truly.

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SECTION I: OVERVIEW OF PROJECT GOALS

This project was designed to investigate the usefulness of the myoelectric signal as a control signal in robotics applications. More specifically, the neural patterns associated with human arm and hand actions were studied in an attempt to determine the efficacy of using these myoelectric signals to control the manipulator arm of a robot. The advantage of this approach to robotic control was the use of well-defined and well-practiced neural patterns already available to the system, as opposed to requiring the human operator to learn new tasks and establish new neural patterns in learning to control a joystick or mechanical coupling device.

Examples are readily available of the high-level skill possessed by humans in controlling their own limbs, despite the fact that this control requires mastering a neuromuscular-skeletal complex with a myriad of degrees of freedom. The virtuosity of the concert pianist or the dexterity of the neurosurgeon, are but two examples from a world of possibilities. Mechanically recreating the kind of dexterity exhibited in the above-mentioned examples was clearly beyond the scope of the proposed research. However, evidence of electromyographically (EMG) controlled limb behavior with a minimal, but sufficient, level of dexterity was available - in the area of prosthetics design and application (Childress, 1973; 1982; Rubenstein, 1984). Thus, not only was there an intuitively logical basis for the proposed research, but part of the answer was already known. That is, under the right circumstances, neural signals can be utilized in the control of artificial, and perhaps, external limbs.

A basic premise of prosthetics research, and the research presented here, was that the patient/subject utilized an endigenous neural pattern in concert with the musculoskeletal complex to control the artificial limb (Childress, Holmes, & Billock, 1974). The myoelectric signals could be tapped from related muscles, or those muscles generally considered to be the "prime movers" or agonists of a particular limb action. It was hoped that a steep learning curve in control could be avoided by tapping into the neural circuits of the non-pathological nervous system, and using the same agonist/antagonist muscle relationships (as known by their myoelectric signals) practiced and mastered over the years.

Thus, it was an accomplished fact that the neural signal could be used to control an artificial limb. What was critical in the current investigation was determination of the usefulness of established neural patterns for controlling an external device with multiple degrees of freedom. Such a determination required answering the following questions. Could the myoelectric signals used for limb control be consistently reproduced? How susceptible was the recorded electromyographic pattern to changes in remote degrees of freedom?

SECTION II:

LESSONS OF PROSTHETICS AND ELECTROMYOGRAPHIC RESEARCH

It has long been recognized that an internal process, such as muscle contraction, could be monitored through an associated external measure - recording of an electrical signal which accompanies the contraction process. The functionality of such a measure carries with it some limits and cautions. A brief discussion of the human neuromuscular system and some limitations to our interpretation of system function is useful in understanding the approach taken in this investigation.

The functional unit of the muscular system, the motor unit (MU), is composed of a neuron and the muscle fibers (cells) that it innervates (Figure 1). Muscle contraction is ultimately the result of an electrical signal transmitted from nerve to MU. During gross motor task voluntary muscular action any number of MUs may be recruited. The number of MUs involved relates to the force requirements of the task. The greater the force, the larger the number of MUs involved (Burke, 1981). It is possible to monitor muscular activity by measuring the electrical signal which is a

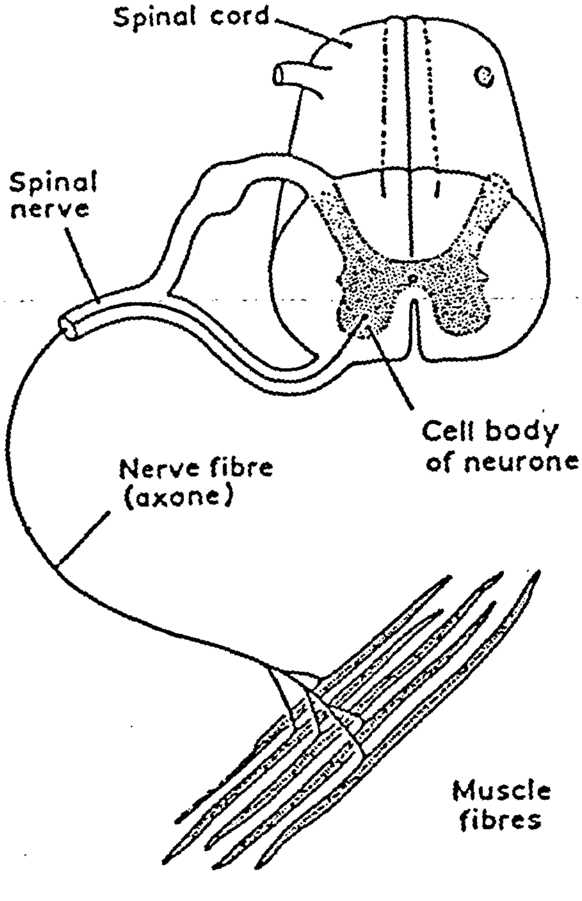


Figure 1. A motor unit. (Adapted from Muscles Alive (p. 7) by J. V. Basmajian, 1979, Baltimore: The Williams and Wilkins Company.)

byproduct of contraction; for like force output, the greater the number of active MUs, the greater the magnitude of the electrical signal recorded. Thus we derive a relationship between the magnitude of force, and the magnitude of electrical signal. This relationship is not linear under all circumstances, but under the controlled conditions of constant velocity muscle contraction it is interpretable (Bigland & Lippold, 1954; Stevens & Taylor, 1972).

The organization of the human musculoskeletal system is such that limb behavior is controlled by agonist and antagonist muscular pairs. In a one-degree-of-freedom task such as elbow flexion in the transverse (i.e. horizontal) plane, flexion of the forearm about the elbow is controlled by those muscles crossing anterior to the joint. Extension is controlled by muscles crossing posterior to the joint. Lack of motion is the result of either no active muscular force, or the cocontraction of agonist and antagonist muscle pairs such that the net torque created by their contraction is zero. Under constant velocity conditions the electrical activity emanating from either muscle group may be interpreted as a reasonably direct indication of active flexion or extension (depending on the activated muscle group) (Bigland & Lippold, 1954). So far the story is reasonably straightforward. However, numerous factors interact to confound the interpretation of the myoelectric signal as an indicator of muscle force or position.

Muscle force is modulated through MU recruitment and activation frequency (i.e. rate coding) (Bigland-Ritchie, 1981). Since these two factors also determine myoelectric activity it is logical to expect a relationship between muscle force and myoelectric activity. However, the nature of this relationship cannot be explicitly described for all circumstances.

Difficulties arise in relating muscle force and myoelectric activity because they are derived through different means. Mechanical calculations of muscle moments (Muscle moment = muscle force times perpendicular distance to the point of force application from the point of rotation) obtained with an inverse dynamics approach assume that the sum of agonist and antagonist muscle activity for all muscles crossing the joint of interest has been included (e.g. Dul, Townsend, Shiavi, & Johnson, 1984). (Note: The validity of this assumption has been questioned but it is commonly used.) These calculations also presumably account for the potential force production of the series elastic component of the muscle. EMG data reflects only myo-electric activity from the contractile element of the muscle of interest (Winter, 1979) and usually only the agonist muscle(s) versus an agonist/antagonist pair. Thus

EMG/force relationships may vary because the internal estimate of muscle force (i.e. myoelectric activity) and the external estimate of muscle force (i.e. mechanical calculations) are obtained in different ways.

In addition, muscle force production depends upon factors independent of myoelectric activity such as movement velocity and muscle length (Bigland-Ritchie, 1981). As movement velocity increases potential force production decreases (Hill, 1938). As muscle length decreases, potential force production decreases (Gordon, Huxley, & Julian, 1966). EMG records reflect these factors but not in direct proportion to muscle force changes (Bigland & Lippold, 1954). Faster movements create greater integrated EMG records, but less force. Concentric muscle contractions (i.e. decreasing muscle length) which have less potential force production (Winter, 1979), produce greater integrated EMG records than eccentric contractions (i.e. increasing muscle length). So the demands of the task may influence the EMG/force relationship.

Physiological differences also hamper the interpretation of EMG as muscle force. Under fatiguing conditions accompanied by decreased force generation (this was not a factor in collection of these data but may be a factor in the application of these data) the EMG record will increase (Asmussen, 1979; Edwards, 1981). This increase, normally attributed to increased MU recruitment thus increased force production, may be caused by synchronization of MU firing or changes in action potential size associated with fatigue (Bigland-Ritchie, 1981). Temperature changes also alter the action potential size and influence the EMG record (Bigland-Ritchie, 1981). Thus increased EMG activity may not indicate increased force production.

The size of the myoelectric signal varies with the size of the MU potential which may be influenced by fiber type (Bigland-Ritchie, 1981). MUs composed of mostly fast twitch muscle fibers produce larger electrical responses than MUs composed of mostly slow twitch muscle fibers. This may not seem important to EMG/force relationships since faster MUs are usually recruited for high force short duration tasks and slower MUs are recruited for lower force longer duration tasks (Henneman, 1974). However, muscles differ in their dependence upon rate coding and recruitment for force generation. For example, in the adductor pollicus and first dorsal interosseous muscles of the hand all MUs are recruited at 30-50% of the maxium voluntary contraction (MVC), but in the biceps brachii new MUs are recruited at forces greater than 85% of the MVC (Bigland-Ritchie, Kukulka & Woods, 1980). In addition, under conditions of high force generation increases in activation may exceed the tetanic fusion frequency of the muscle. As a consequence the EMG record increases disproportionately to the force produced (Bigland-Ritchie, 1981). Thus the use of different strategies for force production may create different EMG/force relationships.

Morphological differences such as distribution of MU types throughout a muscle create additional problems (Bigland-Ritchie, 1981). Slower MUs tend to be less superficial than faster MUs (Burke, 1981). Surface electrodes (invasive electrodes were unrealistic in our current investigation and in prosthetic design) when properly secured directly over the muscle belly pick up EMG activity at the surface from a small part of the muscle. Thus signals removed from the recording site may not be fully detected. If slower MUs have been selectively recruited, the EMG record and the actual force generated would be disproportional. In addition, since surface electrodes are sensitive to all electrical signals within a given range signals from active muscles removed from the primary site may interfere with a clean recording from the muscle of interest.

In addition to the aforementioned factors which make the interpretation of EMG activity as muscle force or position difficult, there are methodological considerations. Selection of surface electrodes may influence the EMG/force relationship; monopolar electrodes tend to show linear relationships, bipolar tend to show nonlinear relationships (Moritani & deVries, 1978). Since surface electrodes are sensitive to a variety of signal sources and pick up a global signal, proper positioning of the electrode relative to the active muscle is imperative. This becomes a substantive issue when the electrical activity of deep versus superficial muscles is of prime concern. As will be pointed out in discussion of the data, the inability to accurately monitor deep muscles hindered the recording of activity related to certain gross motor movements (e.g. differentiation of forearm pronation/supination from wrist flexion/extension; and internal rotation of the humerus at the shoulder from external rotation). Movement artifact also is of concern. Electrodes must be sufficiently secured so that external surface shape changes, due to underlying muscle movement, do not disrupt the integrity of the electrode contact.

So to name EMG activity as muscle force and thus an indicator of position would be a misnomer. In fact the reported relationships between EMG and muscle force vary from linear (Bigland & Lippold, 1954; Stevens & Taylor, 1972), to quasilinear (Lawrence & DeLuca, 1983), to nonlinear (Bigland-Ritchie, Kukulka & Woods, 1980), to logarithmic (Perry & Bekey, 1981). Given the influences of task conditions and methodology perhaps Lawrence and DeLuca

(1983) summed it up best: the EMG/force relationship is determined by the muscle under investigation. For this study this means that comparison of the EMG data as a representation of force or position is confined: myoelectric activity from two muscles of the same subject, from the same muscle of two different subjects, and from two different muscles of two different subjects can not be compared in terms of force or position.

SECTION III: METHODS AND INSTRUMENTATION

The project, conducted in two phases, involved simultaneous collection of EMG signals and the corresponding limb displacement data. These data were collected by an opto-electronic imaging system with synchronized analog signal recording capabilities, in Phase I, and by a Sperry IT microcomputer equipped with digital oscilloscope software (CODAS), in Phase II. Investigations were limited to one and two-degree-of-freedom movements of the upper extremity. Table 1 contains a listing of the movement conditions studied.

Table 1: Movement Tasks and Conditions

Task	Musculature	Special Conditions
Elbow flexion/ extension	biceps brachii triceps brachii anterior deltoid	sagittal plane (across speeds; [b]accelerated movement w/ isometric)
Elbow flexion/ extension	biceps brachii triceps brachii	transverse plane (w/ and w/out cocontraction; [a]across speeds)
Shoulder flexion/ extension	biceps brachii anterior deltoid	sagittal plane
Shoulder abduction/ adduction	middle deltoid posterior deltoid pectoralis major trapezius	frontal plane ([a]across speeds; [b]w/ and w/o cocontraction)
Shoulder internal/ external rotation	infraspinatus teres major anterior deltoid pectoralis major	transverse plane (w/ and w/out cocontraction)
Grasping	forearm flexors forearm extensors	[a]w/ & w/out cocontraction
Wrist flexion/ extension	forearm flexors forearm extensors	[b]sagittal plane (accelerated movement w/ isometric) [b]transverse plane
Forearm pronation/ supination	supinator pronator teres biceps brachii	[a]w/ & w/out cocontraction
Thumb abduction/ adduction	adductor pollicus	[b]w/ & w/out cocontraction

Table 1: Movement Tasks and Conditions (cont'd)

Task	Musculature	Special Conditions
Fifth digit (pinky) abduction/adduction	abductor digiti minimi	[b]transverse plane
Reaching	biceps brachii triceps brachii anterior deltoid latissimus dorsi posterior deltoid	sagittal plane (w/ & w/out cocontraction; across speeds)

Note. All tasks were conducted in both phases unless otherwise noted.
[a]Conducted only in Phase I.
[b]Conducted only in Phase II.

Phase I Position-time Data

A SELPOT II opto-electronic imaging system was used to collect position-time data for limb displacements. The SELSPOT system is a video camera system sensitive to infra-red light. Small infra-red (950 nm) light emitting diodes (LED) are used to mark joint centers so that rigid body motion may be recorded. A dedicated PDP 11/23 LSI computer coordinated the data collection tasks and synchronized the simultaneous acquisition of displacement data with analog inputs. Using a two-camera system, the 3-dimensional coordinates for any LED marked point in space could be determined.

Phase II Position-time Data

Position-time data were collected using a goniometer (i.e. two dowel rods attached to a potentiometer) interfaced with a Sperry IT microcomputer equipped with analog to digital conversion capabilities and CODAS, digital oscilloscope software. The goniometer detected changes in joint angle as changes in voltage. This signal was stored on disc and displayed in real-time. Position-time data were available for only one joint during each task and due to the size of the potentiometer, unavailable for smaller joints (i.e. first carpometacarpal and fifth metacarpophalangeal joints).

Electromyographic Data (Phases I and II)

The Motion Control Myolab II (Model ML-200) equipped with a preamplifier (Model ML-220) was used to moniter the EMG signal. Surface electrodes were attached to the skin directly over the motor point(s) of the muscle(s) under investigation. The detected EMG signals were amplified and filtered (Preamplifier filter bandwidth = 9 Hz - 27 kHz; Myolab filters = second order high frequency filter (roll-off = 1000 Hz) and third order low frequency filter (roll-off = 50 Hz)). The conditioned analog (i.e. EMG) signals were converted to digital signals and stored on disc. An analog representation of the signal, either the integrated EMG or the raw EMG, was viewed during the task in Phase II but unavailable until after the task in Phase I. The simultaneous collection of EMG and limb displacement data were synchronized through the use of a PDP 11/23 LSI computer in Phase I, and a Sperry IT microcomputer system in Phase II.

SECTION IV: ANATOMICAL AND MOVEMENT REFERENCES

All anatomical references are given with respect to the three cardinal planes of motion and three orthogonal axes about which segmental rotations occur. Figure 2 shows the sagittal, frontal, and transverse planes with the corresponding axes. The reference positions for all movements are depicted in Figure 3.

SECTION V: TASK DEFINITIONS AND DATA

Elbow Flexion/Extension

1.0 Anatomical Considerations

Multiple muscles cross the elbow joint, the moment arms of which create varying influences on the flexor and extensor torques at the elbow. Three of these muscles act as primary elbow flexors during concentric contraction; brachialis, the brachioradialis and the biceps brachii, (Figure 4a,b,c). The biceps brachii, a two-joint muscle which crosses the elbow and shoulder, is the most superficial muscle of the upper arm. Except under circumstances of high load, the role of the biceps at the shoulder is generally small. However, since the biceps attaches to the radius its role at the elbow is directly influenced by forearm position. Thus the biceps brachii is defined as an

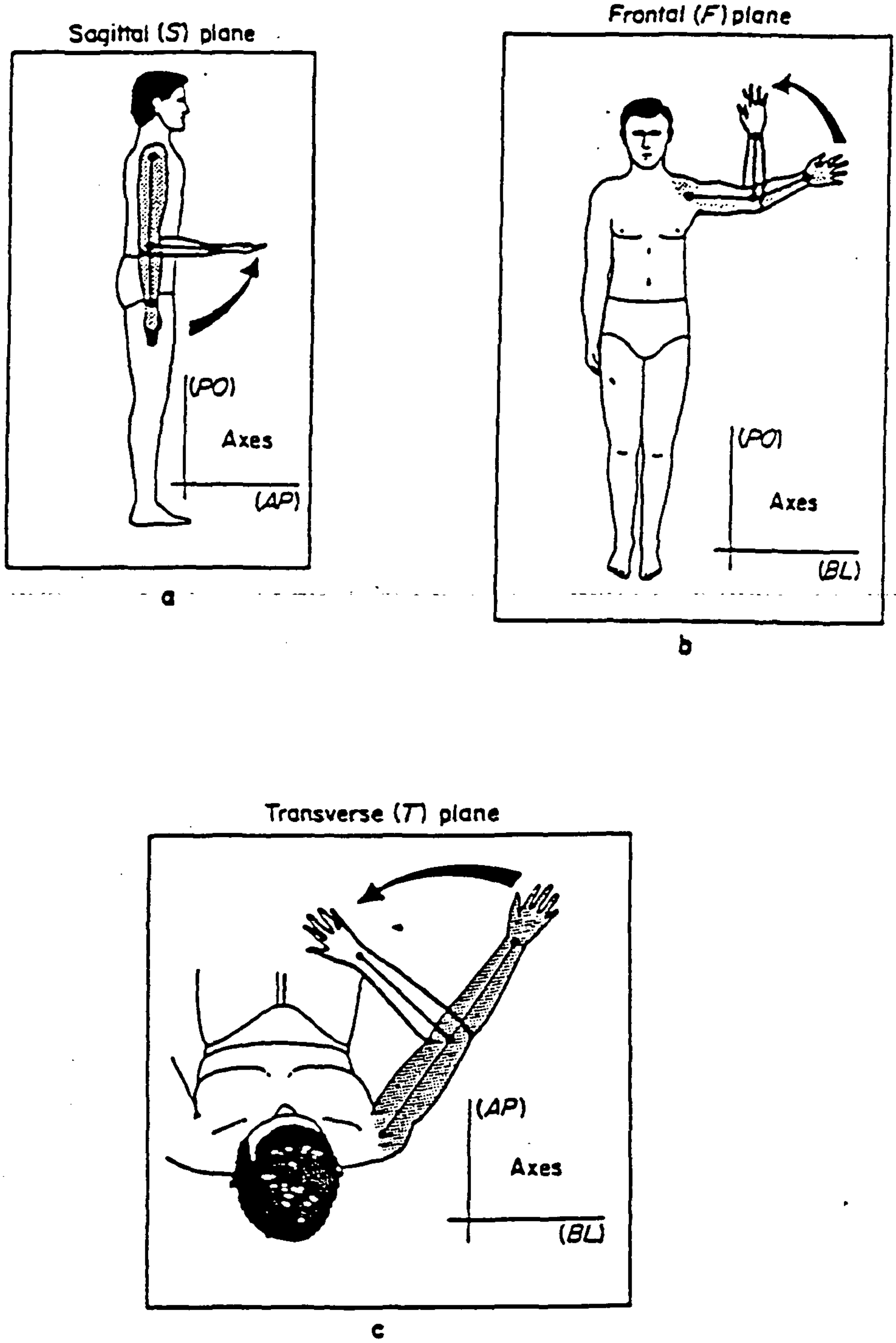


Figure 2. Cardinal planes of motion and orthogonal axes. (Adapted from Kinesiology Fundamentals of Motion Description (p. 80) by D. L. Kelley, 1971, New Jersey: Prentice-Hall.)

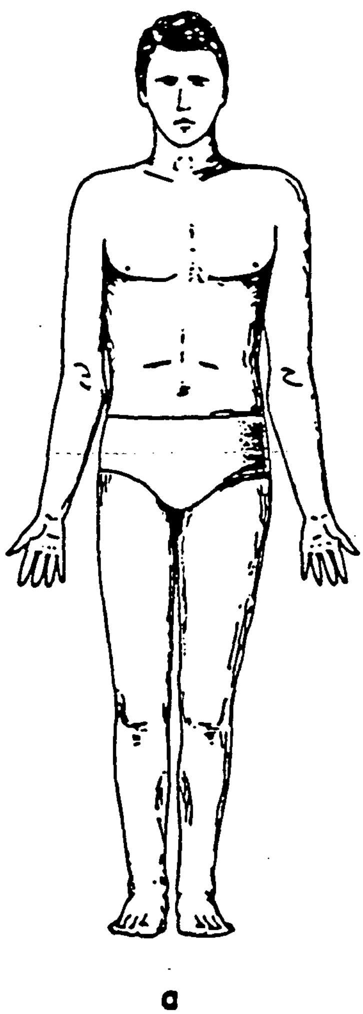


Figure 3. Standing positions: (*a*) the anatomical position; (*b*) the fundamental position.

(Adapted from Kinesiology Fundamentals of Motion Description (p. 70) by D. L. Kelley, 1971, New Jersey: Prentice-Hall.)

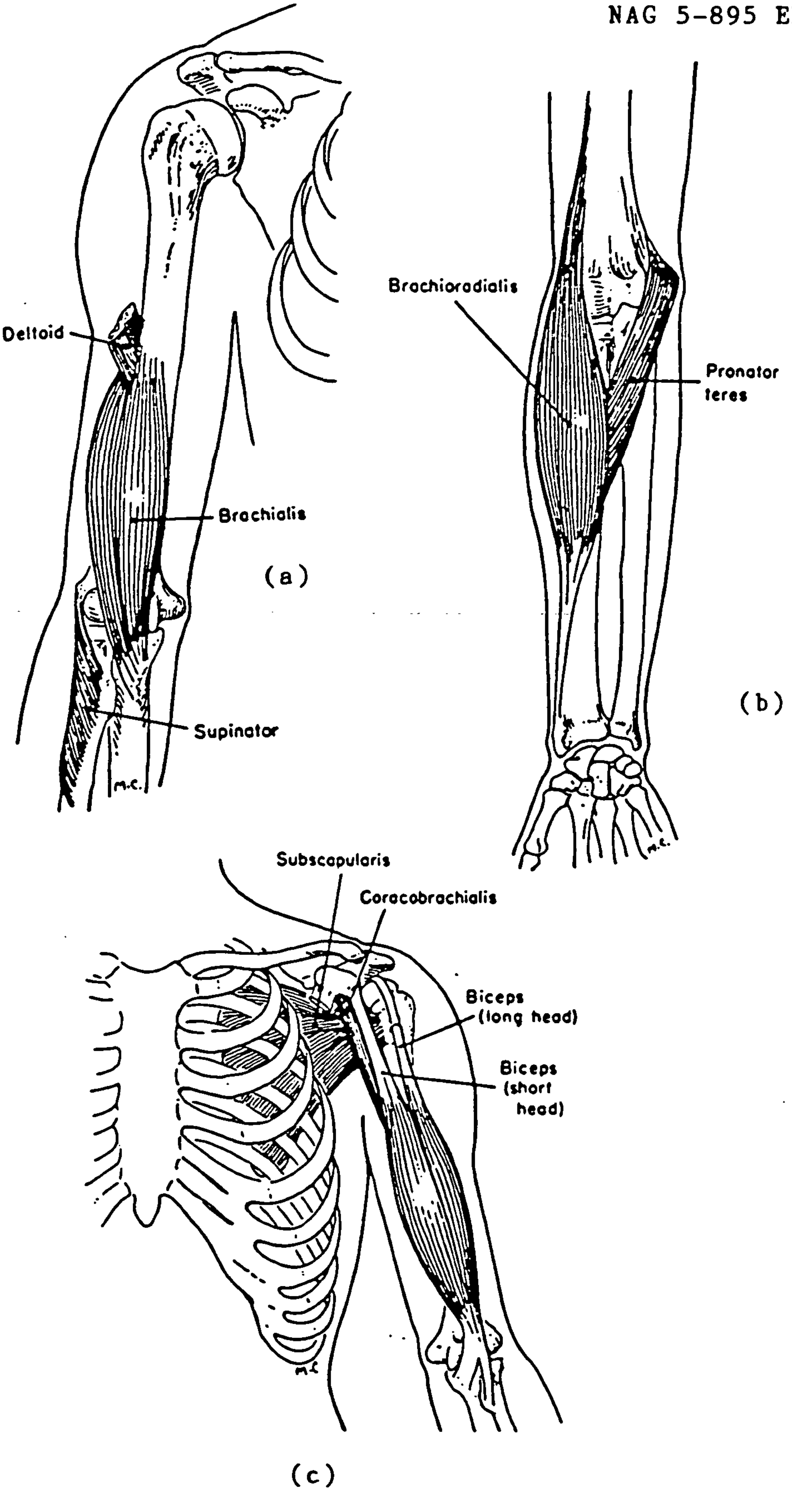


Figure 4. Primary elbow flexors: (a) bracialis, (b) brachioradialis, (c) biceps brachii. (Adapted from Kinesiology : Scientific Basis of Human Motion (p. 86, 119-120) by K. Luttgens and K. F. Wells, 1982, Philadelphia: Saunders.)

elbow flexor and forearm supinator. With the forearm in the semi-prone (or neutral) position the biceps has it greatest mechanical advantage.

The brachialis, a single-joint muscle, is considered the primary elbow flexor. The brachialis is in large part covered by the biceps brachii and only in the lower third and medial aspect of the upper arm may the brachialis be palpated directly. With an insertion on the ulna, the mechanical advantage of the brachialis is independent of forearm position (e.g., magnitude of pronation or supination).

The brachioradialis, a two-joint muscle crossing the elbow and wrist, originates just above the humeral epicondyles and inserts at the distal end of the radius. The bulk of the brachioradialis lies along the forearm. Because of the small moment arm created by the tendon of the brachioradialis as it crosses the elbow joint, its role is predominantly one of elbow stabilization.

The triceps brachii, a two-joint muscle (Figure 5) crossing the shoulder and elbow, acts as the agonist in forearm extension against resistance. The triceps is not a prime mover at the shoulder but the influence of shoulder position on triceps activity must be kept in mind.

Control of limb behavior is the result of interaction among those muscles crossing the joint; their levels of

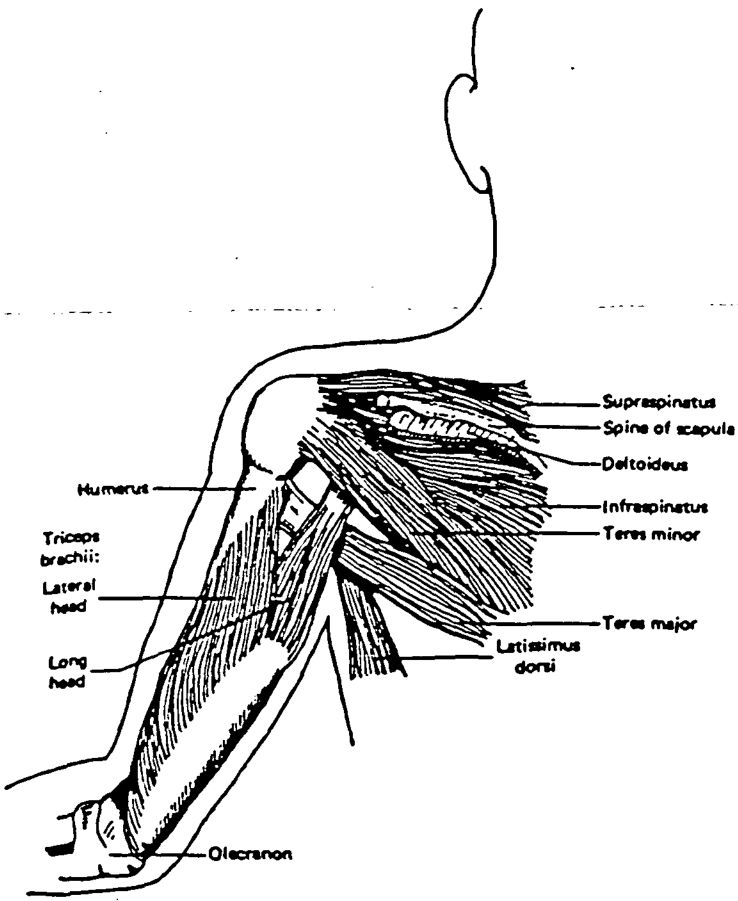


Figure 5. Triceps brachii; lateral and long heads. (Adapted from Kinesiology: The Science of Movement (p. 75) by J. Piscopo and J. A. Baley, 1981, New York: Wiley.)

activation and any mechanical biases operating on the muscles. Thus, a complete description of elbow joint control must consider not only activation of the agonist muscles but also (1) angle at the shoulder, (2) forearm position, (3) elbow angle, and (4) external force considerations (e.g., effects of gravity).

1.0.1 Position at the Glenohumeral Joint (Shoulder Angle)

Consideration must be given to the degree of flexion or extension present at the glenohumeral joint (shoulder) due to the two-joint involvement of the biceps and triceps brachii. The nature of a two-joint muscle will influence the excursion ratio of that muscle during performance of the task. A full range of motion (ROM) may be impossible to achieve if simultaneous flexion or extension of multiple joints is required. In such a case, it is often helpful to maintain muscle stretch across one joint while the muscle affects the action at the next joint.

In the present study, the excursion ratio of the biceps brachii is more of an academic concern than one of practical importance. Although a two-joint muscle, examination of the proximal attachments of the biceps reveals that its function will be affected in small measure by any change in the degree of shoulder flexion. The attachments for both the long and short heads of the biceps are on the lateral and anterior aspects of the glenohumeral structure. Thus shoulder position within the range of FSP to 90° of flexion would not appear to appreciably change either the amount of stretch in the biceps or the relationship of the line of pull to the axis of rotation at the elbow joint. In conditions of light load (e.g., arm supported in a 90° shoulder flexed position) shoulder angle should not have a significant influence on biceps activity. However, under dynamic conditions, or non-support of an extended arm, the biceps may be involved in stabilization of the shoulder joint.

1.0.2 Degree of Forearm Supination or Pronation

Consider the three primary elbow flexors; biceps brachii, brachialis, and the brachioradialis. The distal attachment of the brachialis is on the ulna. Forearm position will not affect the action of this muscle as pronation and supination are related to changes in position of the radius about the ulna. However, both the biceps brachii and the brachioradialis have attachments on the radius so that their strength in elbow flexion will be affected by forearm position.

Numerous studies have used the elbow joint as the investigative site for studying muscle interactions (Basmajian & Latif, 1957; Doss & Karpovich, 1965; Hagberg, 1981; Hagberg & Ericson, 1982; Liberson, Dondey & Maxim, 1962; Lloyd, 1971; Rodgers & Berger, 1974; Singh & Karpovich, 1966; Wakim, Gersten, Elkins, & Martin, 1950).

The most thorough of these was the investigation of elbow flexor strength undertaken by Basmajian & Latif (1957). In this study the level of electrical activity of the biceps brachii (long and short heads), brachialis, and brachioradialis was identified under conditions of flexion, extension, and isometric contraction at angles of 135° and 90°. During slow flexion of the forearm under load, the short head of the biceps, the brachialis and the brachioradialis showed the greatest EMG activity with the forearm in the semi-prone postion. During quick flexion under load, the supinated position displayed the highest level of EMG activity in all muscles except the brachioradialis. During position maintenance tests at 135° and 90° the supinated position was preferred for biceps strength, but the semi-prone or prone position was preferred for brachioradialis strength. Finally it was observed that during elbow flexion maximal EMG activity occurred in all three muscles with the forearm in the semi-prone position.

If biceps activity is of primary concern, then the prone forearm position is contraindicated. This position substantially reduces the involvement of the biceps in quick and slow flexion (Basmajian & Latif, 1957). The semi-prone postion is best suited to the study of the integrated activity of the three elbow flexors.

1.0.3 Angle at the Elbow Joint

Isometric strength at the elbow has been studied throughout the range of 60° to 150° (Lloyd, 1971; Singh & Karpovich, 1966, 1967; Wakim, et al., 1950). With little question the greatest strengths are exhibited between 80° and 115° (Singh & Karpovich, 1966, 1967).

1.0.4 Effects of External Forces

Textbook definitions of muscle function define the muscles crossing anterior to the elbow as forearm flexors, and those muscles passing posterior to the joint axis as forearm extensors. This definition is true only under conditions of concentric contraction and a freely moving distal segment (i.e., the forearm is not fixed). With free motion in the sagittal plane, e.g., forearm rotation about the bilateral axis, the anterior muscles (brachialis, biceps brachii, and brachioradialis) are responsible for forearm flexion. If gravity is the only resistance offered to the flexion, then forearm extension is also controlled by the anterior muscles. The "flexors" control the extension through an eccentric contraction, or a lengthening under tension. Thus, even though the triceps brachii is the defined forearm extensor, the triceps acts as an extensor only against resistance. For sagittal plane motion, gravity is an external force acting on the limb which is controlled eccentrically by the forearm flexors.

1.1 Elbow Flexion Flexion/Extension Data

1.1.1 Elbow Flexion/Extension: Sagittal Plane

Special conditions: Slow, moderate and fast speeds

Phase I EMG: biceps brachii, anterior deltoid
Phase II EMG: biceps brachii, triceps brachii

Phase I description: Initial position; arm hanging relaxed at the side. The movement was forearm flexion and extension. Thus the forearm was flexed to a 90° angle with the humerus and returned to the FSP position.

Phase II description: Same as Phase I except forearm was moved through entire ROM at the elbow (i.e. from FSP to 30° angle with the humerus and back to FSP).

Phase I figures: D1 a,b,c; slow: D2 a,b,c; moderate. Top strip chart (1Y) = displacement representing a change in elbow angle. Peaks (e.g. 850 mm) indicate maximum flexion; valleys (e.g. 250 mm) indicate maximum extension. Second strip chart (1A) = EMG recording from the biceps. Third strip chart (2A) = EMG recording from the anterior deltoid.

Phase II figures: D3 a,b,c,d; moderate: D4 a,b,c,d; fast. EMG data from the biceps and triceps is displayed in the top graphs of D3a,c, and D4a,c. Bottom graphs (D3a,c; D4a,c) = displacement representing a change in the elbow angle (peaks indicate maximum flexion; valleys indicate maximum extension). Top graph = raw EMG data from the triceps (D3b,d) and biceps (D4b,d). Bottom graph = EMG data from the triceps (D3b,d) and biceps (D4b,d).

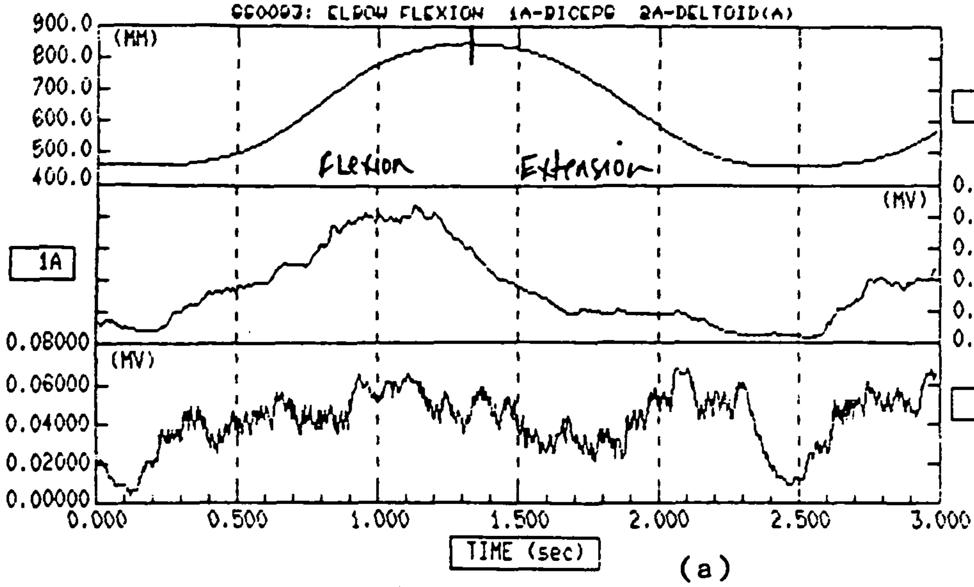
Observations:

Phase I: The biceps was monitored as prime mover for forearm flexion. As seen in other sagittal plane movement trials the biceps pattern correlated well with the position-time curve for the forearm. In anticipation of performing multi-segmented tasks, the deltoid was monitored for a response to forearm action. For example, in a reaching task, the deltoid might be used as the source for a shoulder flexion control signal. How contaminated might that signal be by distal limb behavior?

Under conditons of slow movement, the deltoid showed undifferentiated activity (Figures D1a,b,c). This pattern was interpreted to be little more than noise. Under faster movement conditions however, a definite deltoid pattern became evident (Figures D2a,b,c). In this case, the deltoid peak which occured at the end of forearm extension, may be a stabilizing activation evoked to control arm swing created by the momentum of the forearm returning to FSP.

Phase II: The function of the biceps/triceps pair were established for elbow flexion/extension to show the lack of dependence upon the triceps during elbow extension in a gravitational environment. As in Phase I, the biceps activity pattern correlated well with elbow flexion and extension at both movement speeds (Figures D3a,c, D4a,c). A slight peak in tricep activity just prior to joint reversal (i.e. from flexion to extension) was probably responsible for decreasing the speed of flexion in preparation for extension. At the moderate movement speed (Figure D3a,c) tricep activity also peaked at maximum extension (i.e. where the displacement graph flatlines along the baseline). This activity was probably evoked by hyperextension of the elbow joint, which was beyond the range of detectable goniometer signals. There also was a slight peak in bicep activity at this time which may have corresponded with a stretching of the biceps due to elbow hyperextension. The correspondence between the raw and IEMG tricep data (Figures D3b,d) was better than that between the raw and IEMG bicep data (Figures D4b,d).

EMG = BICEPS
ANTERIOR DELTOID



(a)

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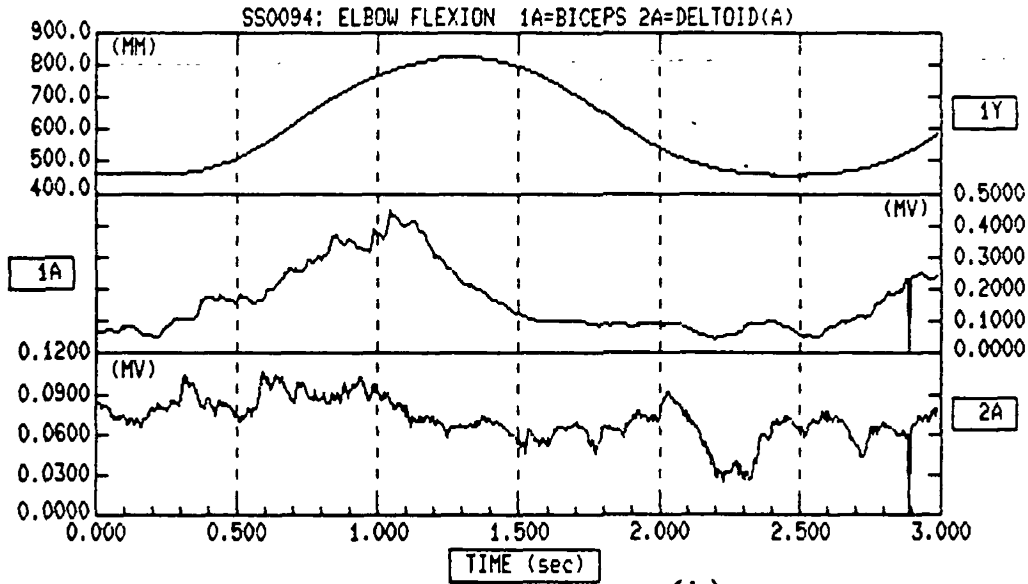
GAIN 1A = 10 ×1
GAIN 2A = 4

Note scale magnitudes. At slow speeds deltoid has minimal activity. At fast speeds it is used to stabilize the shoulder at elbow extension



(b)

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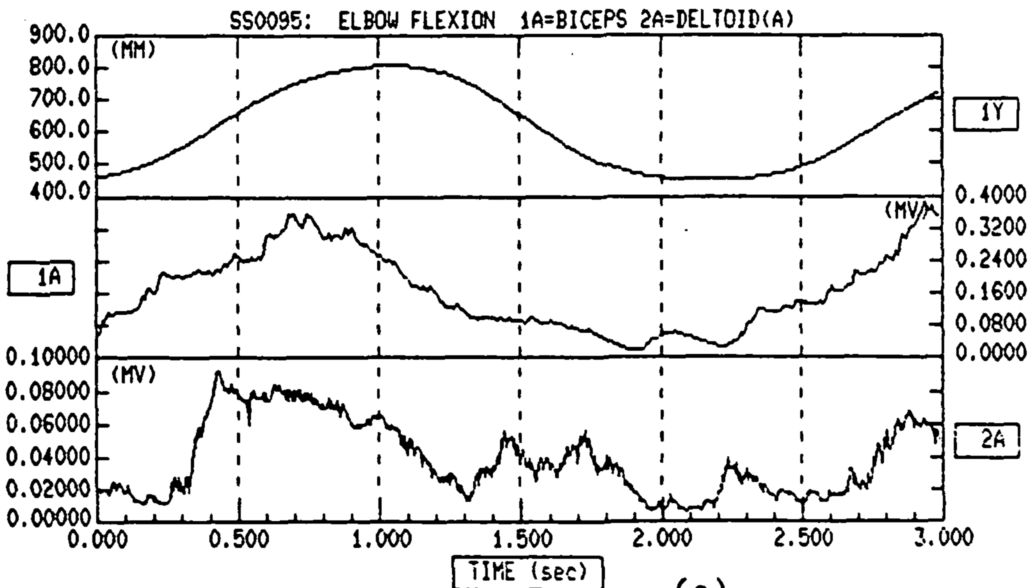
Figure D1.

Elbow flexion/extension in the sagittal plane.



(c)

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EMG = BICEPS, ANTERIOR DELTOID

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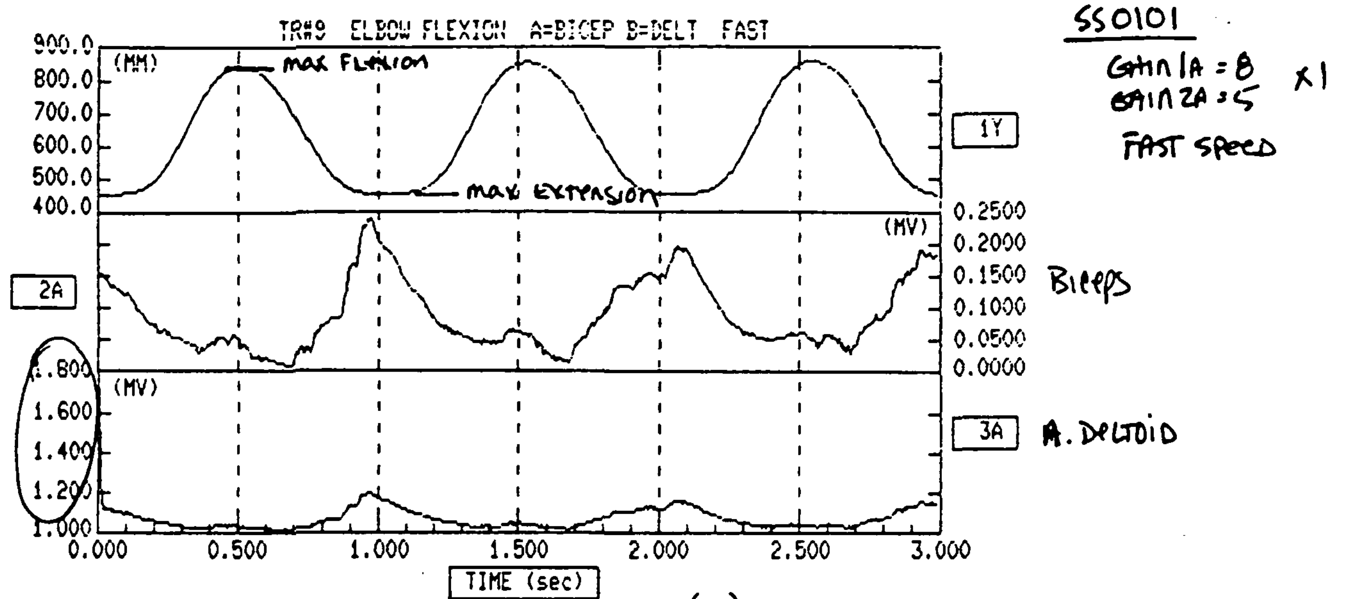
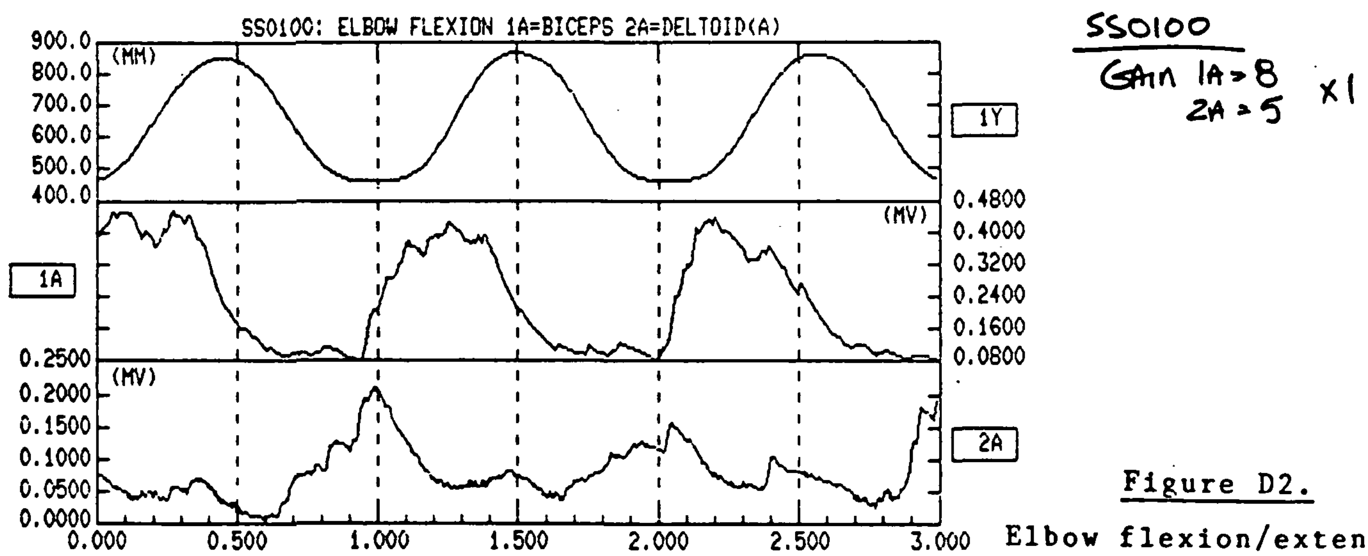
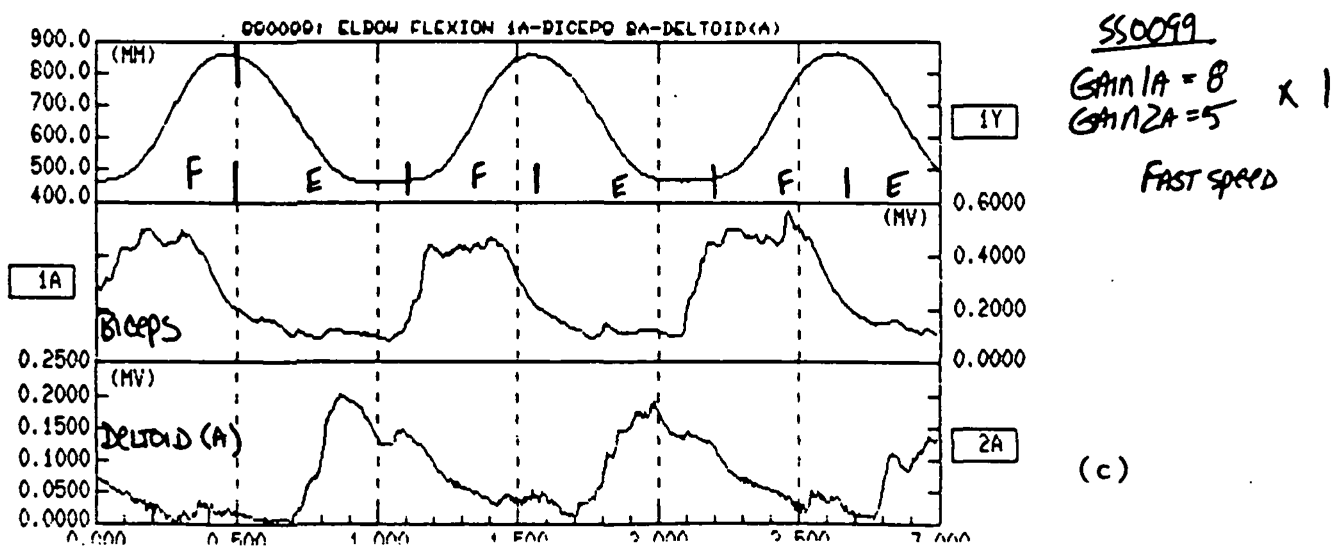


(a)



(b)

Figure D2.
Elbow flexion/extension in the sagittal plane.



(c)

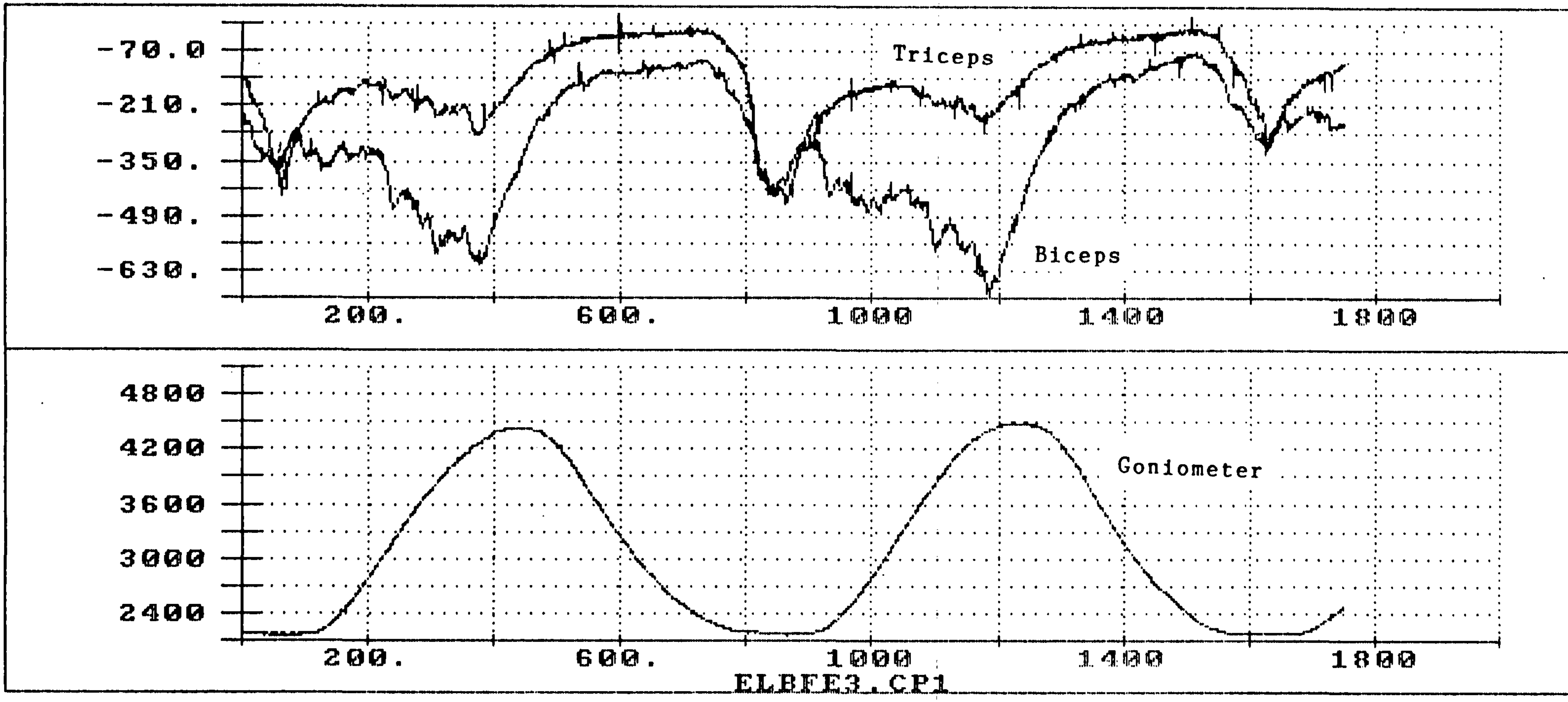


Figure D3a. ELBOW FLEXION & EXTENSION IN THE SAGITTAL PLANE

MOVEMENT SPEED: Medium SAMPLING RATE: 400 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

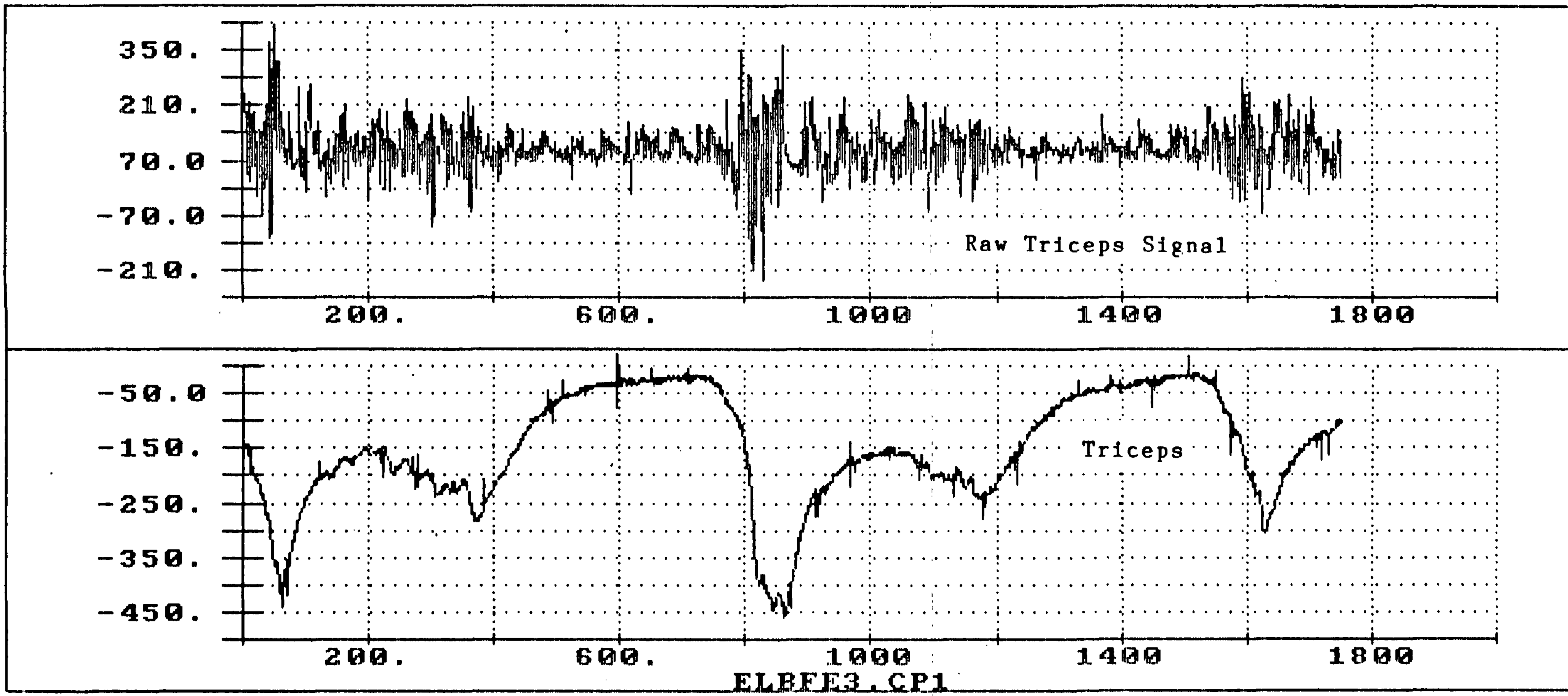


Figure D3b. ELBOW FLEXION & EXTENSION IN THE SAGITTAL PLANE

MOVEMENT SPEED: Medium SAMPLING RATE: 400 Samples/Sec/Channel

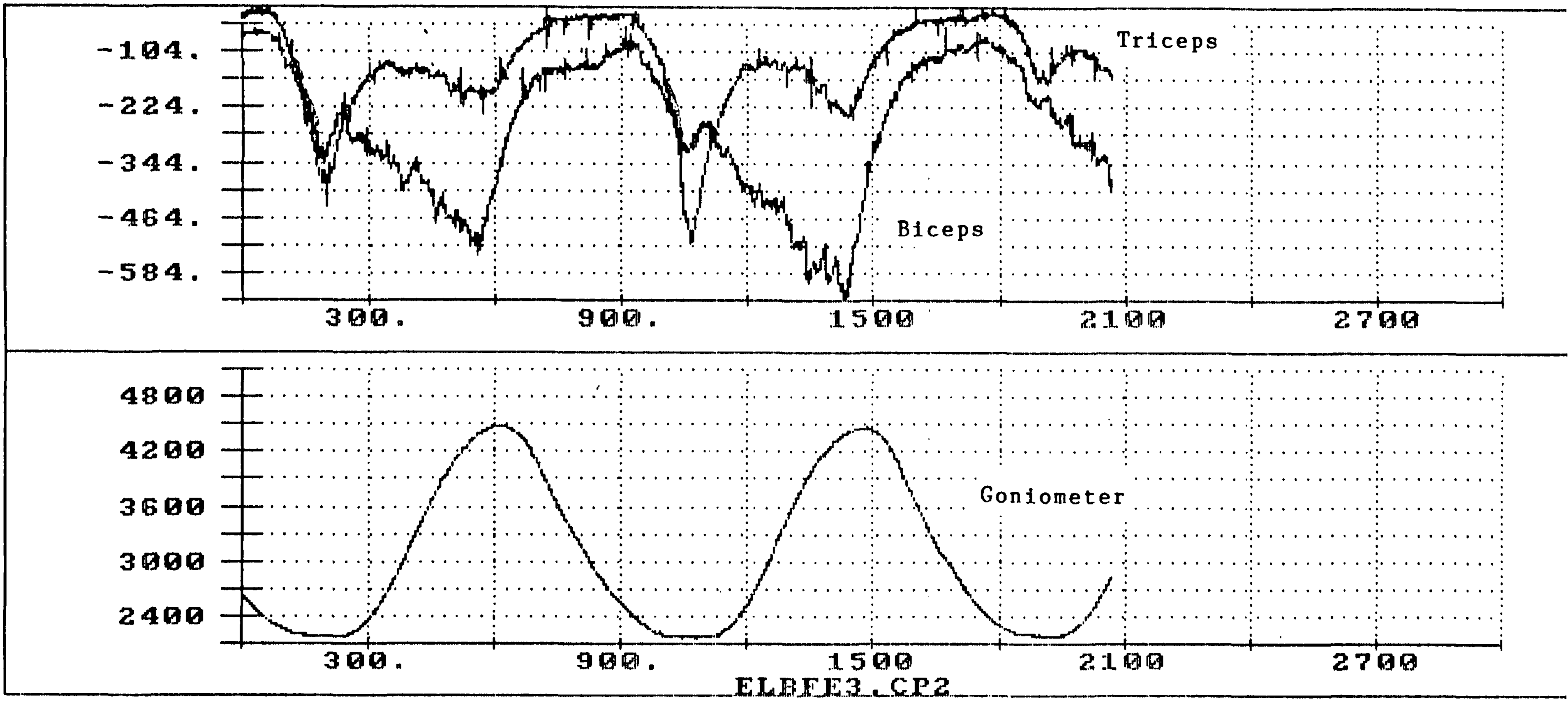


Figure D3c. ELBOW FLEXION & EXTENSION IN THE SAGITTAL PLANE

MOVEMENT SPEED: Medium **SAMPLING RATE:** 400 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

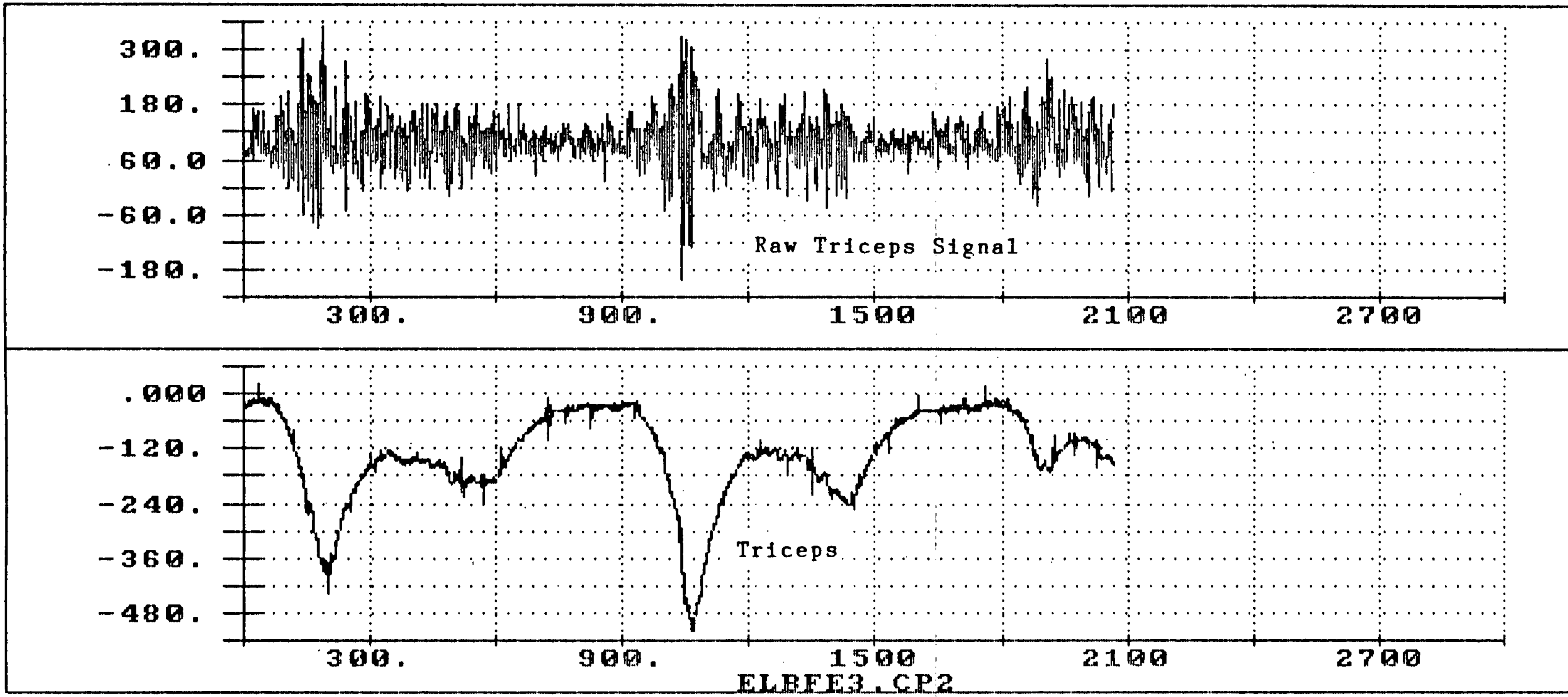


Figure D3d. ELBOW FLEXION & EXTENSION IN THE SAGITTAL PLANE

MOVEMENT SPEED: Medium SAMPLING RATE: 400 Samples/Sec/Channel

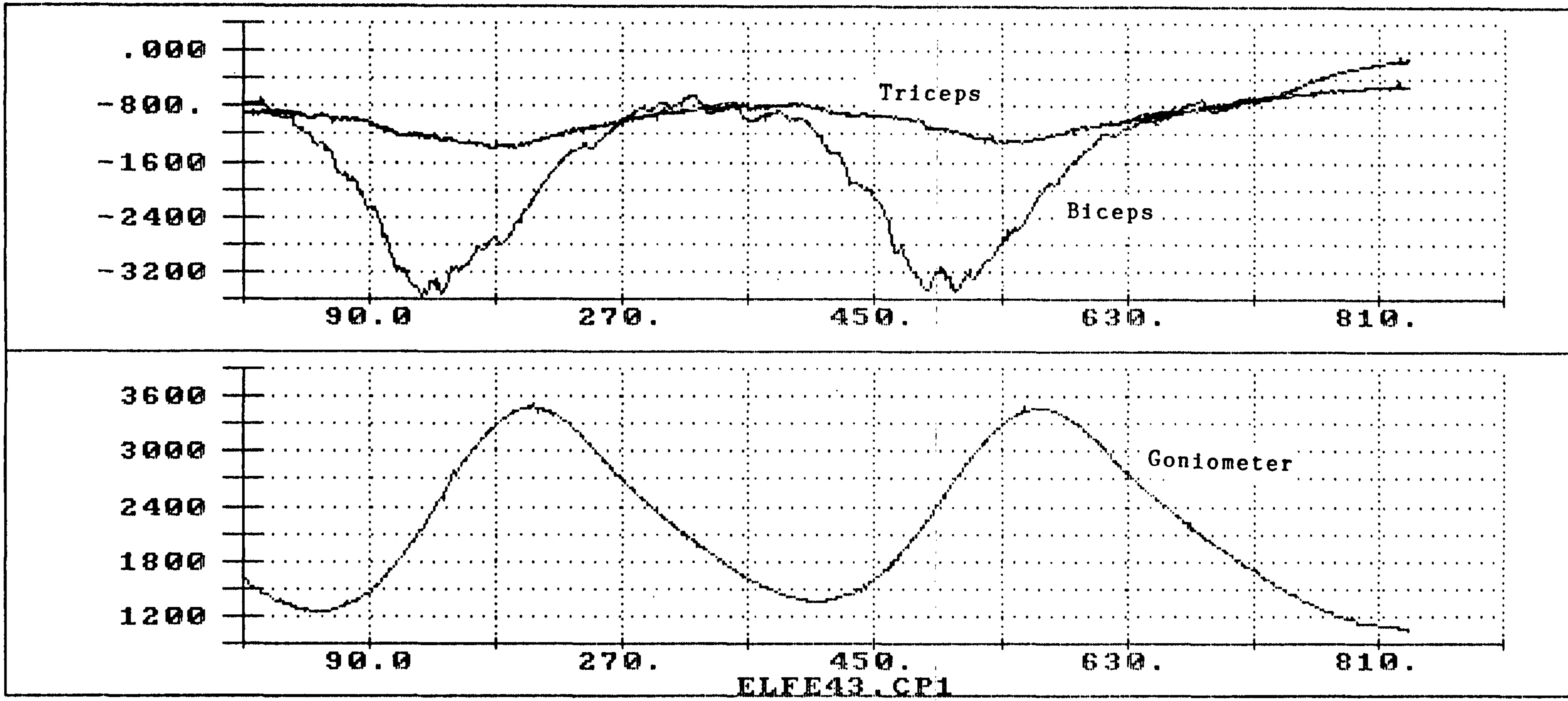


Figure D4a. **ELBOW FLEXION & EXTENSION IN THE SAGITTAL PLANE**

MOVEMENT SPEED: Fast SAMPLING RATE: 400 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

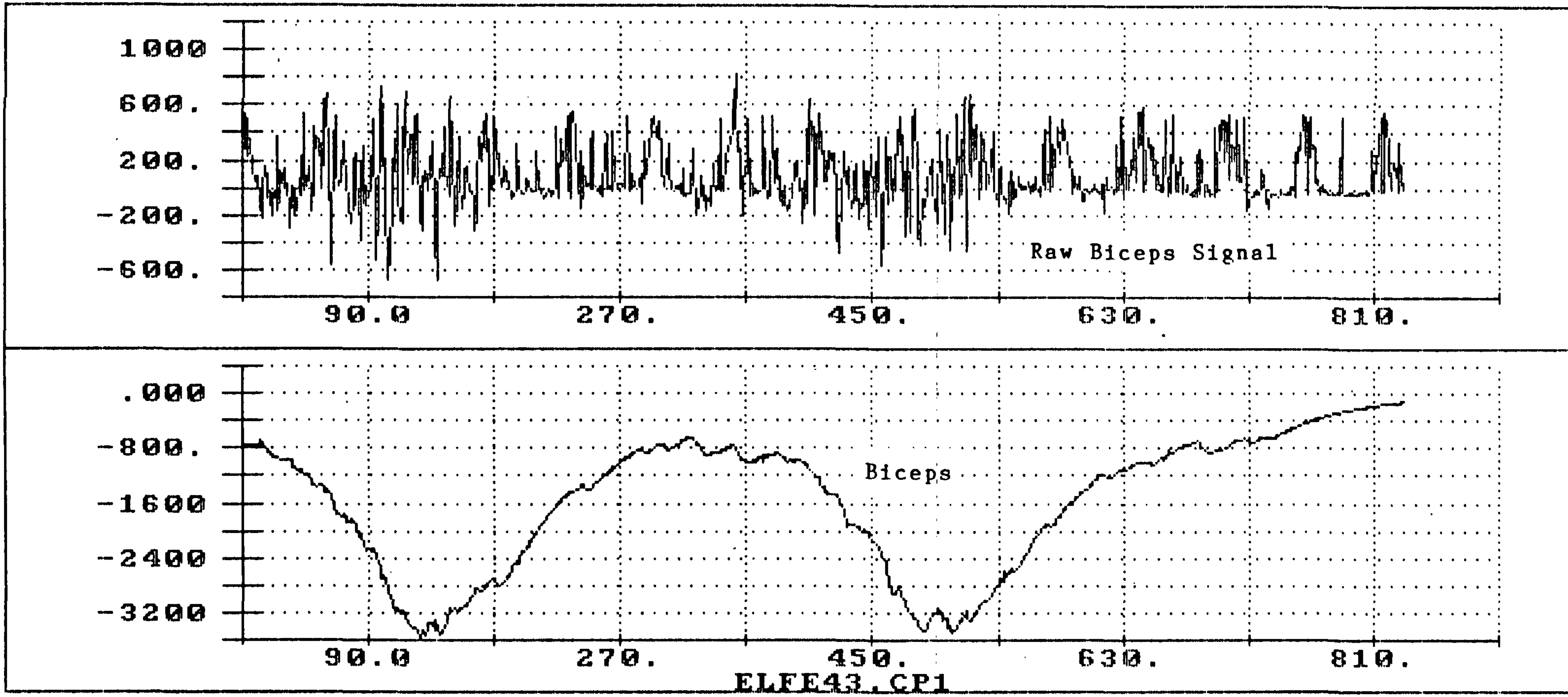
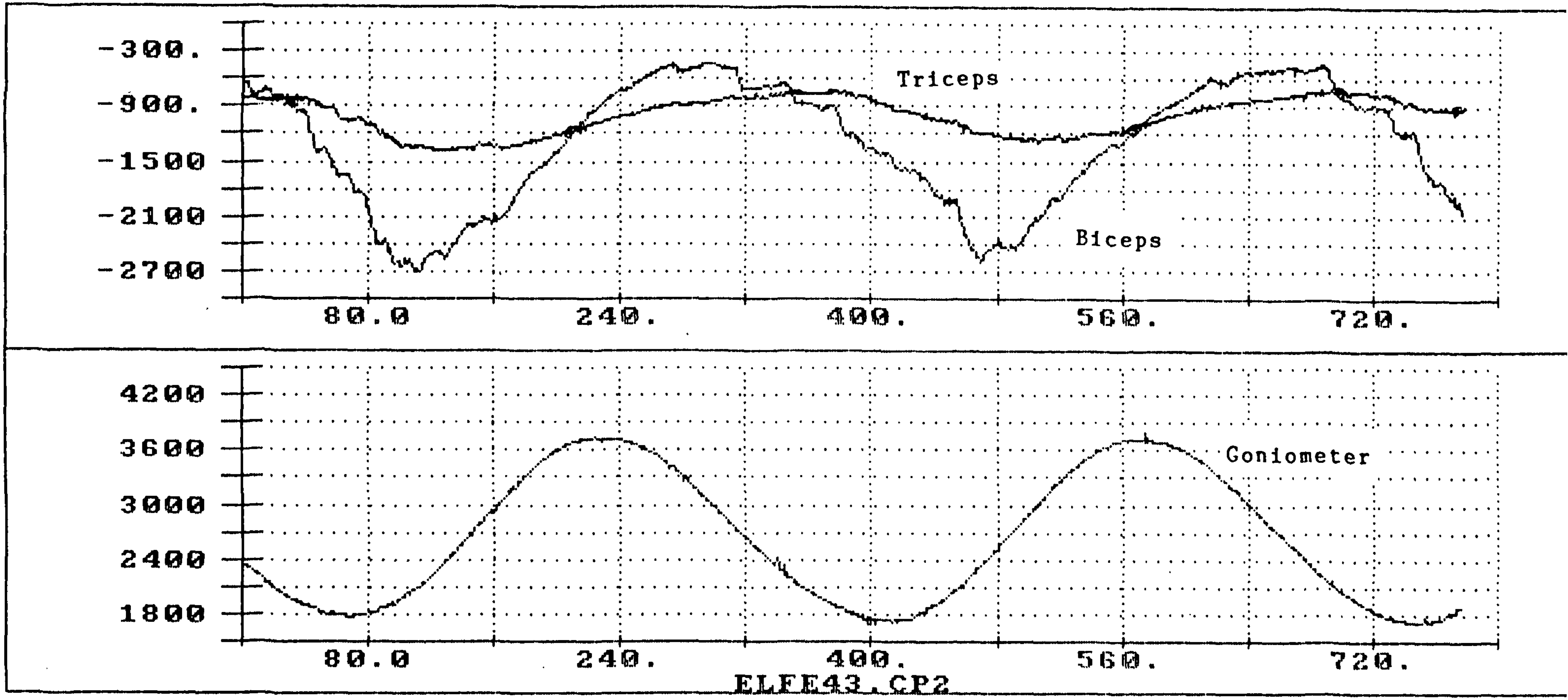


Figure D4b. **ELBOW FLEXION & EXTENSION IN THE SAGITTAL PLANE**

MOVEMENT SPEED: Fast SAMPLING RATE: 400 Samples/Sec/Channel



<u>Figure D4c.</u> ELBOW FLEXION & EXTENSION IN THE SAGITTAL PLANE

MOVEMENT SPEED: Fast SAMPLING RATE: 400 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

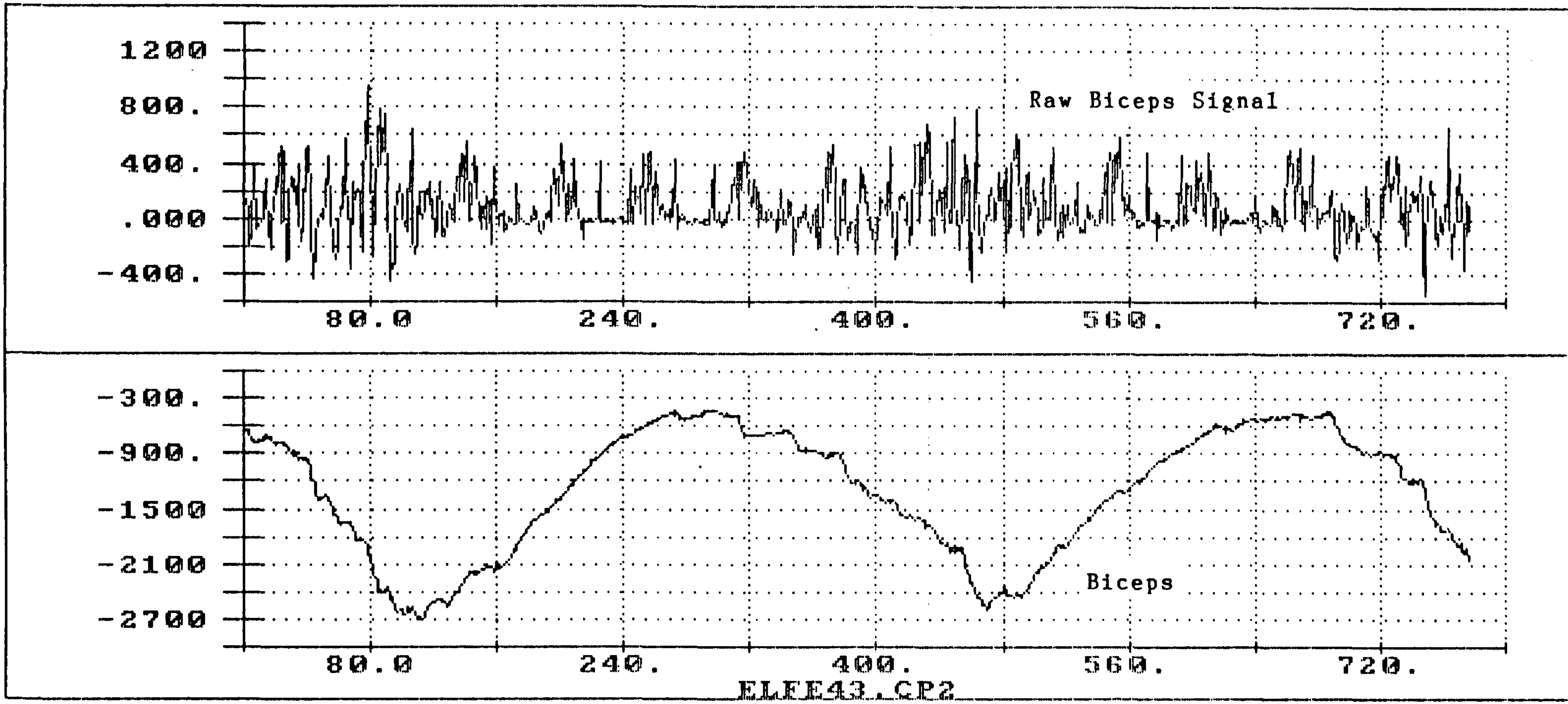


Figure D4d. ELBOW FLEXION & EXTENSION IN THE SAGITTAL PLANE

MOVEMENT SPEED: Fast SAMPLING RATE: 400 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

1.1.2 Elbow Flexion/Extension; Sagittal Plane

Special conditions: Accelerated movement between joint reversals and isometric contraction at joint reversal (Phase II only)

EMG: biceps brachii and triceps brachii

Description: Inital position; arm hanging relaxed at the side. The movement was forearm flexion and extension through the entire ROM at the elbow joint (i.e. from FSP to 30° angle with the humerus and back to FSP).

Figures: D5 a,b.
Top graph = EMG data from the biceps and triceps. Bottom graph = displacement representing a change in elbow angle (peaks indicate maximum flexion; valleys indicate maximum extension).

Observations:

As in the previous sagittal plane movement trials, the bicep activity pattern correlated well with the change in joint angle (Figures D5a,b): increased activity with elbow flexion; decreased activity with elbow extension. The gradual tapering off of bicep activity at maximum flexion reflected the isometric contraction. In this accelerated movement task the tricep appeared to play an active role during the later part of forearm extension evidenced by a rise in activity which peaked just before maximum extension and gradually tapered off with the isometric contraction. Biceps activity also increased slightly prior to maximum elbow extension to slow the limb as joint reversal was approached. There was actually slight elbow flexion and then extension before the limb was held in an isometric contraction at maximum extension (Figure D5a).

These data showed the importance of agonist/antagonist muscle pairs in controlling a limb and holding it in a certain position. The muscles worked together to slow the limb, reverse its direction and initiate movement in the opposite direction. In addition to holding a limb in position at the extremes of its ROM, agonist activity must be coordinated with antagonist activity (Figures D5a,b). This coordinated effort will be seen again throughout these data.

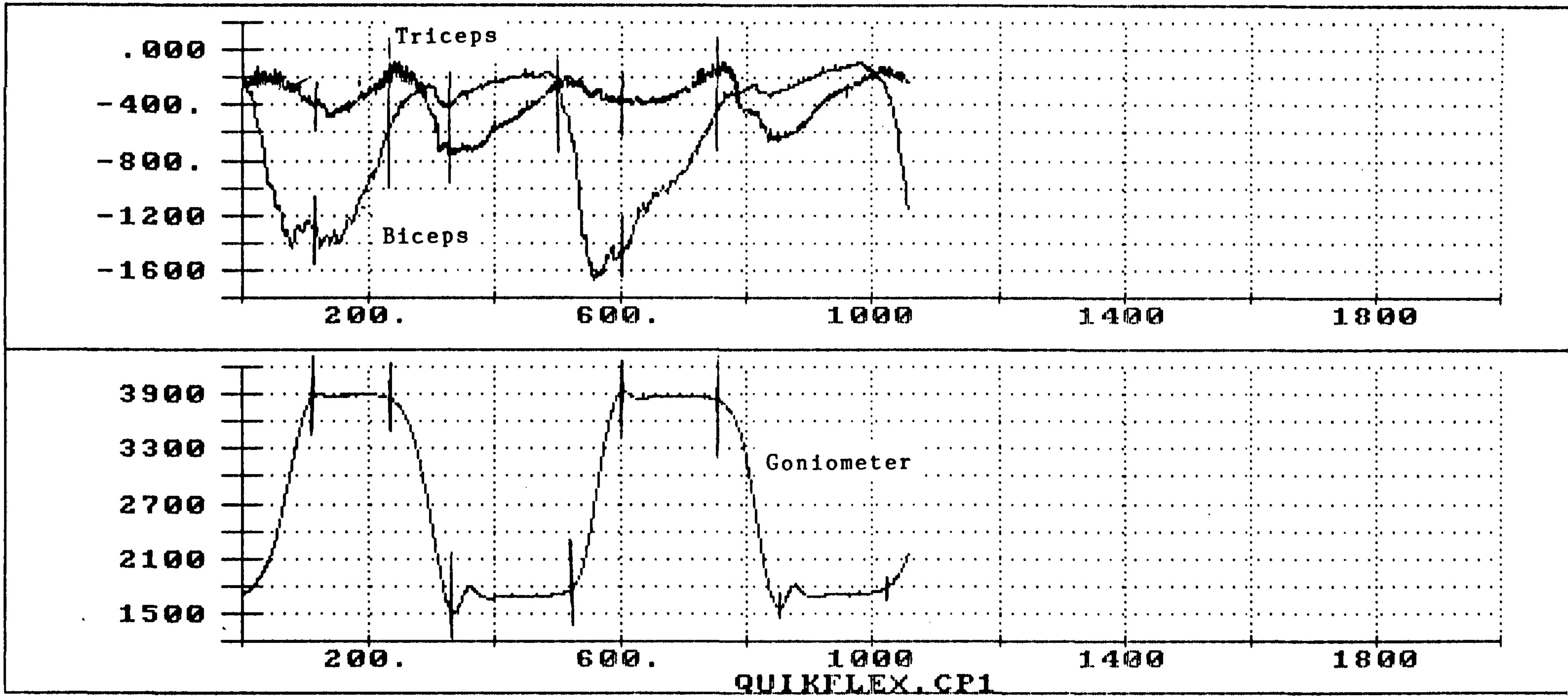


Figure D5a. ELBOW FLEXION & EXTENSION - QUICK ACCELERATED MOVEMENT WITH HELD POSITION
Robot Movement in the Sagittal Plane

MOVEMENT SPEED: Fast SAMPLING RATE: 333 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

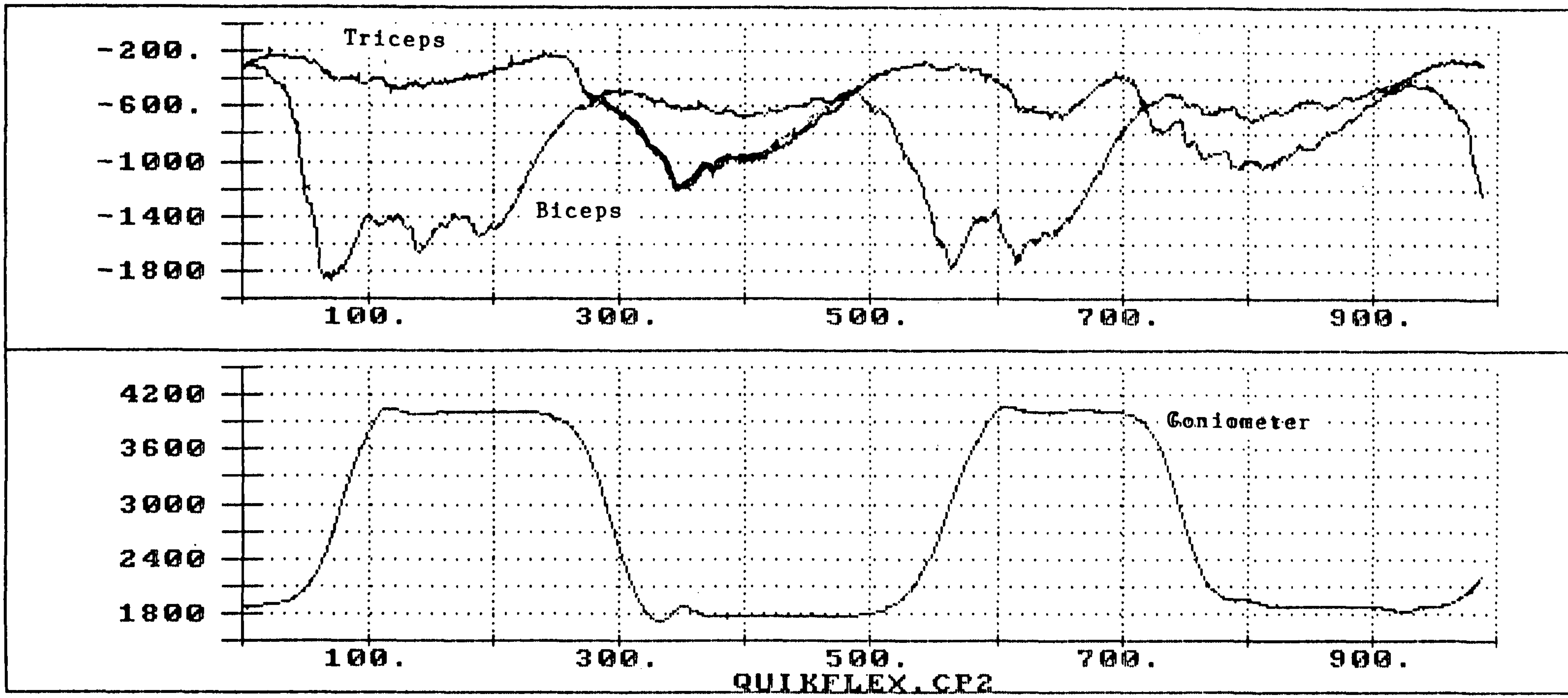


Figure D5b. ELBOW FLEXION & EXTENSION - QUICK ACCELERATED MOVEMENT WITH HELD POSITION
Robot Movement in the Sagittal Plane

MOVEMENT SPEED: Fast SAMPLING RATE: 333 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

1.1.3 Elbow Flexion/Extension; Transverse Plane

Special conditions: With and without cocontraction

Phases I & II EMG: biceps brachii and triceps brachii

Phase I description: Upper arm was abducted 60°-80° from FAP. Elbow was placed coincident with the axis of rotation of a mechanical arm which moved in the transverse plane. A light grasp was maintained on the handle at the distal end of the mechanical arm, resulting in a supinated forearm position. Movement was initiated from a 90° elbow position; the forearm was extended to approximately 120° and returned to the starting position.

Phase II description: The same as Phase I except the movement began from an extended forearm position (elbow angle = 130°). The forearm was flexed to form a 30° angle with the humerus and then returned to the starting position.

Phase I figures: D6 a,b,c; no cocontraction: D7 a,b,c; cocontraction; D8 a,b; cocontraction. Top strip chart (7Z) = displacement representing a change in elbow angle. Peaks (e.g. 500 mm) indicate maximum flexion; valleys (e.g. 250 mm) indicate maximum extension. Second strip chart (1A) = EMG recording from the triceps. Third strip chart (2A) = EMG recording from the biceps.

Phase II figures: D9 a,b,c; D10 a,b,c; D11 a,b,c; cocontraction. EMG data from the biceps and triceps is displayed in D9b, D10b, D11b and the top graphs of D9a, D10a, and D11a. Displacement representing a change in the elbow angle (peaks indicate maximum flexion; valleys indicate maximum extension) is displayed in D9c, D10c, D11c and the bottom graphs of D9a, D10a, and D11a.

Observations:

Phase I: The triceps is the agonist for extension and in the transverse plane acts as the prime mover. EMG activity rose (1A) during extension, leveled off at peak extension, and slowly declined as the forearm was slowed and ultimately reversed by the biceps (2A). Triceps activity reliably, coincided with the extension movement phase.

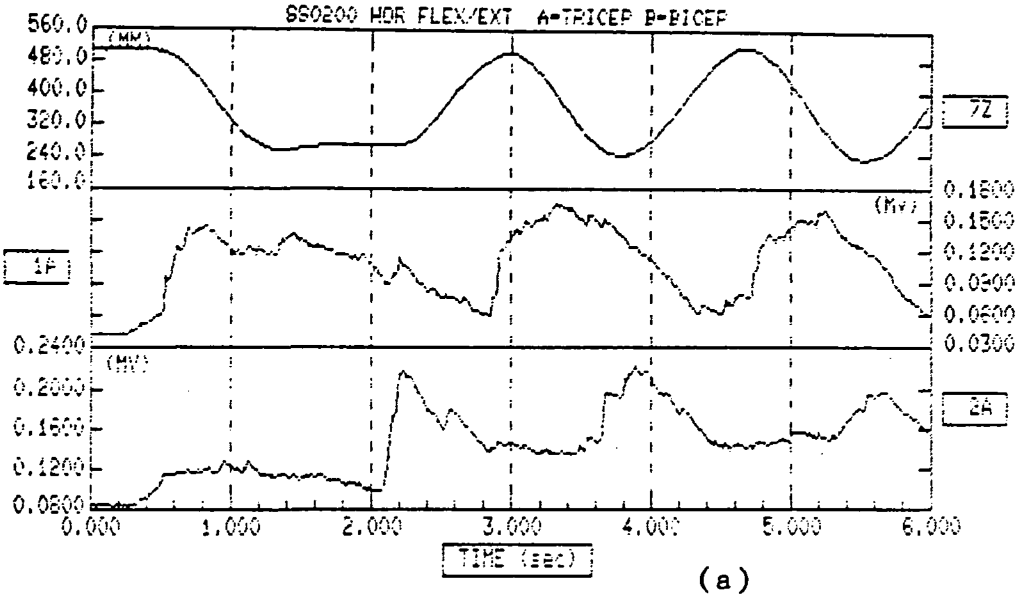
The biceps is the agonist for flexion. During the initial extension phase, biceps activity would not necessarily be expected. The low-level biceps activation observed may have been induced by a passive stretch resulting from the act of extension. A steep rise in biceps activity was expected prior to full extension as biceps activation is required to slow extension and reverse forearm direction. The greatest biceps activation was observed coincident with forearm reversal (Figures D6a,b,c).

Although the triceps and biceps showed the expected phase relationships with the displacement pattern, the EMG patterns showed large variations from trial to trial.

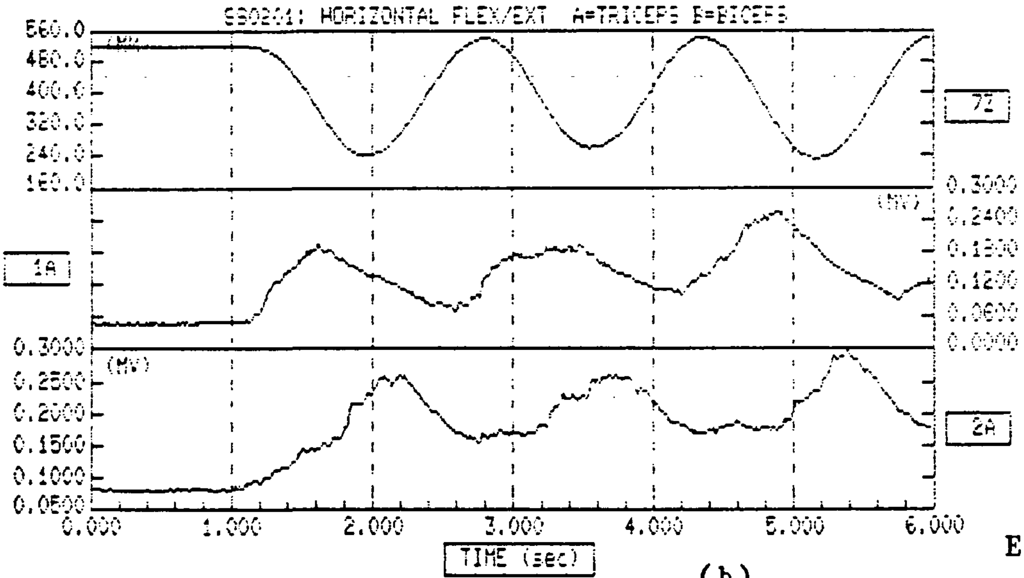
Trials performed under conditions of cocontraction (Figures D7a,b,c, D8a,b) showed no significant change in the EMG phase relations. The baseline level of EMG was somewhat elevated and variability from trial to trial persisted.

Phase II: Data collected on the same transverse plane elbow flexion/extension task during Phase II was quite different than that collected during Phase I. Bicep activity did increase with forearm flexion and decrease with forearm extension (Figures D9, D10, D11). However, tricep activity appeared to be unrelated to elbow extension, even in the trial involving cocontraction.

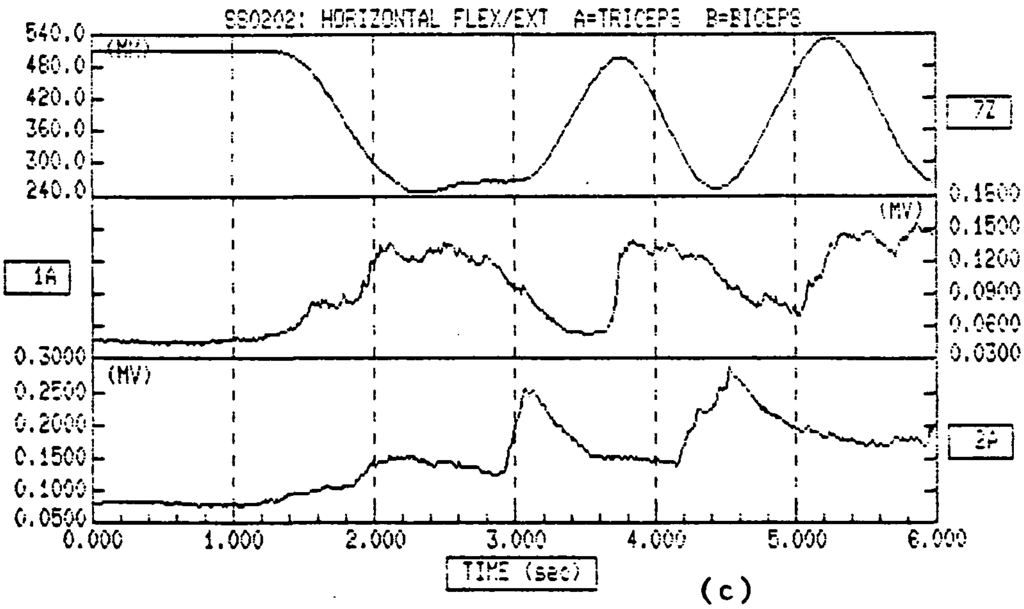
The lack of relationship between tricep activity and elbow extension may have been related to the sampling rate (i.e. 40 samples/second). Signals need to be sampled at a frequency at least twice as great as the highest frequency in the sampled signal (Winter, 1979). If the sampling rate is too slow, aliasing errors produce a false signal. For these data, any frequency greater than 20 Hz. was not adequately represented in the EMG record. Thus, the data from Phase II demonstrated that sampling rate must be selected in accordance with the range of potential signal frequencies to be detected. Violation of this principle would result in inadequate limb control.



(a)

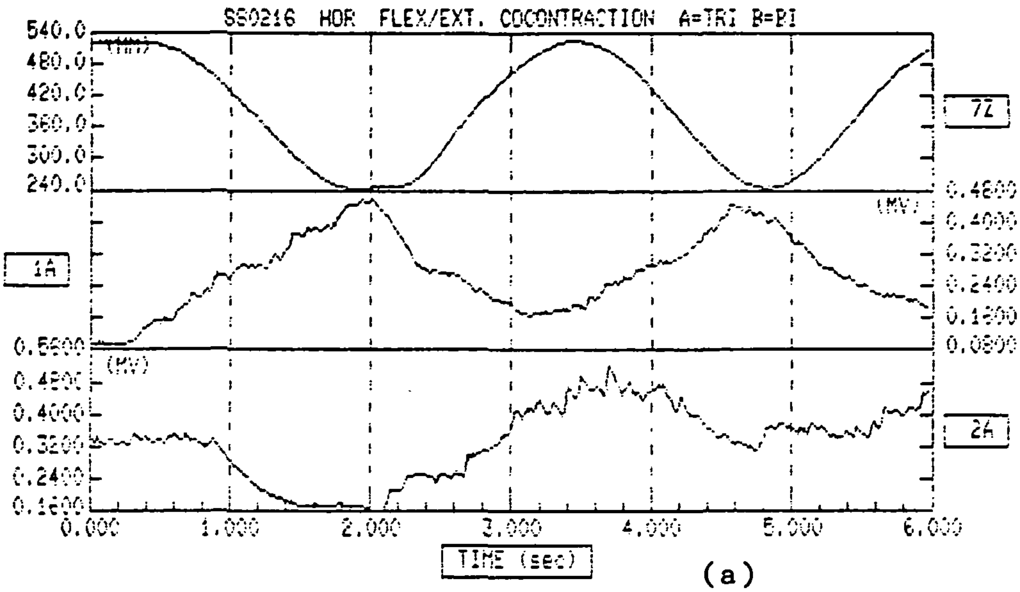


(b)



(c)

Figure D6.
Elbow flexion/extension
in the transverse plane.



(a)

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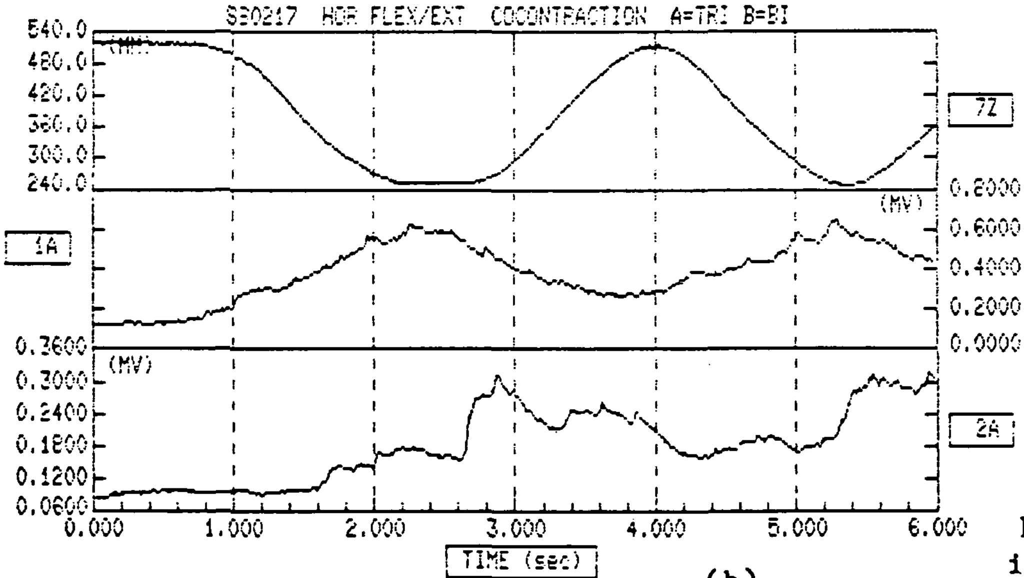
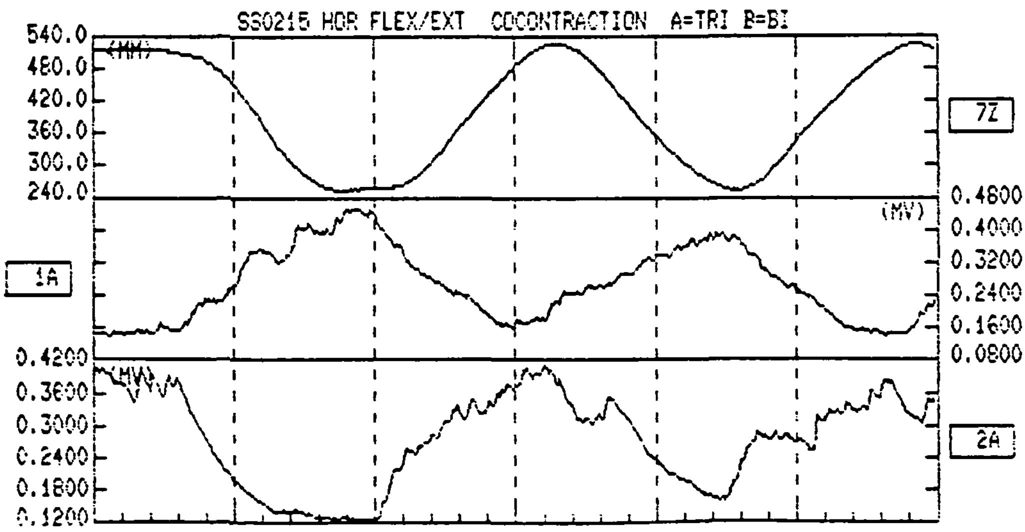
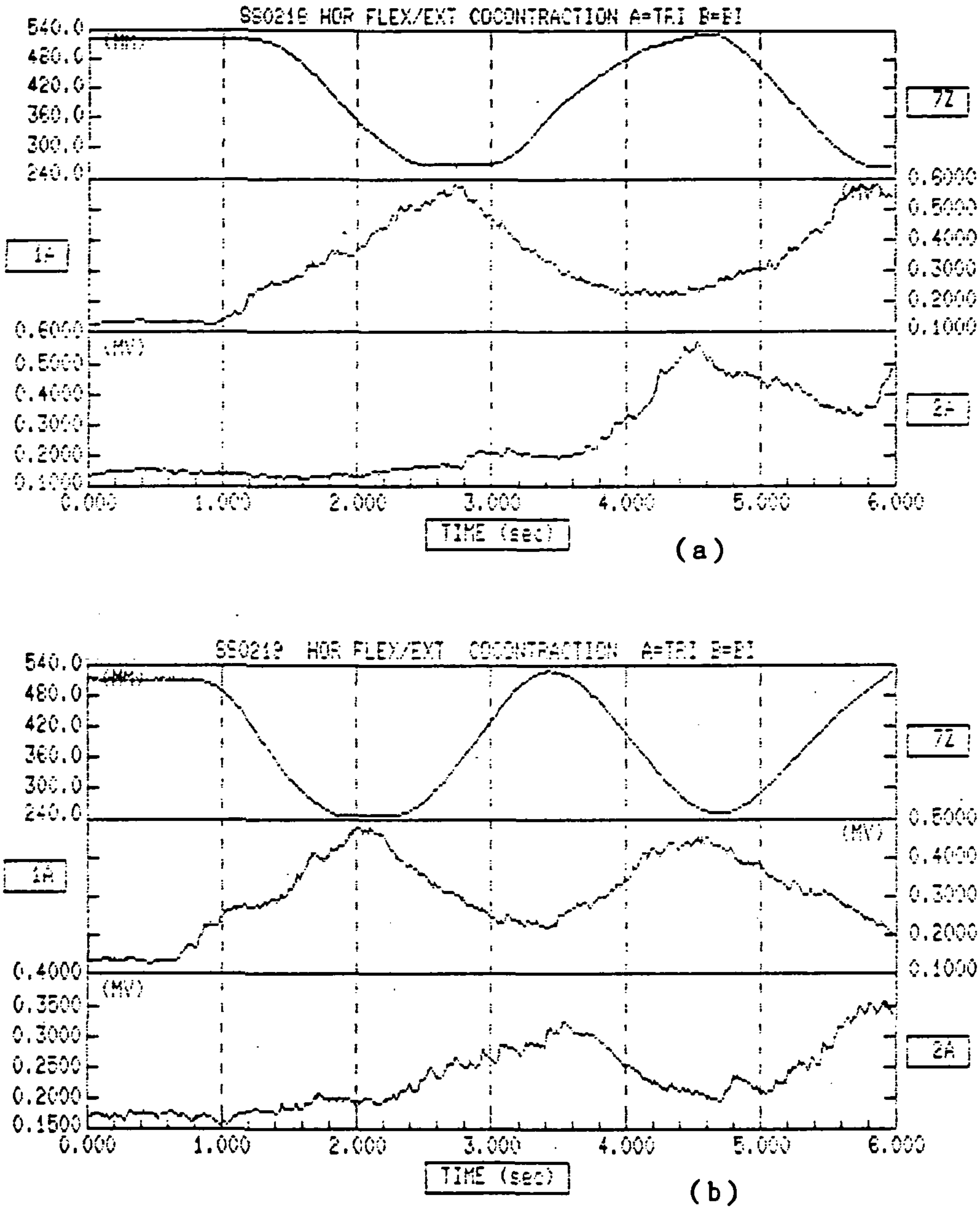


(b)

Figure D7.
Elbow flexion/extension in the transverse plane.



(c)



<u>Figure D8.</u> **Elbow flexion/extension in the transverse plane.**

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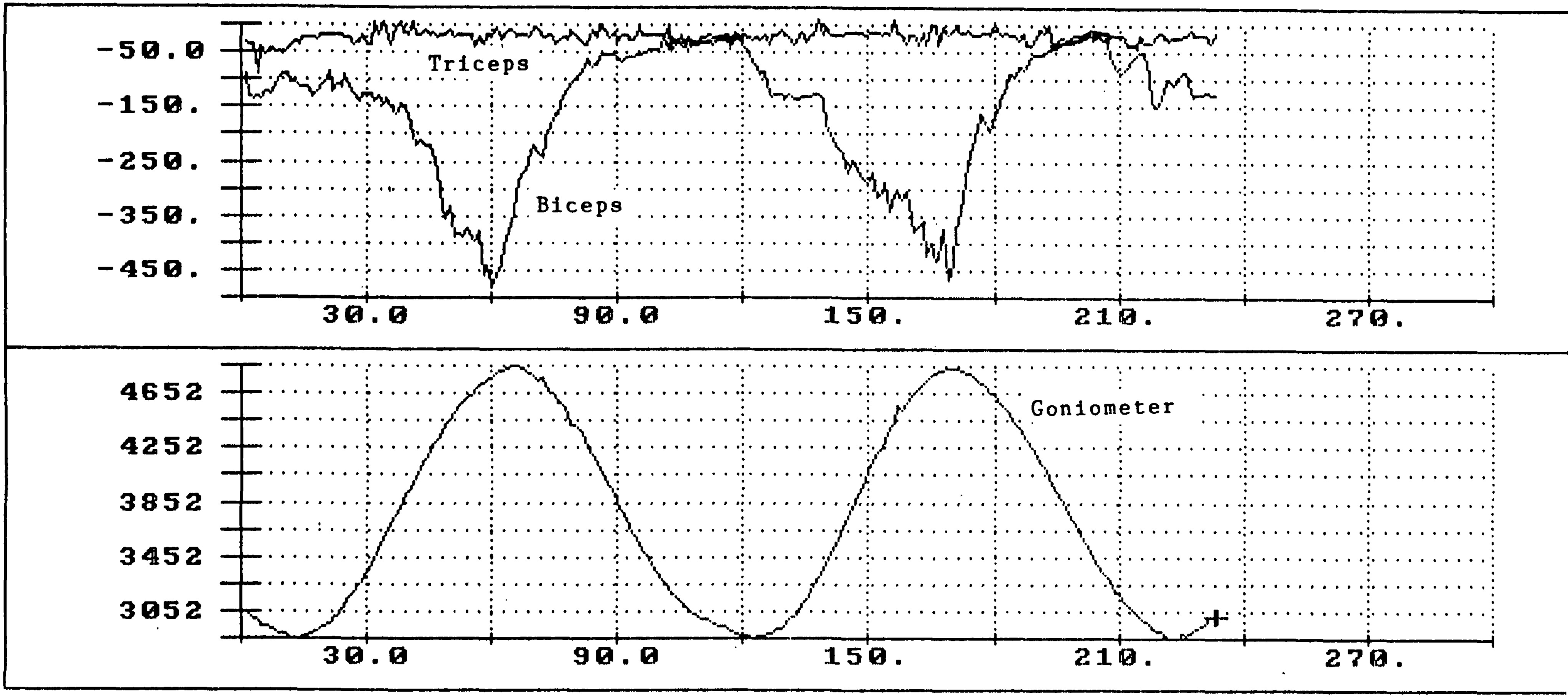


Figure D9a. ELBOW FLEXION & EXTENSION IN THE TRANSVERSE PLANE

MOVEMENT SPEED: Medium SAMPLING RATE: 40 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

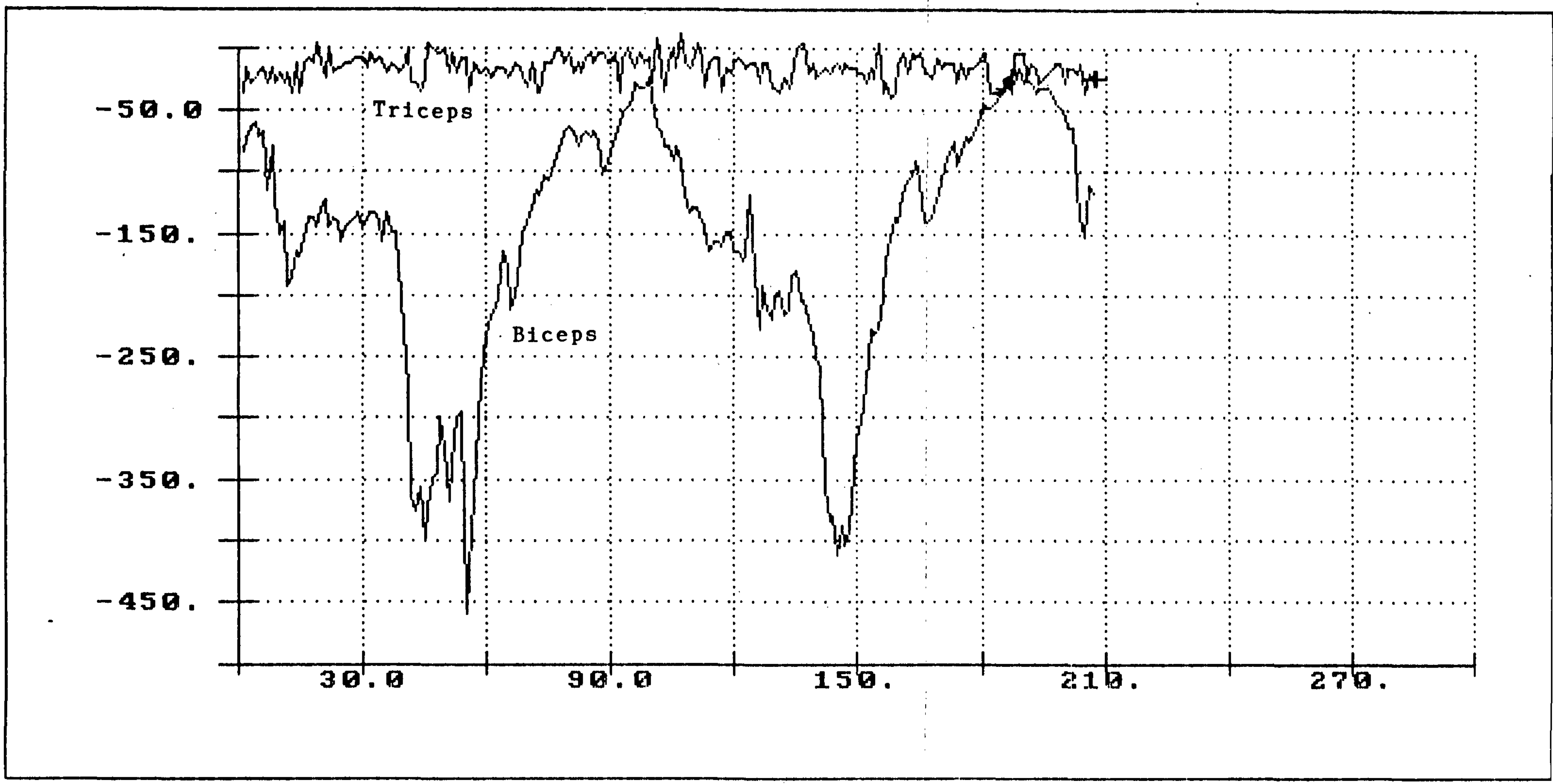


Figure D9b. ELBOW FLEXION & EXTENSION IN THE TRANSVERSE PLANE

MOVEMENT SPEED: Medium SAMPLING RATE: 40 Samples/Sec/Channel

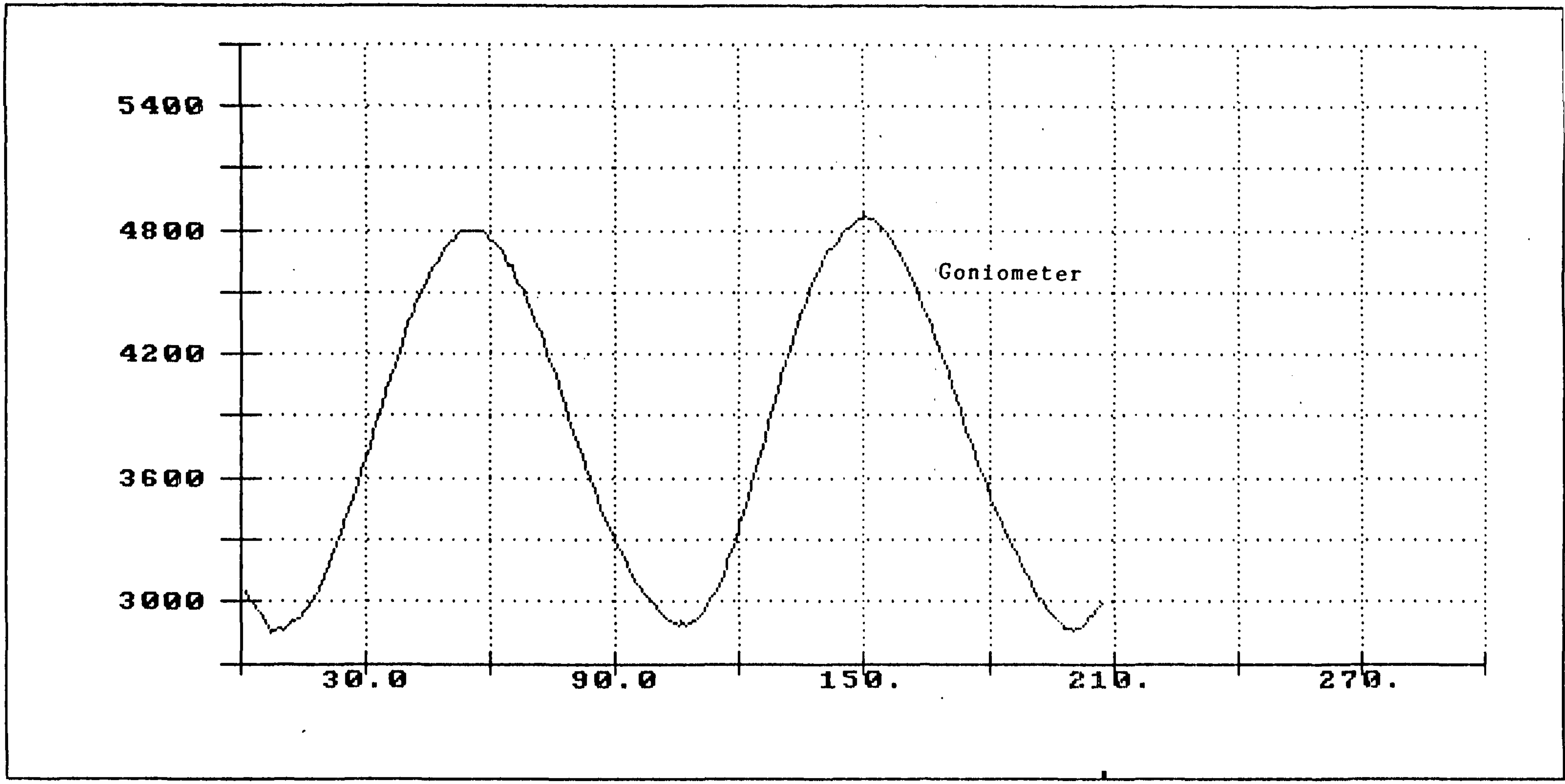


Figure D9c. **ELBOW FLEXION & EXTENSION IN THE TRANSVERSE PLANE**

MOVEMENT SPEED: Medium SAMPLING RATE: 40 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

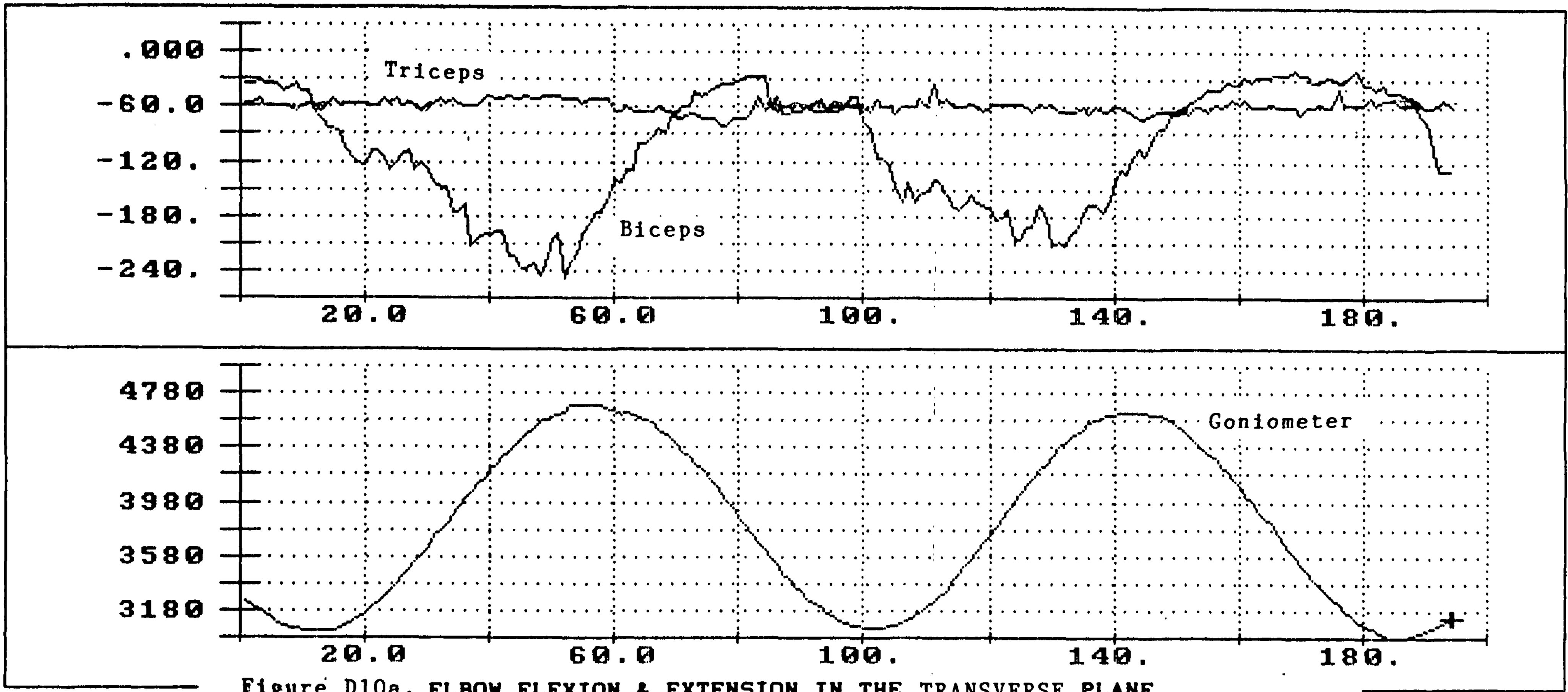


Figure D10a. ELBOW FLEXION & EXTENSION IN THE TRANSVERSE PLANE

MOVEMENT SPEED: Medium SAMPLING RATE: 40 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

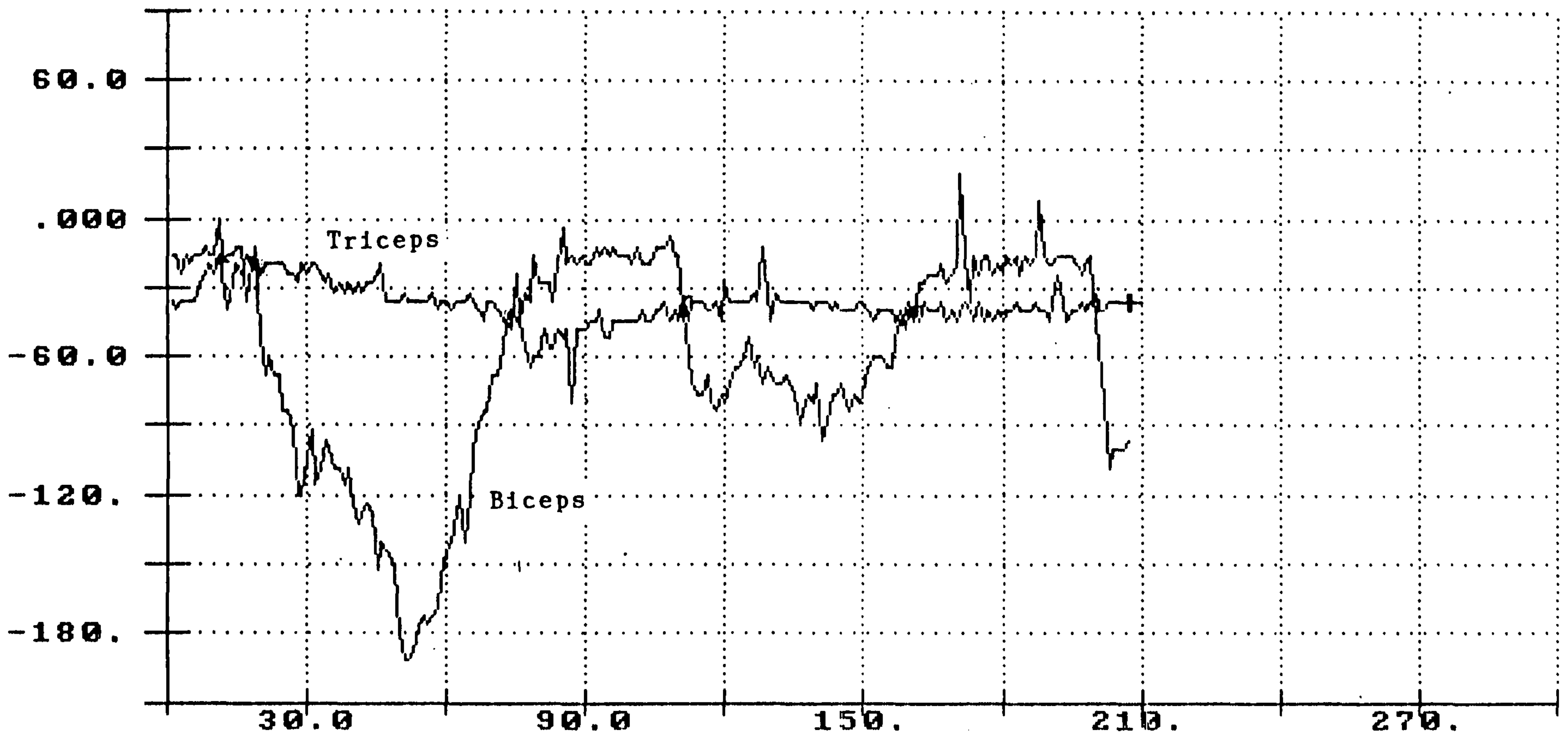


Figure D10b. ELBOW FLEXION & EXTENSION IN THE TRANSVERSE PLANE

MOVEMENT SPEED: Medium SAMPLING RATE: 40 Samples/Sec/Channel

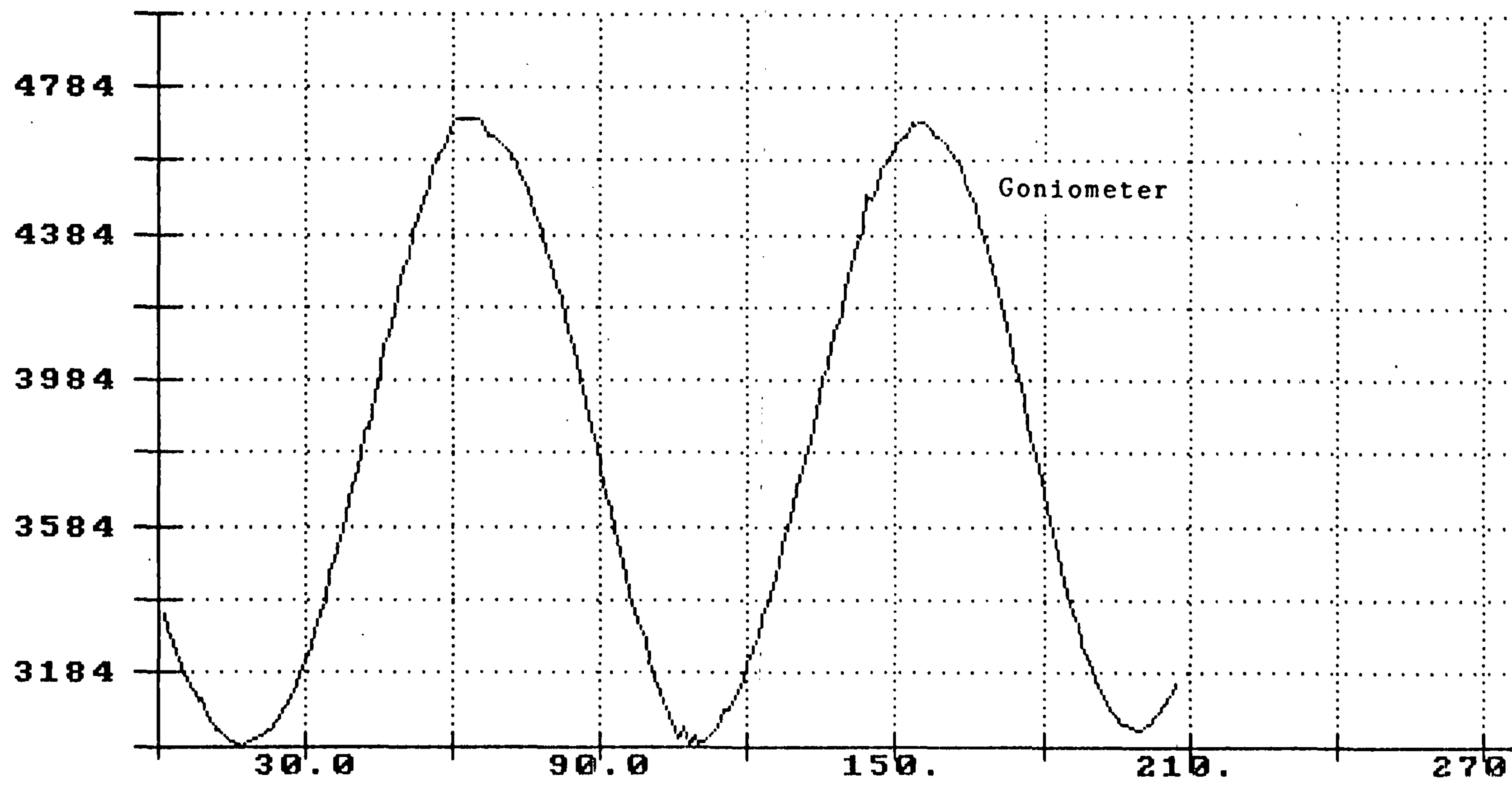


Figure D10c. ELBOW FLEXION & EXTENSION IN THE TRANSVERSE PLANE

MOVEMENT SPEED: Medium SAMPLING RATE: 40 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

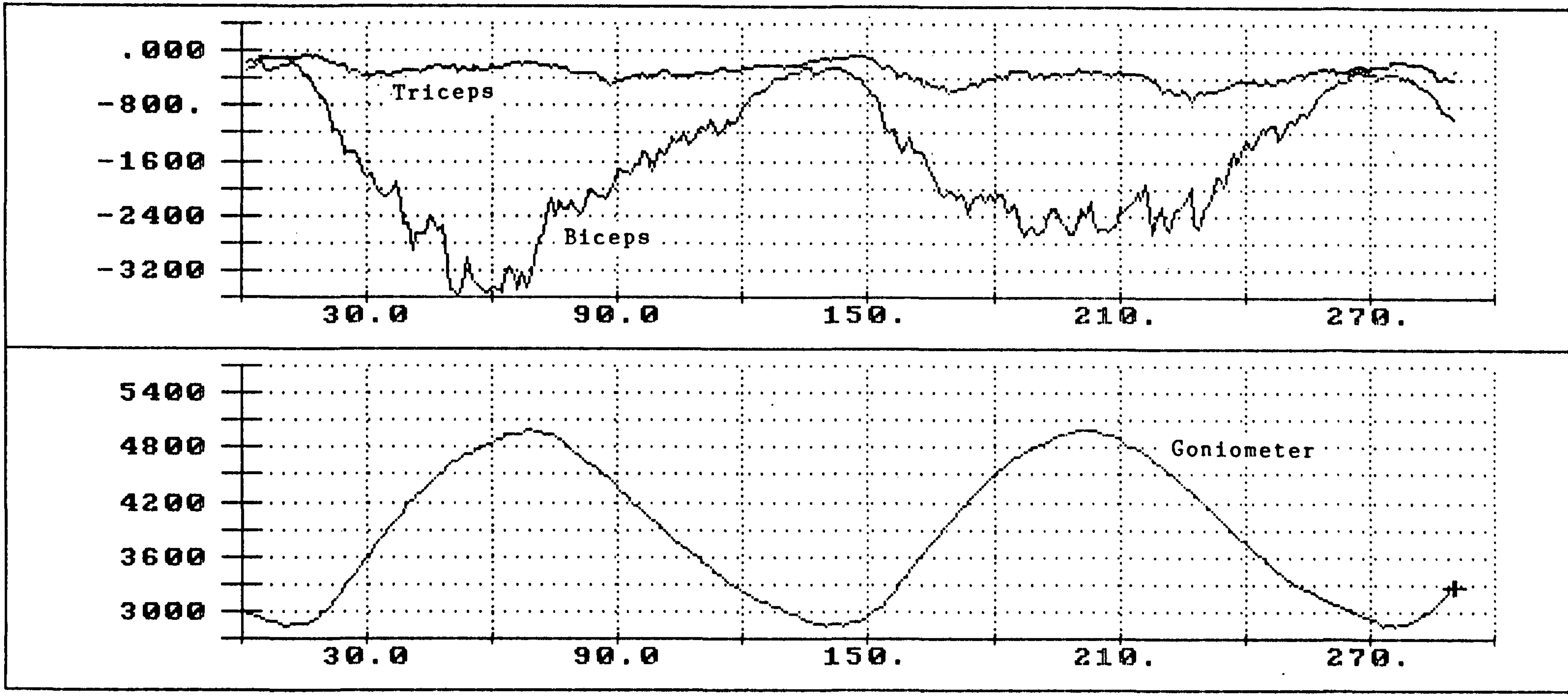


Figure D11a. **ELBOW FLEXION & EXTENSION IN THE TRANSVERSE PLANE with Cocontraction**

MOVEMENT SPEED: Medium SAMPLING RATE: 40 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

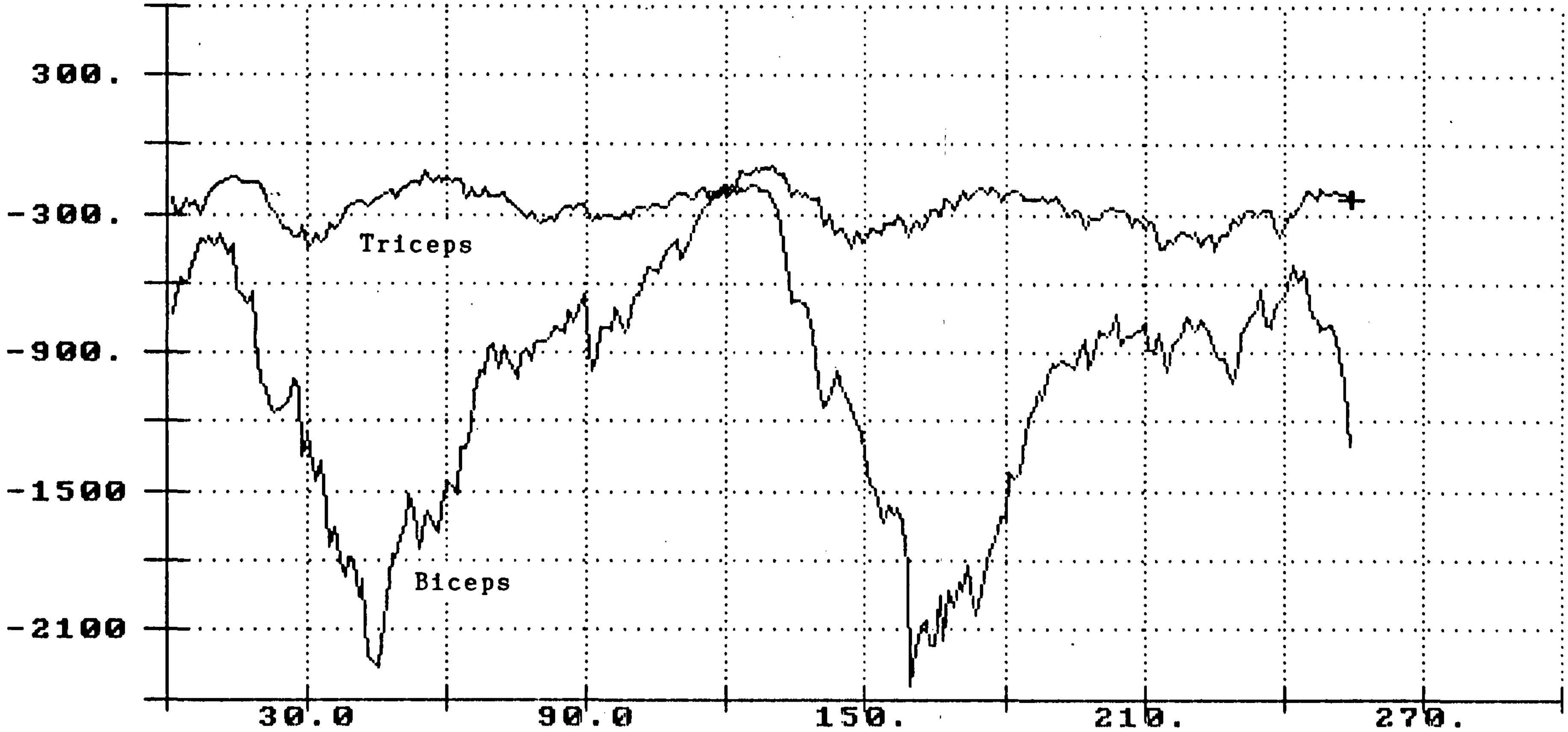


Figure D11b. **ELBOW FLEXION & EXTENSION IN THE** TRANSVERSE **PLANE with Cocontraction**

MOVEMENT SPEED: Medium SAMPLING RATE: 40 Samples/Sec/Channel

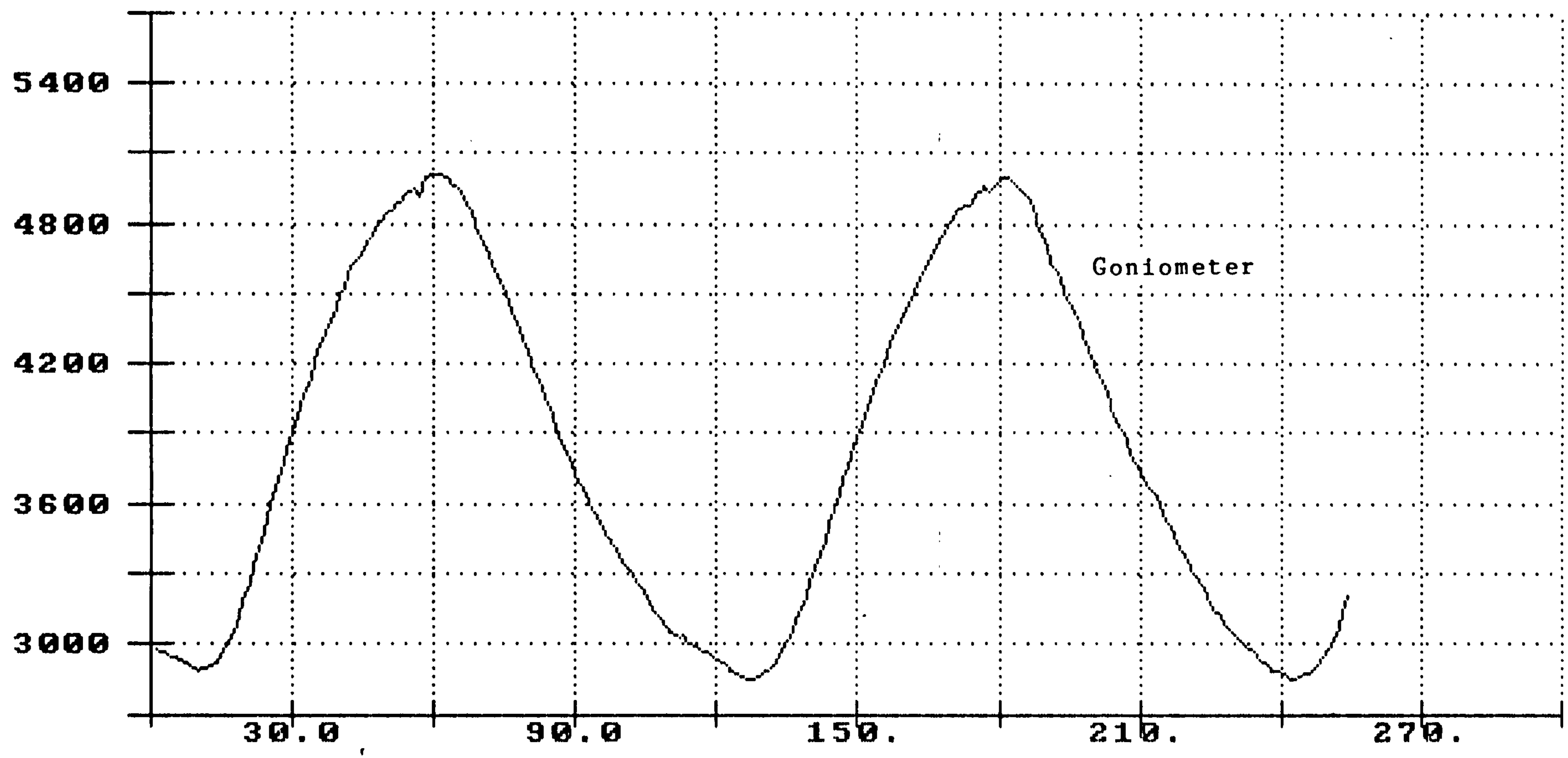


Figure D11c. ELBOW FLEXION & EXTENSION IN THE TRANSVERSE PLANE with Cocontraction

MOVEMENT SPEED: Medium SAMPLING RATE: 40 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

1.1.4 Elbow Flexion/Extension; Transverse Plane

Special conditions: Slow and moderate speeds (Phase I only)

EMG: biceps brachii and triceps brachii

Description: Upper arm was abducted 60°-80° from FAP (fundamental anatomical position). Elbow was placed co-incident with the axis of rotation for a mechanical arm which moved in the transverse plane. A light grasp was maintained on the handle at the distal end of the mechanical arm, resulting in a supinated forearm position. Movement was limited to an approximate 30° range. Two speeds were assessed: (1) approximately 80° /second (slow), (2) approximately 140° /second (moderate).

Figures: D12 a,b,c.
Top strip chart (8Y) = displacement representing a change in elbow angle. Peaks (e.g. 400 mm) indicate maximum flexion; valleys (e.g. 80 mm) indicate maximum extension. Second strip chart (1A) = EMG recording from the biceps. Third strip chart (2A) = EMG recording from the triceps.

Observations:

At slow speeds, EMG activity was less distinctive. Although the triceps continued to bear good phase relations with extensor movements, biceps activity was less definitive (Figures D12a,b). At moderate speeds, however, a much more distinctive pattern emerged (Figure D12c). Two points can be made. First, at slow speeds it was biceps activity which appeared quite undifferentiated by movement phase. This lack of a movement related activation pattern may have been due to the difficulty of monitoring the activation of multiple muscles responsible for elbow flexion. Without external resistance, slow-speed flexion may not have required biceps involvement as much as brachialis involvement.

As previously described, monitoring the brachialis was problematic due to its position under the biceps. It was because of this kind of 'load sharing' problem that cocontraction movements were also studied.

The second point to be made is that at moderate speeds, arm reversal from extension to flexion appeared to be controlled by bursts of biceps activity. Rather than continuous activation, the EMG level rose sharply near reversal, and subsided during the flexion phase to a relatively low baseline level by the time of full flexion. The strategy in the moderate speed movement appeared to be one of ballistic control. The EMG burst resulted in reversing the extension, and supplying sufficient torque to allow the flexion movement to continue ballistically. At reversal from flexion to extension, a steep rise was seen in triceps activity, but with more slowly declining EMG levels over the course of the extension. The extension phase, though no different in duration from flexion, showed a more continuous EMG activation in the triceps.

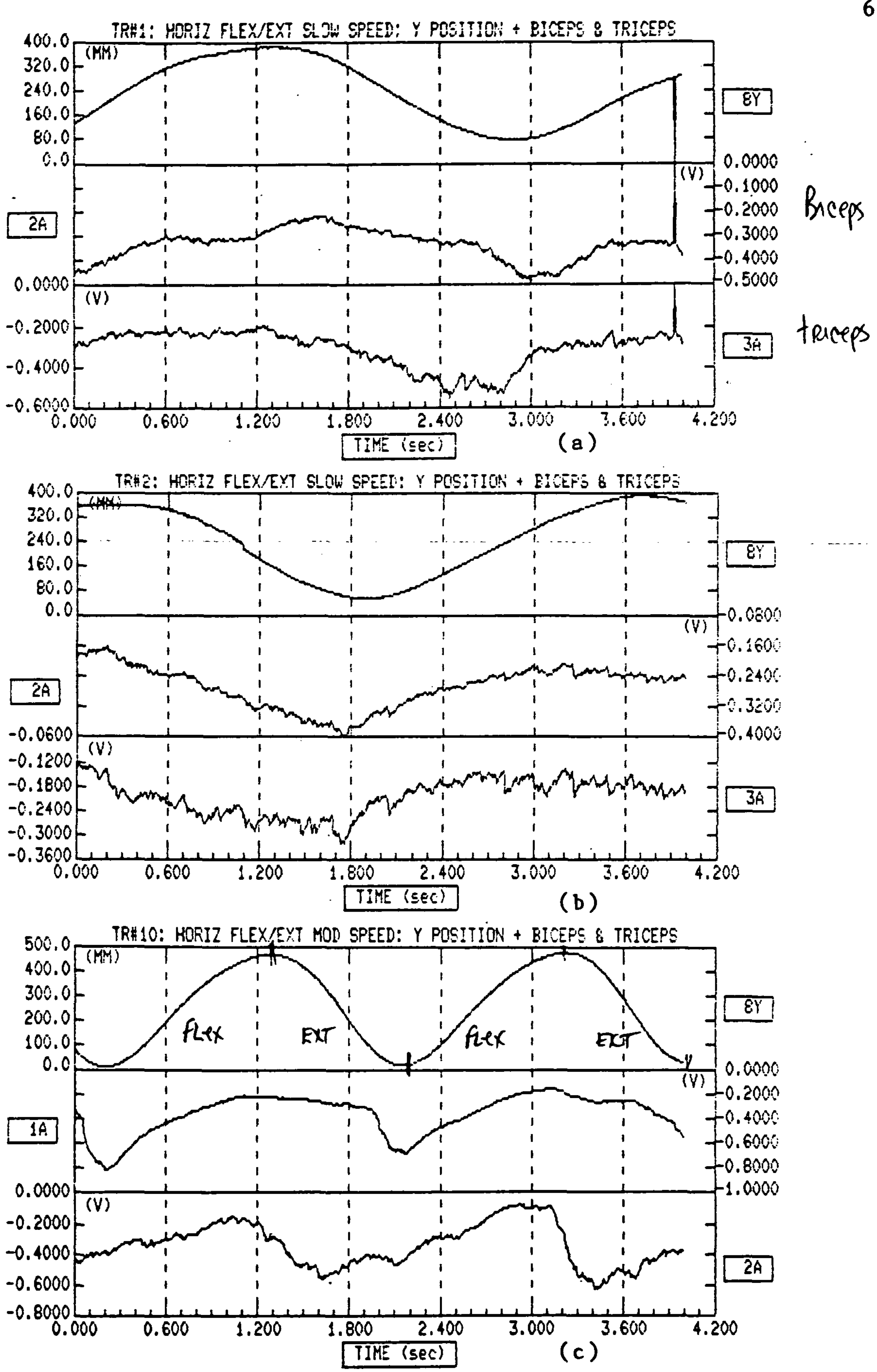


Figure D12. Elbow flexion/extension in the transverse plane.

Humeral Movement-Shoulder Joint Complex

2.0 Anatomical Considerations

Movement at the shoulder is the result of integrated action among four articulations: (1) glenohumeral, (2) sternoclavicular, (3) acromioclavicular, and (4) scapulothoracic (Inman, Saunders, & Abbot, 1944; Engin, 1980). The glenohumeral articulation was of primary interest in the present study. However, some consideration must be given to the other joints because of the multi-articular muscle involvement and the subsequent effect on obtaining clean data for upper arm movements. Complications arising from the architecture of the shoulder complex will be discussed below.

The glenohumeral articulation is an enarthrodial (ball-and-socket) joint created by the upper arm (humerus) and the scapula. Three degrees of freedom are possible at the glenohumeral joint (Figure 6): (1) flexion/extension in the sagittal plane, about a bilateral axis, (2) abduction and adduction in the frontal plane about a anterior-posterior axis, and (3) internal/external rotation in the transverse plane about a polar (i.e. vertical) axis. Prime movers for each degree of freedom are listed below:

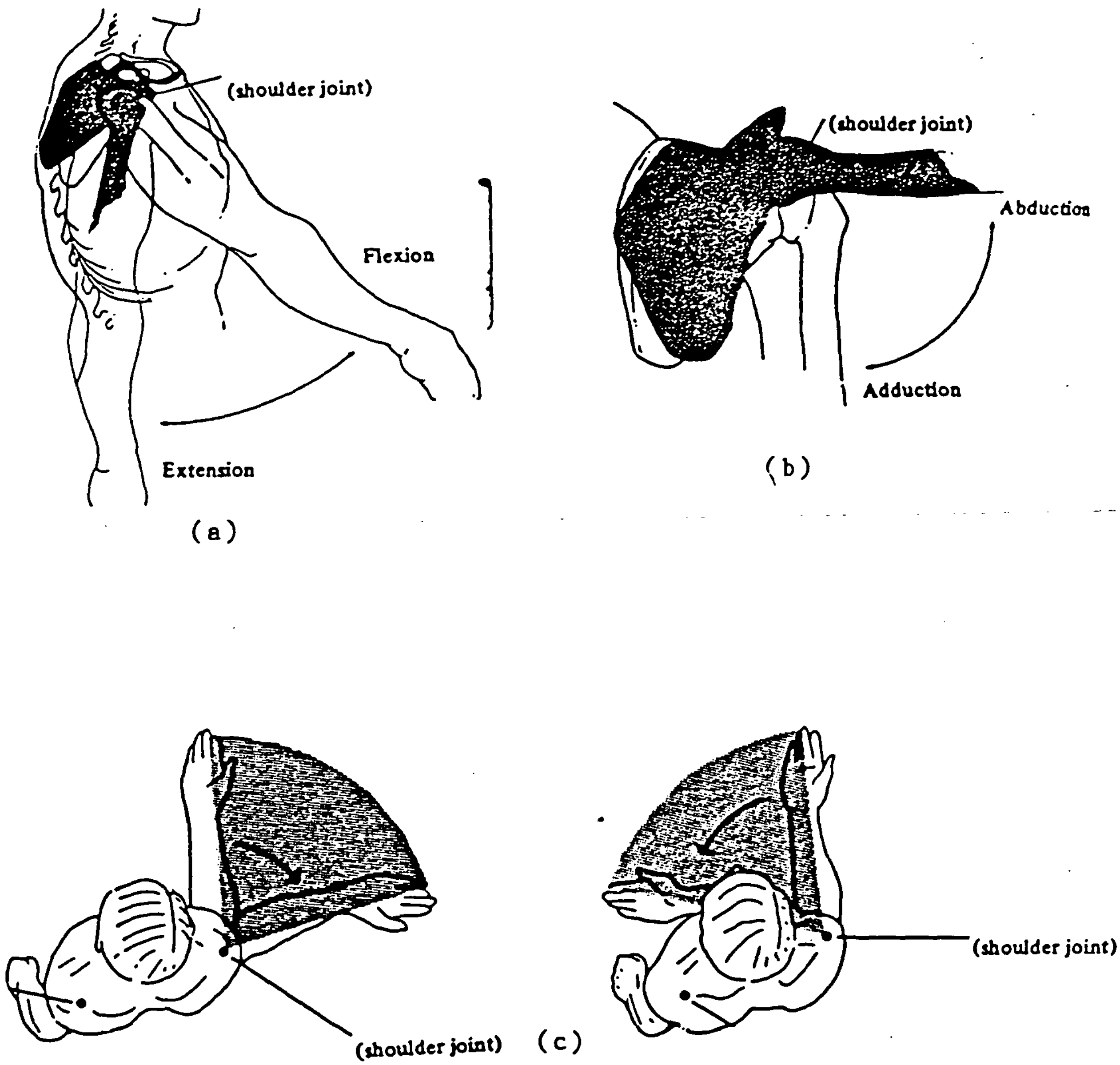


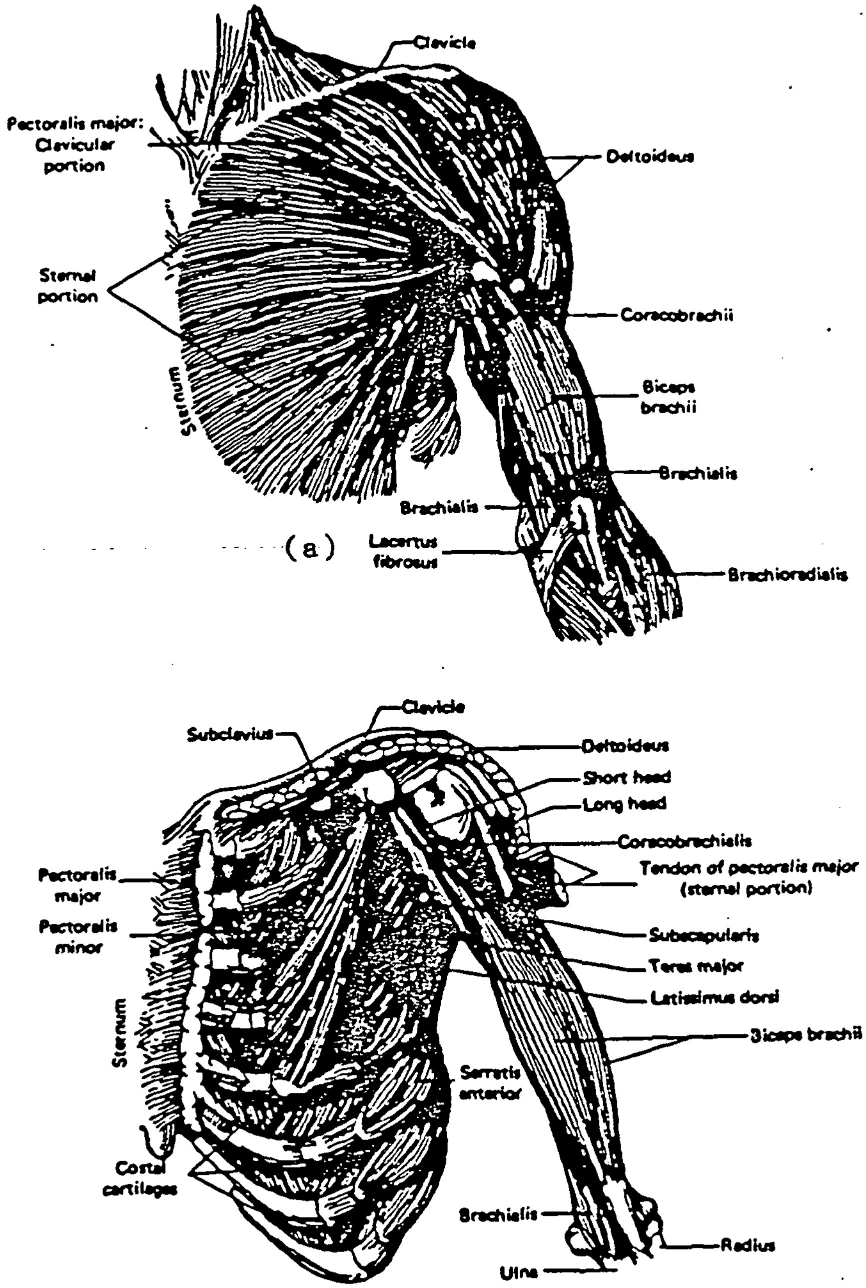
Figure 6. Degrees of freedom at the glenohumeral joint: (a) sagittal plane flexion/extension, (b) frontal plane abduction/adduction, (c) internal external rotation in the transverse plane. (Adapted from Biomechanics: A Qualitative Approach for Studying Human Movement (p. 105, 108, 110) by E. Kreighbaum and K. M. Barthels, Minneapolis: Burgess.)

Action	Prime movers
Flexion	Deltoid (anterior portion) Pectoralis major (clavicular portion) Biceps brachii
Extension (against resistance)	Latissimus dorsi Teres major
Abduction	Deltoid (middle portion) Deltoid (anterior portion) Supraspinatus
Adduction (against resistance)	Latissimus dorsi Teres major
Internal rotation	Deltoid (anterior portion) Subscapularis Teres major
External rotation	Infraspinatus Teres minor
Elevation of the shoulder girdle	Trapezius (parts I & II)

<u>Note.</u> See Figures 8 and 9.

2.0.1 Integrated Movement

In elevation of the humerus, both in flexion and abduction, movement at the glenohumeral joint is accompanied by movement at the scapulothoracic joint. During the first 30°-60° of elevation, movement at the two joints is somewhat individually patterned. Once above 30°-60° ,however, a consistent 2:1 movement relationship between glenohumeral



(a)

(b)

Figure 7. Anterior view of chest and upper arm muscles: (a) superficial muscles, (b) deep muscles. (Adapted from Kinesiology: The Science of Movement (p. 72) by J. Piscopo and J. A. Baley, 1981, New York: Wiley.)

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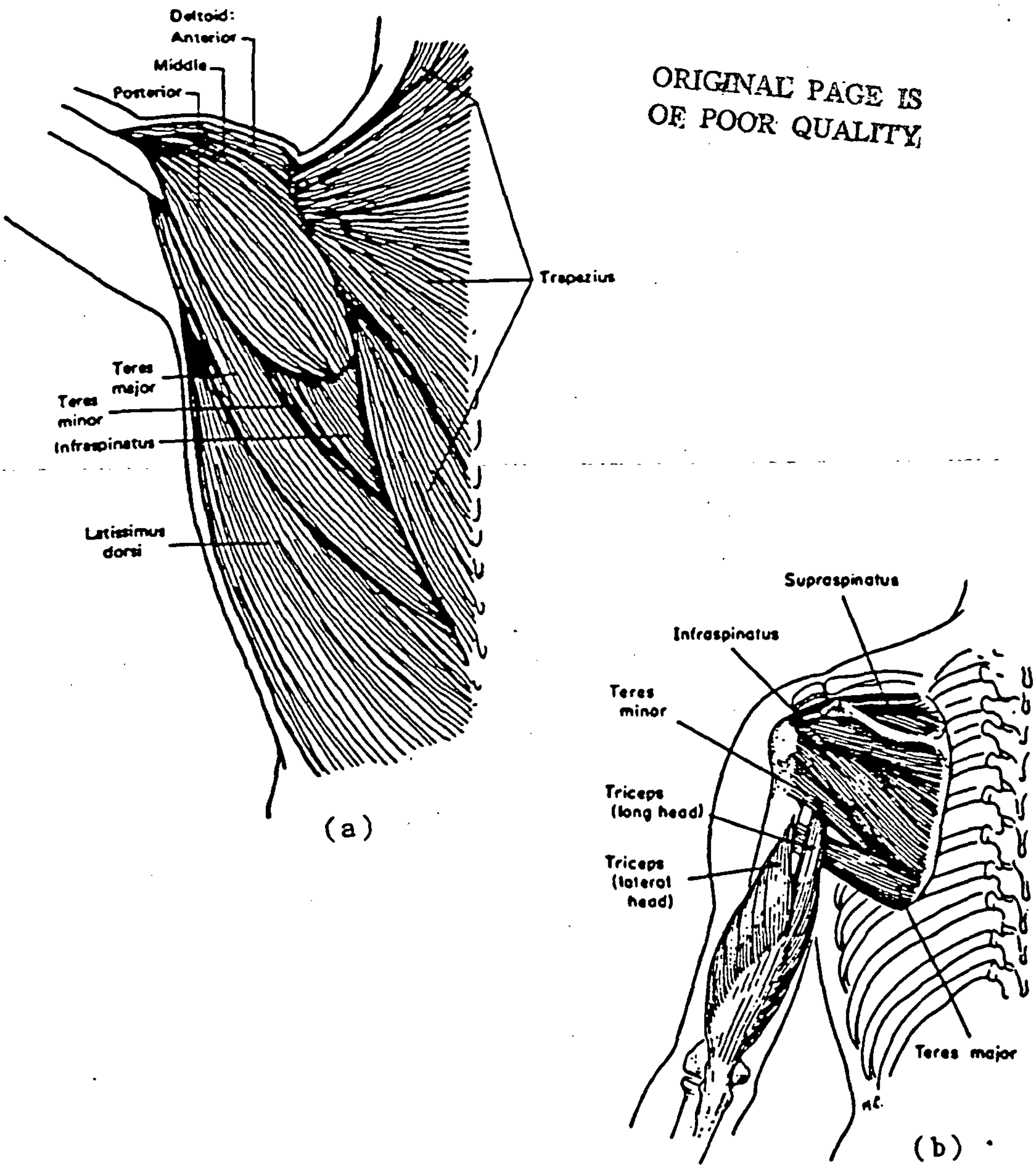


Figure 8. Posterior view of back and upper arm muscles: (a) superficial muscles, (b) deep muscles. ((a) adapted from Kinesiology: The Science of Movement (p. 71) by J. Piscopo and J. A. Baley, 1981, New York: Wiley: (b) Adapted from Kinesiology : Scientific Basis of Human Motion (p. 89) by K. Luttgens and K. F. Wells, 1982, Philadelphia: Saunders.)

and scapulothoracic movement is observed. For every 15° of humeral elevation, 10° is the result of glenohumeral movement; 5° is the contribution of scapular rotation. Because of the multi-articular interactions, isolation of movements for the purpose of recording EMG is difficult. And, in any 'natural' movement, multiple muscle activations occur for the purpose of either executing the intended movement, or stabilizing other articulations in the shoulder complex. Additionally, the superficial vs deep topographical relationship among shoulder-complex muscles increases the difficulty of obtaining clean EMG data from prime movers in certain actions. Examples of this difficulty are addressed in the discussion of specific data sets.

2.0.2 External Force Considerations

As previous described relative to elbow flexion and extension, gravity plays the role of forcing extension and adduction when the limb is flexed or abducted. In this case, extension and adduction are controlled by the eccentric contractions of the humeral flexors and abductors.

2.1 Shoulder Joint Movement Data

2.1.1 Shoulder Flexion/Extension; Sagittal Plane

Phases I & II EMG: biceps brachii and anterior deltoid

Phase I description: Initial position; arm hanging relaxed at the side. The movement was flexion of a straight arm to shoulder level (i.e. 90° angle with the trunk) then extension to return to FAP.

Phase II description: Same as Phase I.

Phase I figures: D13 a,b,c;
Top strip chart (1Y) = displacement representing a change in shoulder angle. Peaks (e.g. 1050 mm) indicate maximum flexion; valleys (e.g. 250 mm) indicate maximum extension. Second strip chart (1A) = EMG recording from the biceps. Third strip chart (2A) = EMG recording from the anterior deltoid.

Phase II figures: D14 a,b,c,d;
EMG data from the anterior deltoid and the biceps are displayed on the top graph of D14a. The bottom graph of D14a shows displacement representing a change in shoulder angle (peaks indicate maximum flexion; valleys indicate maximum extension). EMG data for the anterior deltoid and the corresponding raw data are shown in D14b,c. Shoulder angle displacement data for D14c is shown in D14d.

Observations:

Phase I: The anterior deltoid and the biceps brachii showed similar rising slopes in conjunction with raising the arm. The deltoid is a prime mover in this action. The biceps is a two-joint muscle having some influence on shoulder flexion, but its moment arm does not make it a primary flexor. Nevertheless, a consistent pattern of biceps activity was seen in shoulder flexion.

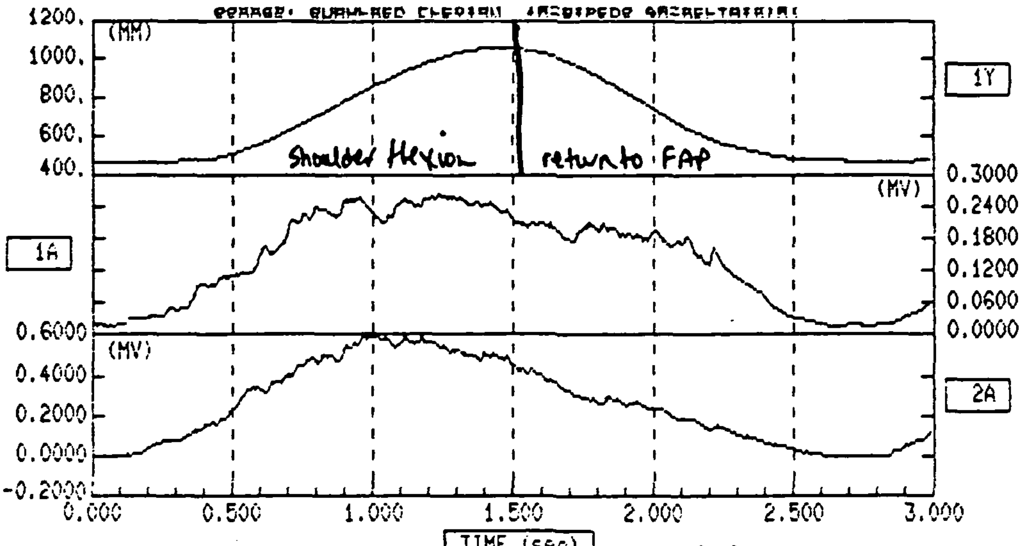
The return from flexion to FAP showed different slopes between the two monitored muscles. The deltoid showed a much closer phase relation with the displacement pattern.

The biceps maintained a relative plateau until extension was almost completed.

Phase II: As in Phase I anterior deltoid activity and bicep activity increased as the arm was raised to shoulder level (Figure D14a). As the arm was returned to FAP the EMG activity slopes of the two monitered muscles appeared similar. The raw EMG data (Figures D14b,c) from the anterior deltoid corresponded well with its processed data.

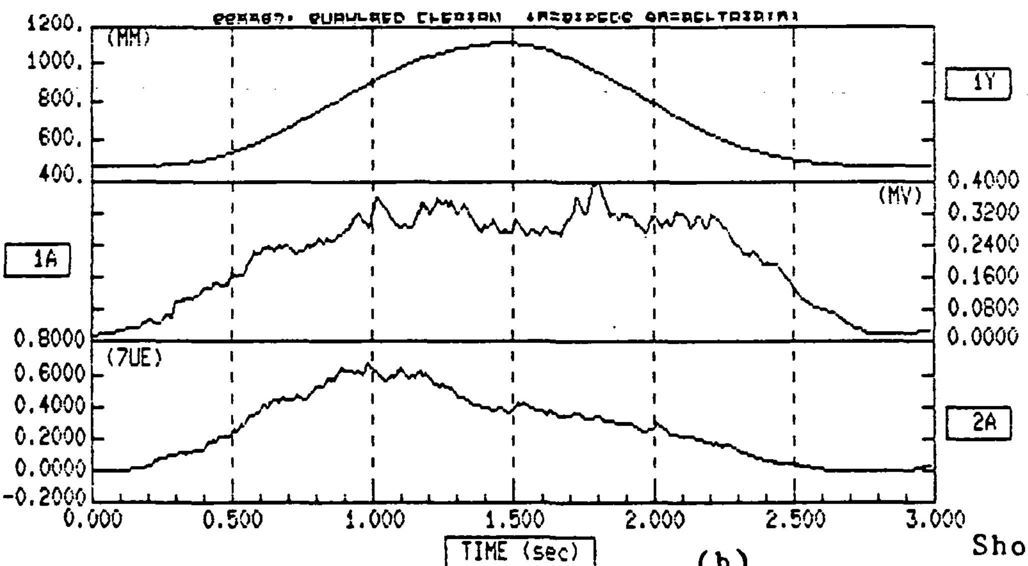
Shoulder Flexion/Extension
EMG = Biceps, Anterior Deltoid

SS0096
Gain 1A = 10
2A = 3



(a)

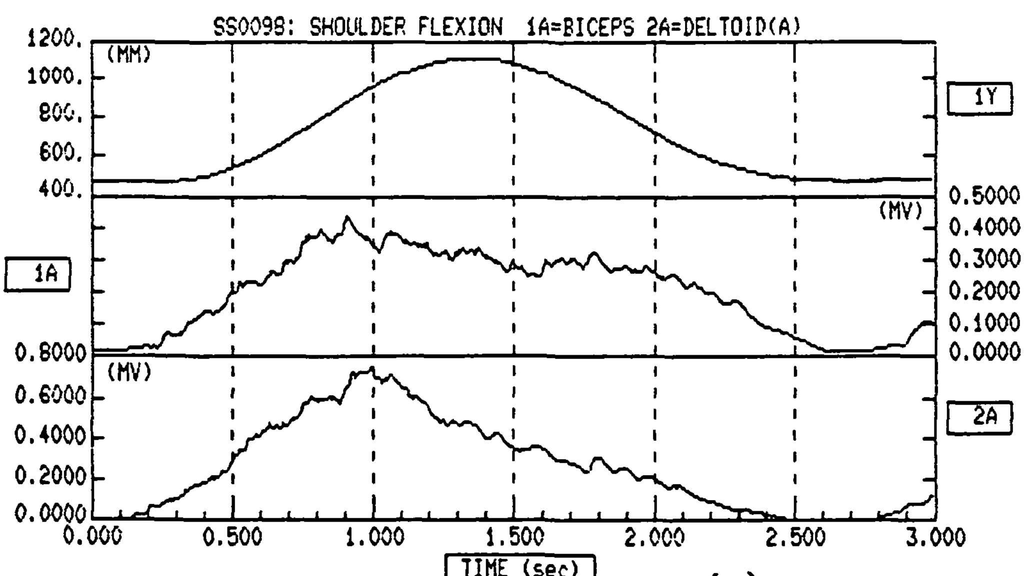
SS0097
Gain 1A = 10
2A = 3



(b)

Figure 13.
Shoulder flexion/extension in the sagittal plane.

SS0098
Gain 1A = 10
2A = 3



(c)

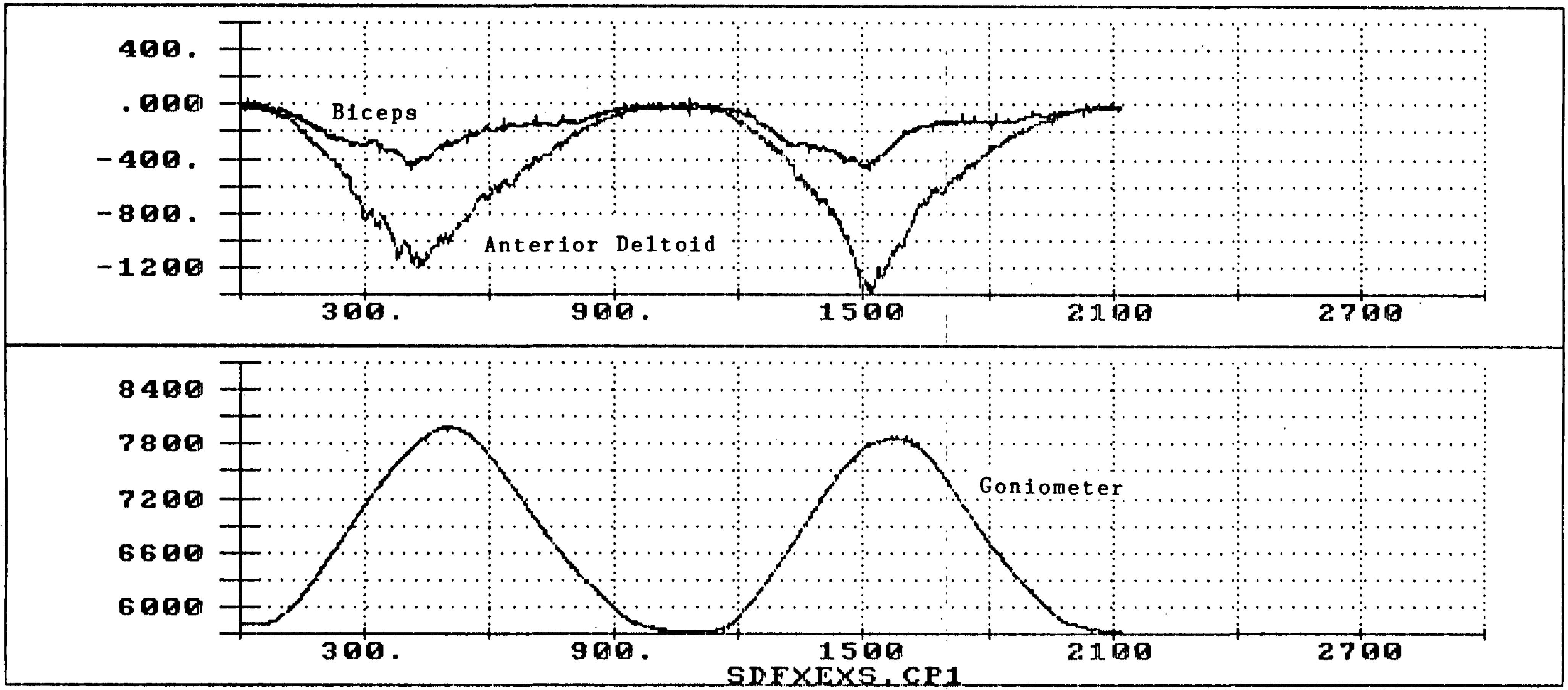
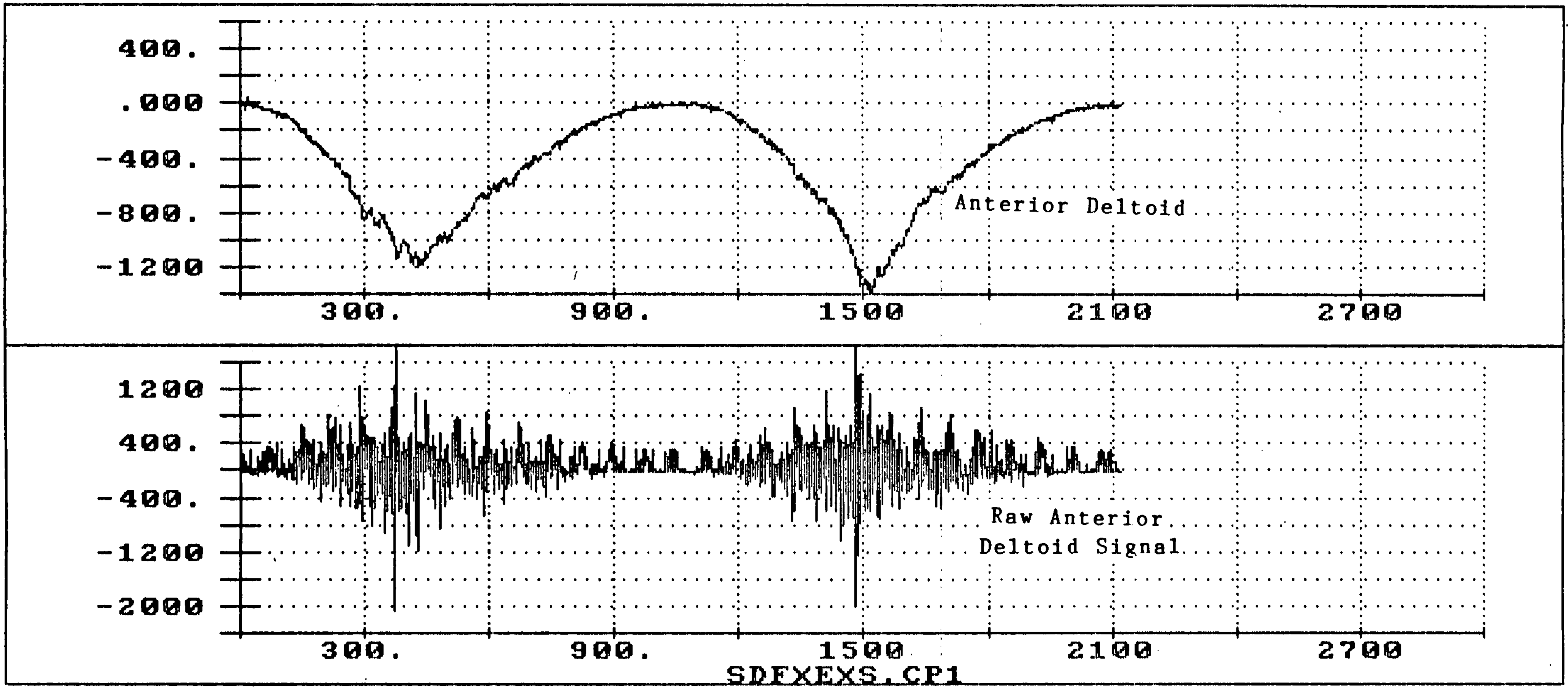


Figure 14a. SHOULDER FLEXION & EXTENSION IN THE SAGITTAL PLANE

MOVEMENT SPEED: Medium SAMPLING RATE: 400 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Flexion
Decreasing Signal Magnitude -- Extension



<u>Figure 14b.</u> SHOULDER FLEXION & EXTENSION IN THE SAGITTAL PLANE

MOVEMENT SPEED: Medium SAMPLING RATE: 400 Samples/Sec/Channel

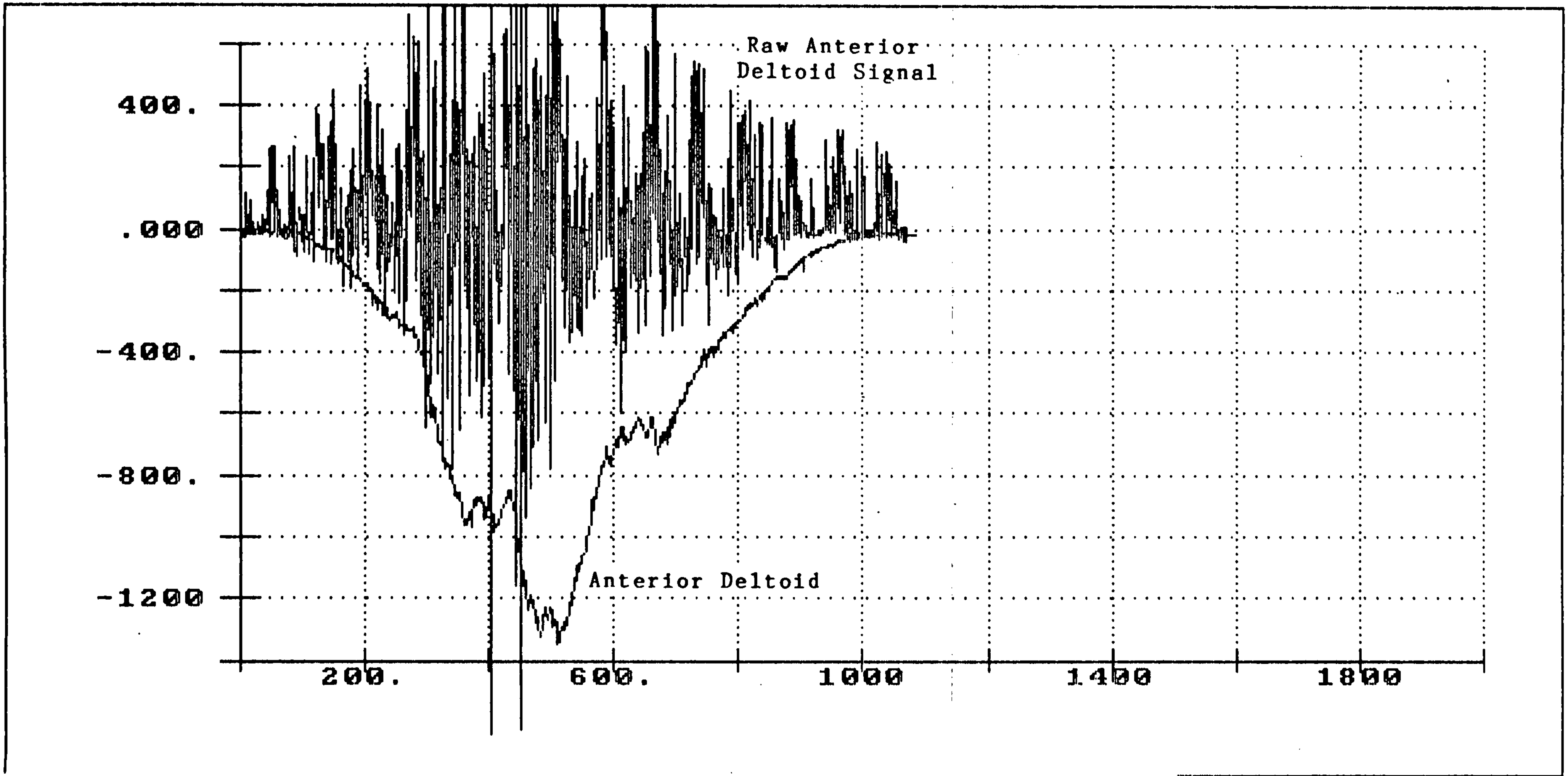


Figure 14c. SHOULDER FLEXION & EXTENSION IN THE SAGITTAL PLANE

MOVEMENT SPEED: Medium SAMPLING RATE: 400 Samples/Sec/Channel

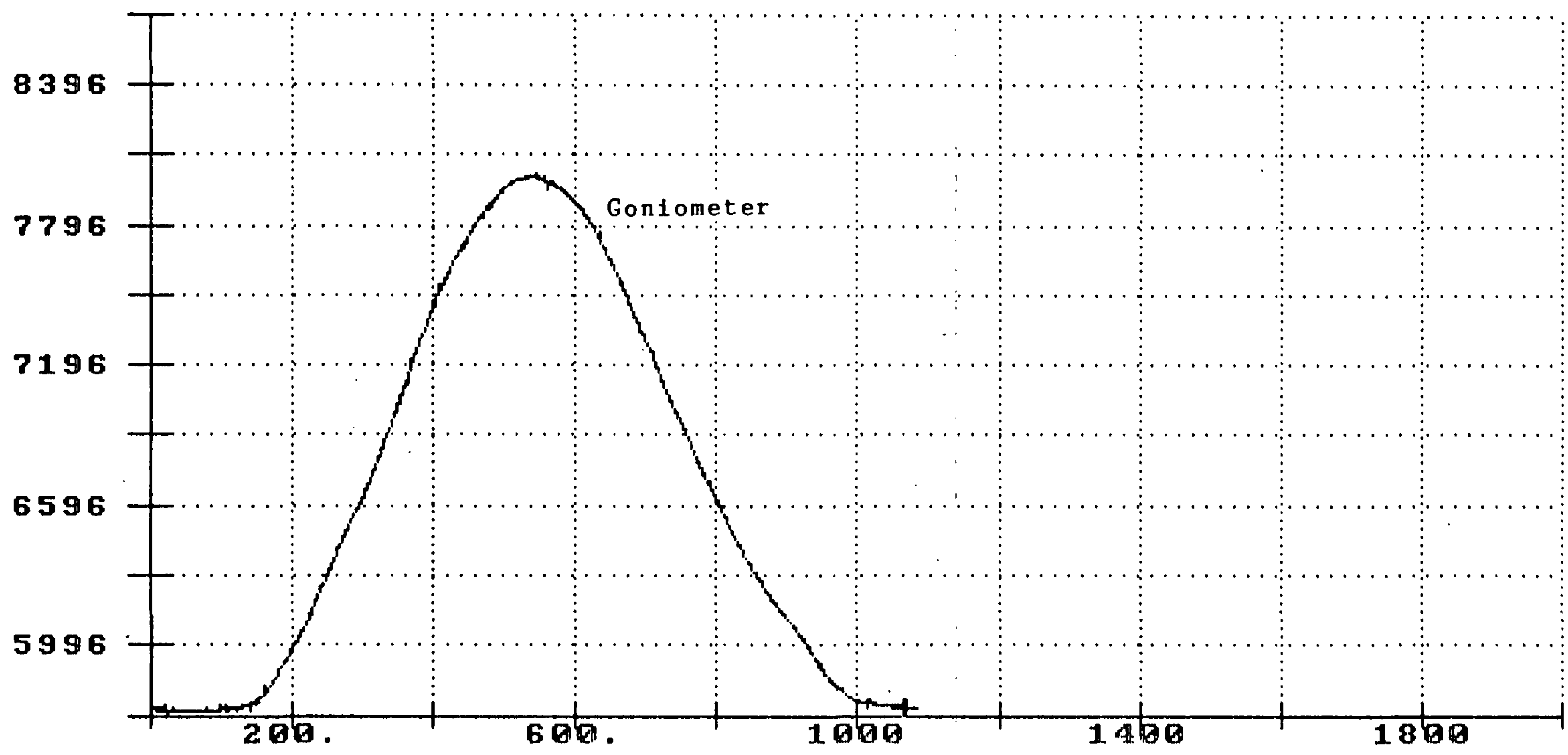


Figure 14d. **SHOULDER FLEXION & EXTENSION IN THE SAGITTAL PLANE**

MOVEMENT SPEED: Medium SAMPLING RATE: 400 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion to Neutral
Decreasing Signal Magnitude -- Elbow Extension

2.1.2 Shoulder Abduction/Adduction; Frontal Plane

Special conditions: Slow (.3 Hz) and fast (1.2 Hz) movements (Phase I only)

EMG: middle deltoid and posterior deltoid

Description: Subject was seated, facing the cameras, with the right arm hanging relaxed at the side. The arm was moved through a 90° ROM. The arm was abducted 90° then returned (adduction) to the starting position. Subjects were asked to perform the movement at two different speeds, slow and fast. The speeds were self-selected.

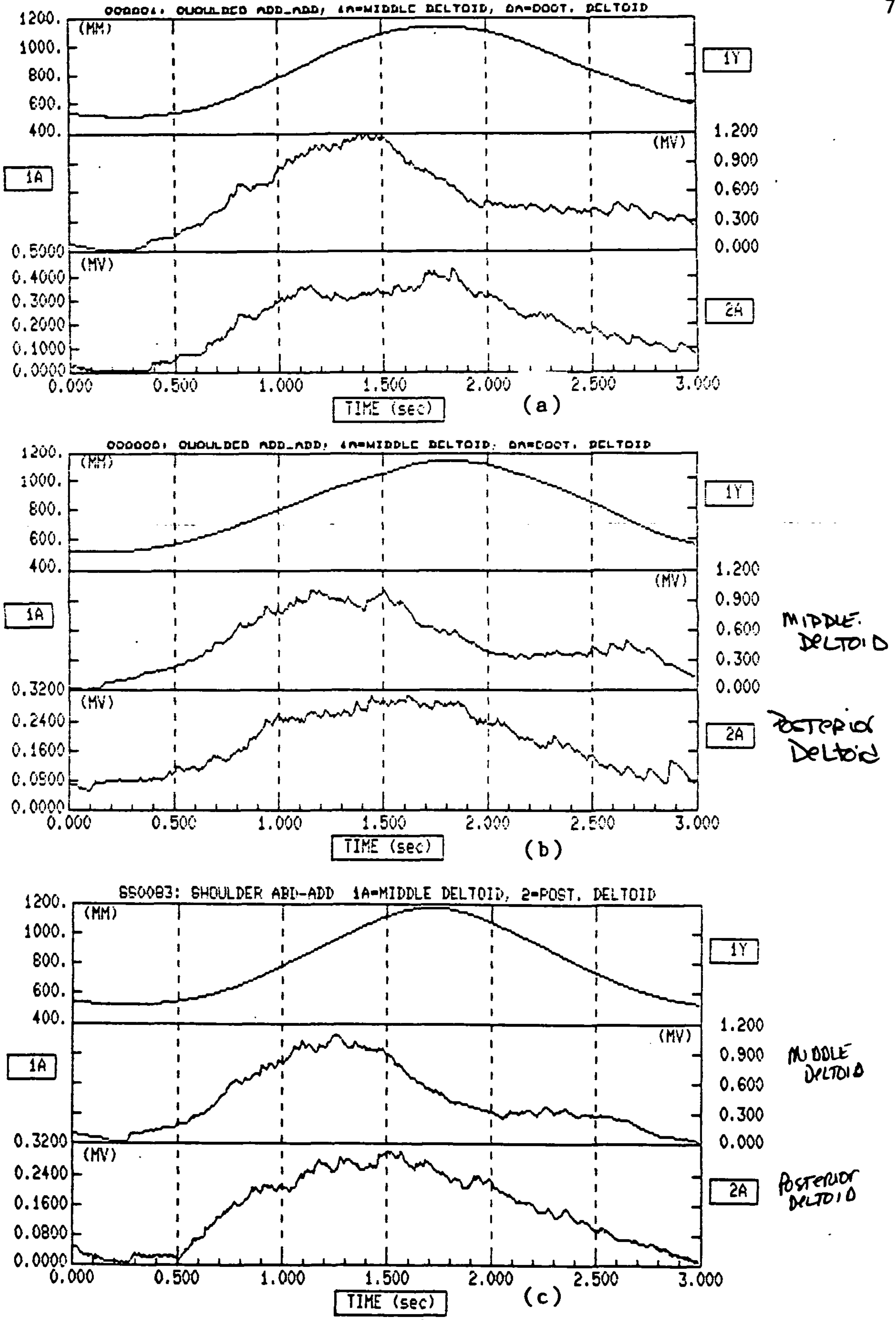
Figures: D15 a,b,c; D16 a,b,c;
Top strip chart (1Y) = displacement representing a change in wrist position as it moved through an arc in the frontal plane. Peaks (e.g. 1200 mm) indicate maximum abduction (a position in which the wrist is at the same horizontal level as the shoulder). Minimums (e.g. 500 mm) indicate a return to the FSP (wrist is vertically in line with the shoulder). Second strip chart (1A) = EMG recording from the middle deltoid. Third strip chart (2A) = EMG recording from the posterior deltoid.

Observations:

In the slow speed trials (Figures D15a,b,c), both the middle and posterior deltoids contributed to the abduction movement. There was a consistent lagging of peaks between the two muscle sections. The middle deltoid rose to its peak half way through the abduction (approximately 45°). The posterior deltoid showed a slope similar to the middle deltoid, but it maintained its maximal activation longer (i.e. through maximum abduction).

Because the movement was performed in the frontal plane, gravity provided the force necessary to return the arm to its initial position. Control of the adduction, therefore, was due to the eccentric contraction of the middle and posterior deltoids. As the position graph showed a return to FSP, the EMG activity too showed a decline. Thus the EMG activation patterns displayed close parallels with the position-time data for the movement. One should be reminded that when working in a gravitational field, the agonists of a movement may control the movement in both directions - first concentrically, then eccentrically. When this is the case, the antagonists are not needed for limb control. In weightless conditions, antagonist muscles would need to be monitored for a control signal to return the arm to FSP.

The middle and posterior deltoid activation patterns were similar across the two speeds selected (Figures D16a,b,c). The ballistic strategy observed in forearm flexion/extension tasks was also observed in the arm abduction/adduction movement. In this case, the envelope of middle deltoid activity reached its peak midway through the displacement pattern, then droped off more sharply, to reach a baseline level before the arm returned to FSP. This pattern may be explained by a strategy that involves generating a high acceleration of the limb early in the movement, then letting inertia carry the limb to its reversal position. Gravity will return the arm to FSP without muscular effort, and control of the limb at the end of the movement (before the arm hits the side of the body) appears to be by small EMG bursts that occur just before reaching the minimum position, particularly in the posterior deltoid.



<u>Figure D15.</u> Shoulder abduction/adduction in the frontal plane.

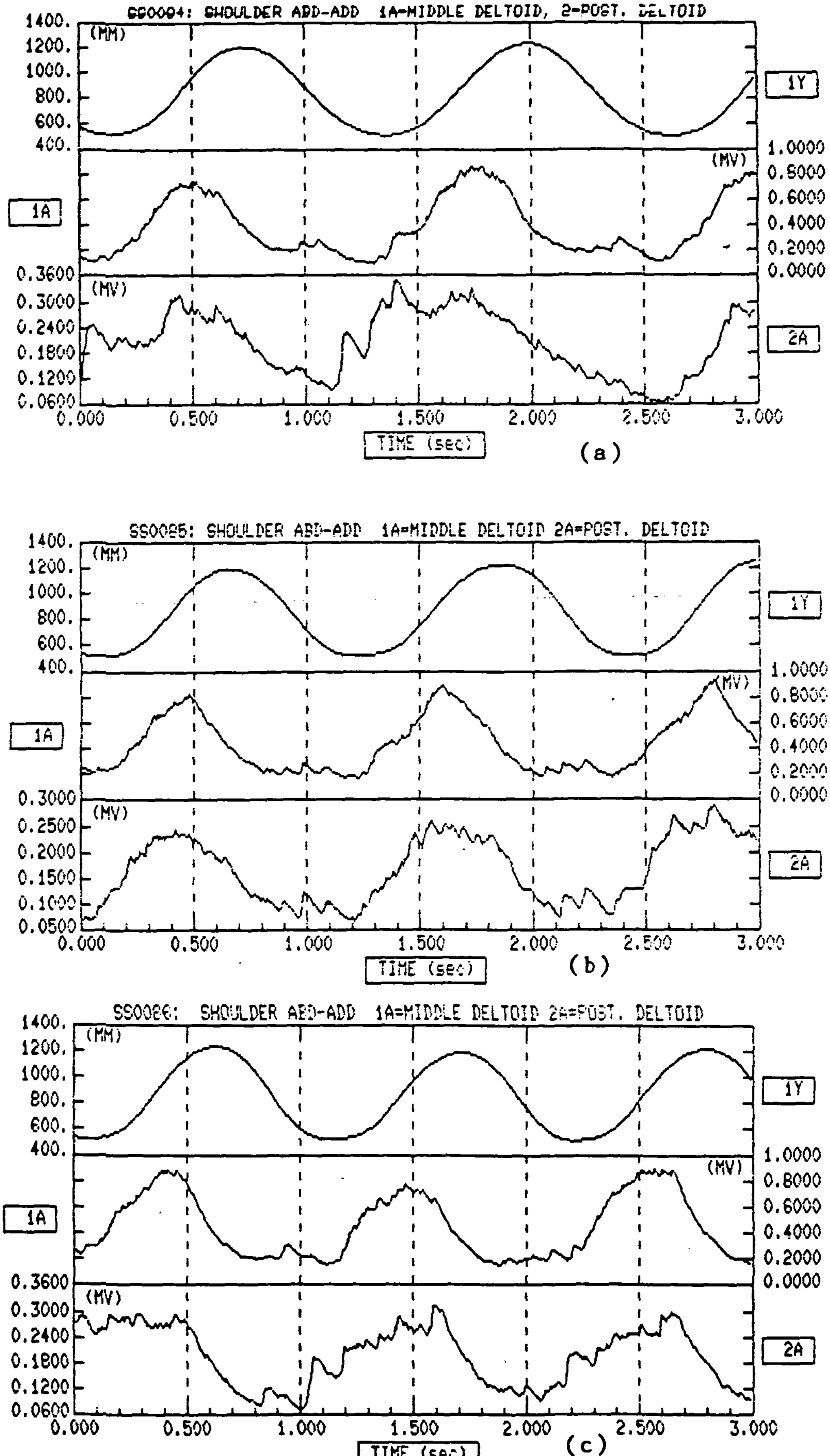


Figure D16. Shoulder abduction/adduction in the frontal plane.

2.1.3 Shoulder Abduction/Adduction; Frontal Plane

Special conditions: Slow (.5 Hz) and fast (1.2 Hz) movements (Phase I only)

EMG: middle deltoid and trapezius

Description: Subject was seated, facing the cameras, with the right arm hanging relaxed at the side. The arm was moved through a 90° ROM. The arm was abducted 90° then returned (adduction) to the starting position. Subjects were asked to perform the movement at two different speeds, slow and fast. The speeds were self-selected.

Figures: D17 a,b,c; D18 a,b;
Top strip chart (1Y) = displacement representing a change in wrist position as it moved through an arc in the frontal plane. Peaks (e.g. 1200 mm) indicate maximum abduction (a position in which the wrist is at the same horizontal level as the shoulder). Minimums (e.g. 500 mm) indicate a return to FSP (wrist is vertically in line with the shoulder). Second strip chart (1A) = EMG recording from the middle deltoid. Third strip chart (2A) = EMG recording from the trapezius.

Observations:

In the slow speed trials (Figures D17 a,b,c) the EMG envelope for the middle deltoid was consistent with the pattern seen in previous tests. Peak activity occured prior to maximum abduction, and declined with a slope similar to that of the displacement. The trapezius showed a pattern similar to that of the posterior deltoid; a rise to peak activity coincident with maximum displacement. This pattern of activity might have been expected as the trapezius acts as a stabilizer of the clavicle and scapula, from which the arm is suspended. Thus, the middle deltoid (along with deep muscles, e.g., subscapularis) initiate the abduction and the posterior deltoid or trapezius acts somewhat later in the motion when the resistance moment arm lengthens and the torque about the shoulder increases.

In the fast speed trials (Figures D18a,b) a similar ballistic strategy was discerned from the EMG activation patterns. In these trials, the secondary middle deltoid burst was even more pronounced in controlling the adduction due to gravity (Figures D18a,b at 1.0 and 2.0 sec). The trapezius also showed some evidence of a secondary burst (Figures D18a at 2.0 sec) but with less consistency.

Shoulder Abduction / Adduction
EMG = MIDDLE DELTOID + TRAPEZIUS

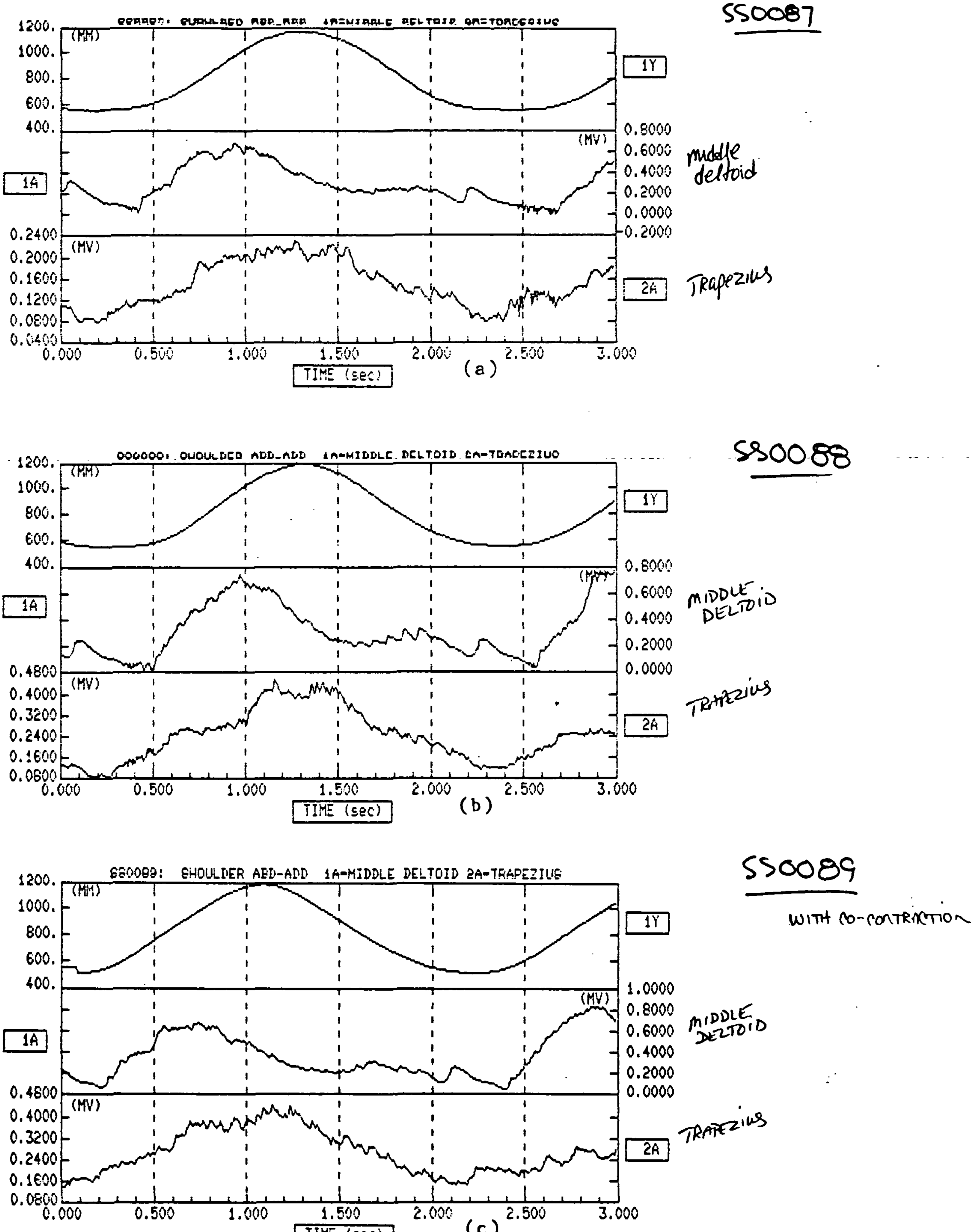


Figure D17. Shoulder abduction/adduction in the frontal plane.

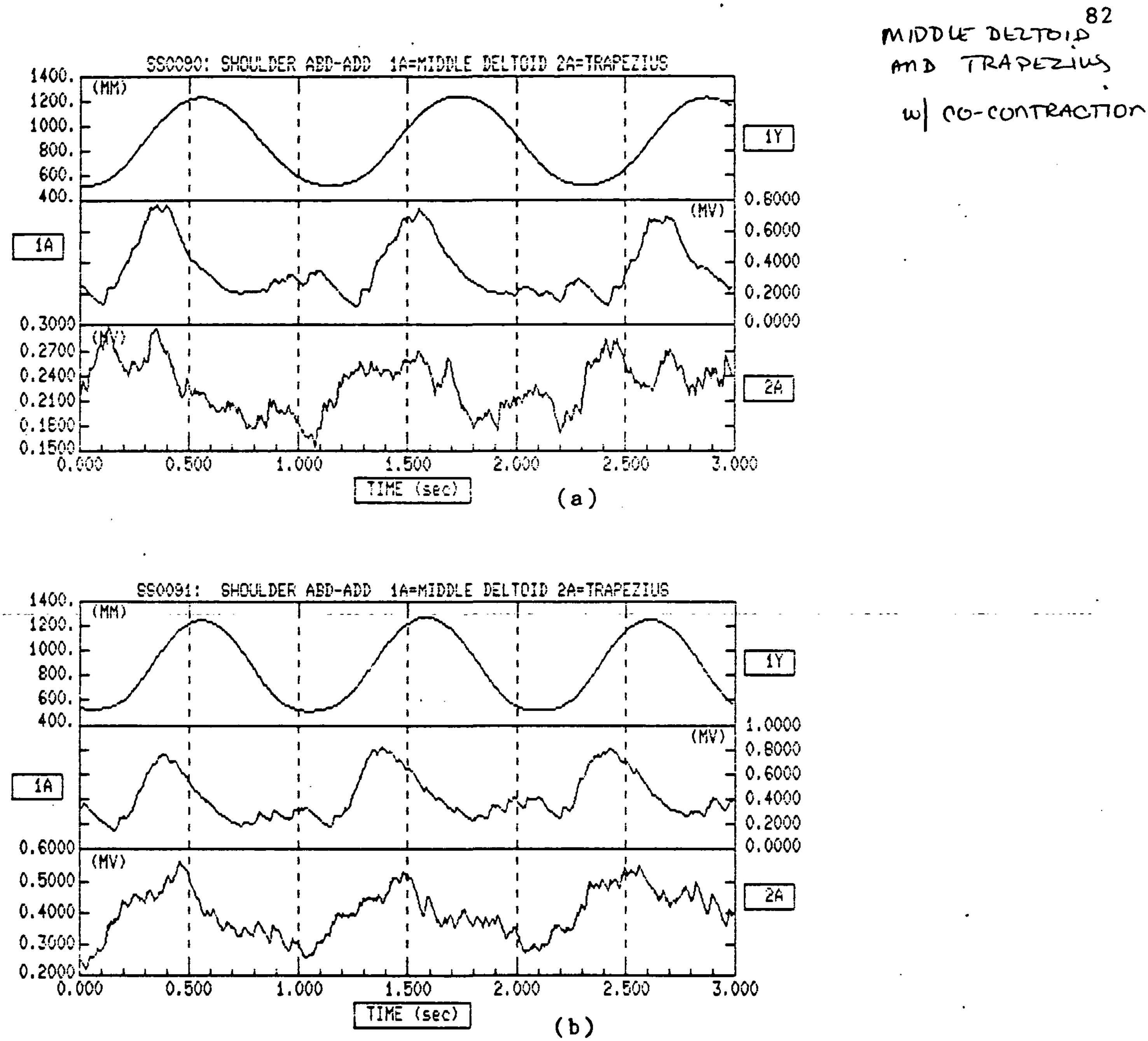


Figure D18. Shoulder abduction/adduction in the frontal plane.

2.1.4 Shoulder Abduction/Adduction; Frontal Plane

Special conditions: With and without cocontraction (Phase II only)

EMG: middle deltoid and pectoralis major

Description: Initial position; right arm hanging relaxed at the side. The arm was abducted to form a 80° angle with the trunk, then returned (adduction) to the starting position.

Figures: D19 a; D20 a,b,c;
Top graph = EMG data from the anterior deltoid and the pectoralis major (D19a, D20a). Bottom graph = displacement representing a change in shoulder angle in the frontal plane (peaks indicate a return to FSP; minimums indicate maximum abduction). Raw EMG data from the middle deltoid (D20c) and the corresponding processed EMG data (D20b) also are displayed.

Observations:

Without cocontraction the middle deltoid EMG activity peaked just prior to or at maximum abduction (Figure D19a). This activity pattern was similar to those observed in the Phase I shoulder abduction/adduction tasks across speeds. Pectoralis major EMG activity appeared to be absent. Since the pectoralis functions as an adductor of the humerus, this result was expected. In a gravitational environment gravity is the force which acts to adduct the humerus, and this action is controlled through eccentric contractions of abductors (e.g., the deltoid).

With cocontraction, the EMG activity pattern of the middle deltoid was quite different. Similar to the results of Phase I activity peaked half way through arm abduction. As suggested by the Phase I results, another abductor (i.e. the posterior deltoid) may control movement of the limb after this point. Middle deltoid activity also peaked half way through adduction. This peak may have been related to the cocontraction task, or an effort to slow the effects of gravity. Regardless, it did not reverse the direction of the movement as evident in Figure D20a. Pectoralis major activity rose to a slight peak as the arm returned to FSP. This activity may have been related to active adduction performed against the resistance of the trunk. The raw EMG data appeared to correlate well with the processed data (Figure D20b,c).

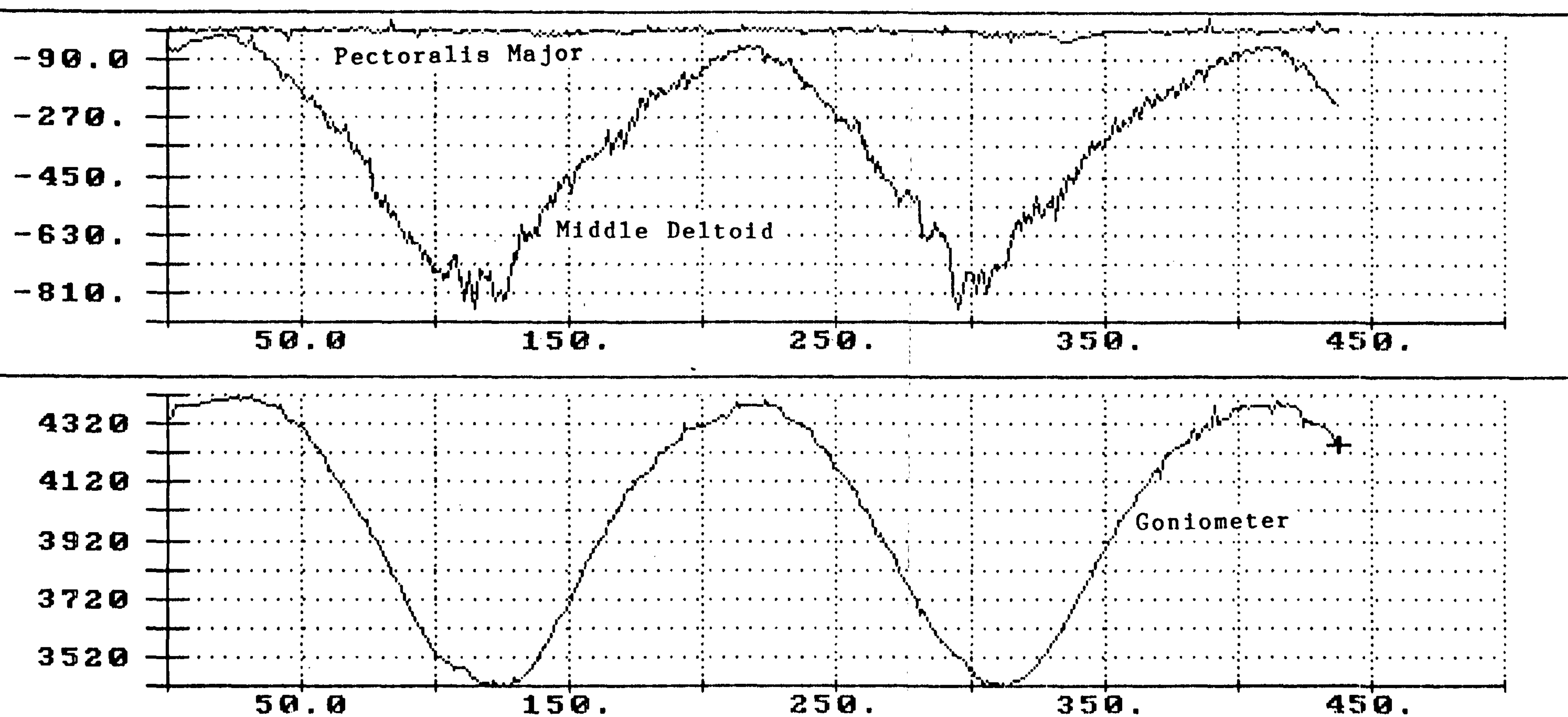


Figure D19a. **SHOULDER ABDUCTION & ADDUCTION IN THE FRONTAL PLANE**

MOVEMENT SPEED: Medium SAMPLING RATE: 40 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Shoulder Adduction
Decreasing Signal Magnitude -- Shoulder Abduction

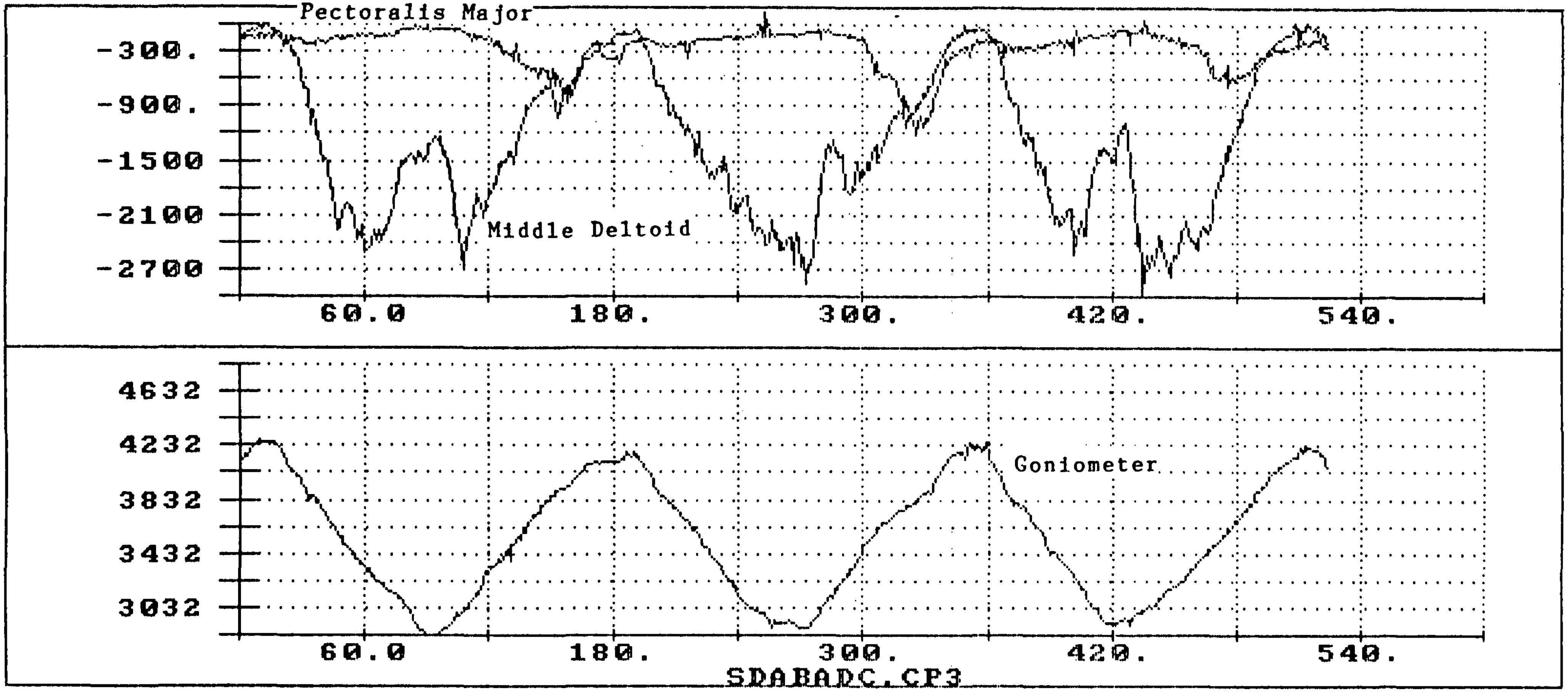


Figure D20a. **SHOULDER ABDUCTION & ADDUCTION IN THE FRONTAL PLANE with Cocontraction**

MOVEMENT SPEED: Medium SAMPLING RATE: 33.3 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Shoulder Adduction
Decreasing Signal Magnitude -- Shoulder Abduction

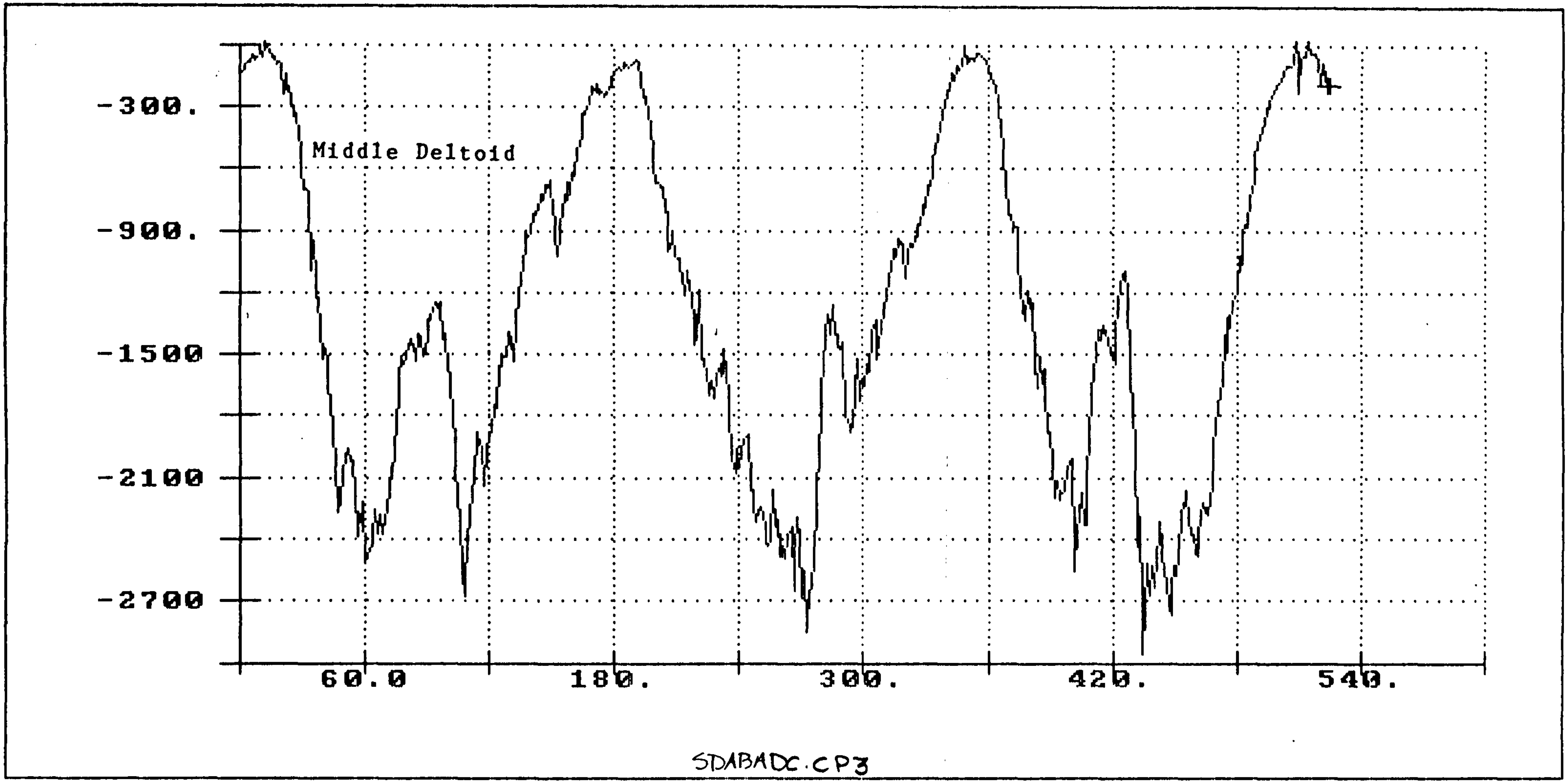


Figure D20b. SHOULDER ABDUCTION & ADDUCTION IN THE FRONTAL PLANE with Cocontraction

MOVEMENT SPEED: Medium SAMPLING RATE: 33.3 Samples/Sec/Channel

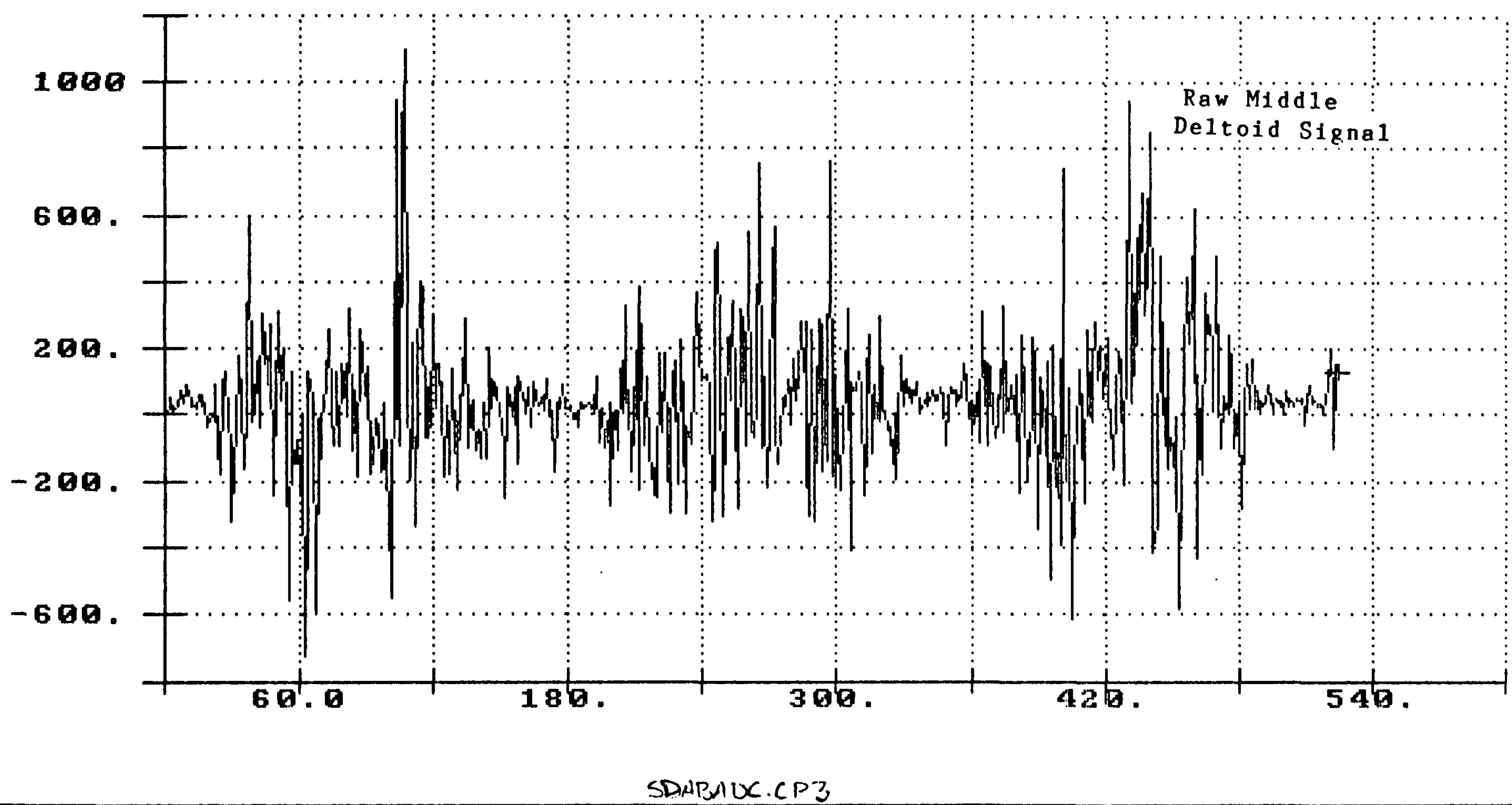


Figure D20c. SHOULDER ABDUCTION & ADDUCTION IN THE FRONTAL PLANE with Cocontraction

MOVEMENT SPEED: Medium SAMPLING RATE: 33.3 Samples/Sec/Channel

2.1.5 Internal/External Rotation of the Humerus; Transverse Plane, Vertical Axis

Special conditions: With and without cocontraction; Intersegmental shoulder angles of 0° and 45°

Phase I & II EMG: teres major and infraspinatus

Phase I description: Position 1: The subject's forearm was flexed 90° at the elbow. With this forearm position, the subject was placed such that the longitudinal axis of the humerus was colinear with the axis of rotation for a mechanical arm. That is, the elbow was fixed on top of, and coincident with, the rotary axis of the mechanical arm. In this position, drawing the hand toward the body was indicative of internal humeral rotation, and swinging the hand away from the body marked external humeral rotation. The intersegmental angle between the humerus and the line of the trunk was as close to 0° as possible. Position 2: The humerus was flexed approximately 45° creating a 45° intersegmental angle with the trunk. To maintain hand contact with the mechanical arm, the intersegmental angle at the elbow was relaxed to an angle greater than 90°.

Phase II description: Subject was seated in a chair. Forearm was flexed to form a 90° angle with the humerus at the elbow joint. From this position, drawing the hand toward the body was indicative of internal humeral rotation, and swinging the hand away from the body marked external humeral rotation. Due to the nature of the movement and the size of the goniometer, monitering changes in joint angle were not possible.

Phase I figures: D21 a,b,c; trunk 45° no cocontraction: D22 a,b; trunk 0° no cocontraction: D23 a; trunk 45° cocontraction: D24 a,b,c; trunk 0° cocontraction. Top strip chart (7Z) = displacement representing a change in rotation angle. Peaks (e.g. 700 mm) indicate maximum internal rotation; valleys (e.g. 250 mm) indicate maximum external rotation. Second strip chart (1A) = EMG recording from the teres major. Third strip chart (2A) = EMG recording from the infraspinatus.

Phase II figures: D25 a,b,c; no cocontraction: D26 a; no cocontraction: D27 a; cocontraction: D28 a,b; cocontraction. EMG records of infraspinatus and teres major activity are displayed in D25c, D27a, D28a,b and the top graph of D26a. The bottom graph of D26a shows the corresponding raw EMG data for the infraspinatus. The EMG records of both muscles are displayed seperately in D25a,b (Top graphs = infraspinatus activity; Bottom graphs = teres major activity).

Observations:

Phase I: The infraspinatus is an external rotator of the humerus at the glenohumeral joint. The teres major is an internal rotator. In theory, these two muscles should display peak EMG activation patterns that are out of phase with one another. However, a couple of a priori problems existed. First, the two muscles are difficult to distinquish superficially. Even though anatomical texts display a reasonable spatial distinction between the muscles, they lie next to one another. As mentioned in the anatomical considerations section, even reasonably close proximity between muscles compromises our ability to record separate EMG patterns. In an attempt to maximize the distance, the electrodes for the teres major were placed as lateral as possible - but this induced difficulties in recording movement artifact created by scapular movement.

The second problem arose out of muscle function. The prime mover for internal rotation is the subscapularis. However, the subscapularis is a deep muscle and not accessible for surface EMG recording. The teres major, although identified as an internal rotator, may be active in that function only against resistance (Basmajian, 1979).

In Figure D21a,b,c, the shoulder intersegmental angle was 45°, and humeral rotation was performed without cocontraction. A clear phasic pattern was displayed by both the teres major and the infraspinatus. Unfortunately, the phasic activity of the two muscles was identical. This failure to distinquish different phasic patterns suggested an inability to distinquish the two muscles in electrode placement. Had the two muscles been properly identified, and if the problem was lack of teres major activity due to low resistance, then the teres major should show no EMG activity. From the figures, it appeared that only the external rotatory activity was monitored. Additionally, the infraspinatus appeared active only at the extremes of the ROM for external rotation.

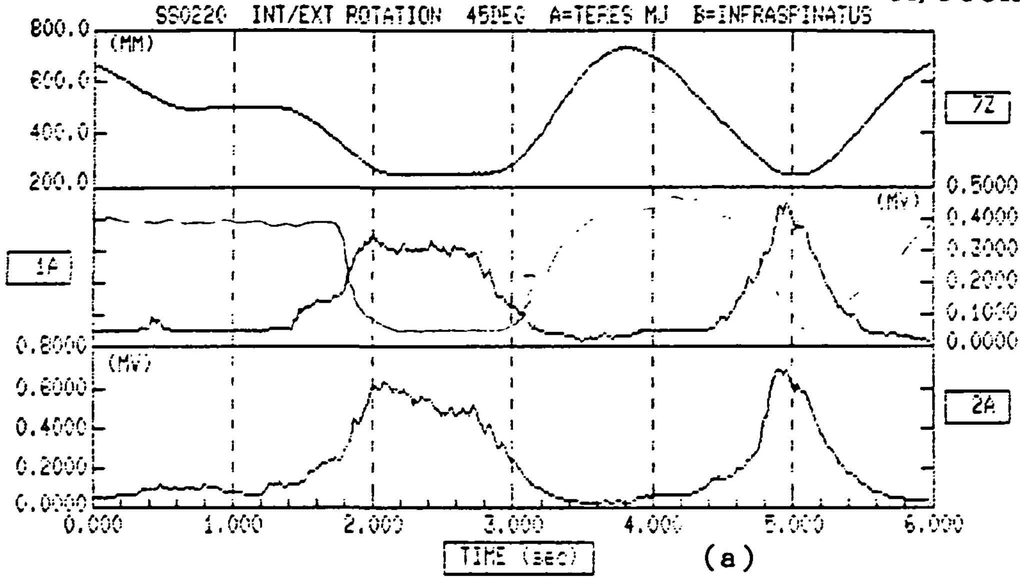
Figure D22a,b are from trials in which the shoulder intersegmental angle was 0°. No change in the EMG activation pattern was observed other than a reduction in signal amplitude. This position was tested to give some indication of the changes that might be expected in the EMG patterns during coordinated, multi-segmented movement. In this case, it appeared that the EMG pattern was minimally altered by shoulder flexion.

Figures D23a and D24a,b show trials in which internal and external rotary movements were monitored under conditions of cocontraction. Again, little change in the phasic pattern was observed; although the pattern was less sharply distinquished than in cases of relaxation.

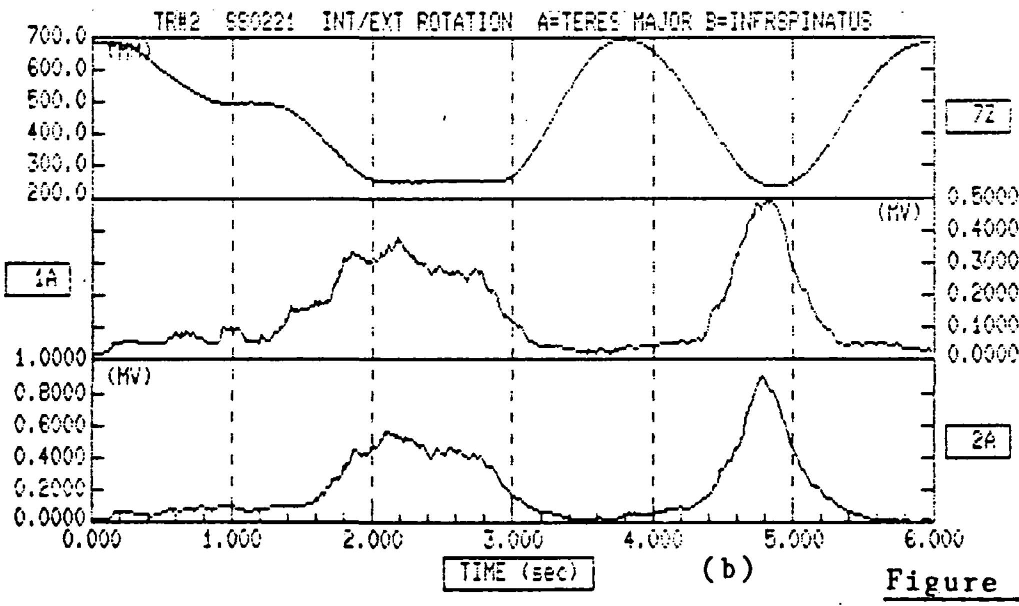
Phase II: The results of Phase II were a bit more promising than those of Phase I. The reason for the difference may have been the muscular definition of the subject.

Limb displacement was not monitered in Phase II so it could not be related to muscle activity. However, the relationship between the phases of muscle activity could be observed. As the initial movement of external rotation was made the EMG activity of the infraspinatus rose to a sharp peak with little if any coincident teres major activity (Figures D25a,b,c). This pattern was also observed as the second external rotation movement was executed. However, the infraspinatus activity also peaked with teres major activity during internal rotation.

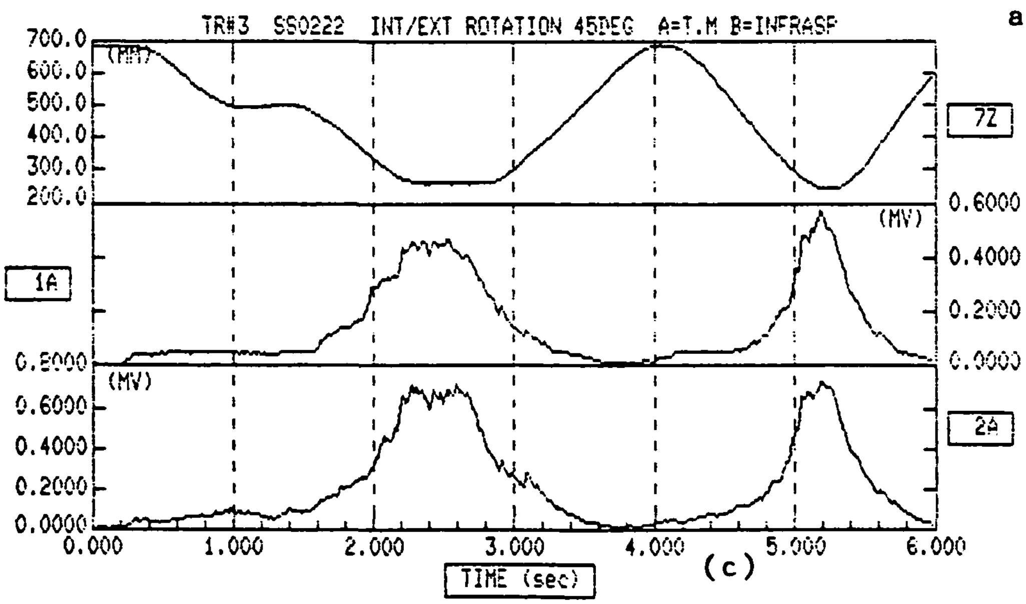
With cocontraction certain rotation movements did display the expected phasic activity: infraspinatus active for external rotation, teres major quiet; teres major active for internal rotation, infraspinatus quiet (Figures D26a, D27a, and D28a,b). However, these patterns were not at all consistent. The problems mentioned in the Phase I discussion of these data also played a role in Phase II. These internal/external humeral rotation activation patterns were not considered distinctive enough to provide precise control for an external limb or robot arm.



(a)



(b)



(c)

Figure 21. Internal/external rotation of the humerus in the transverse plane about a vertical axis.

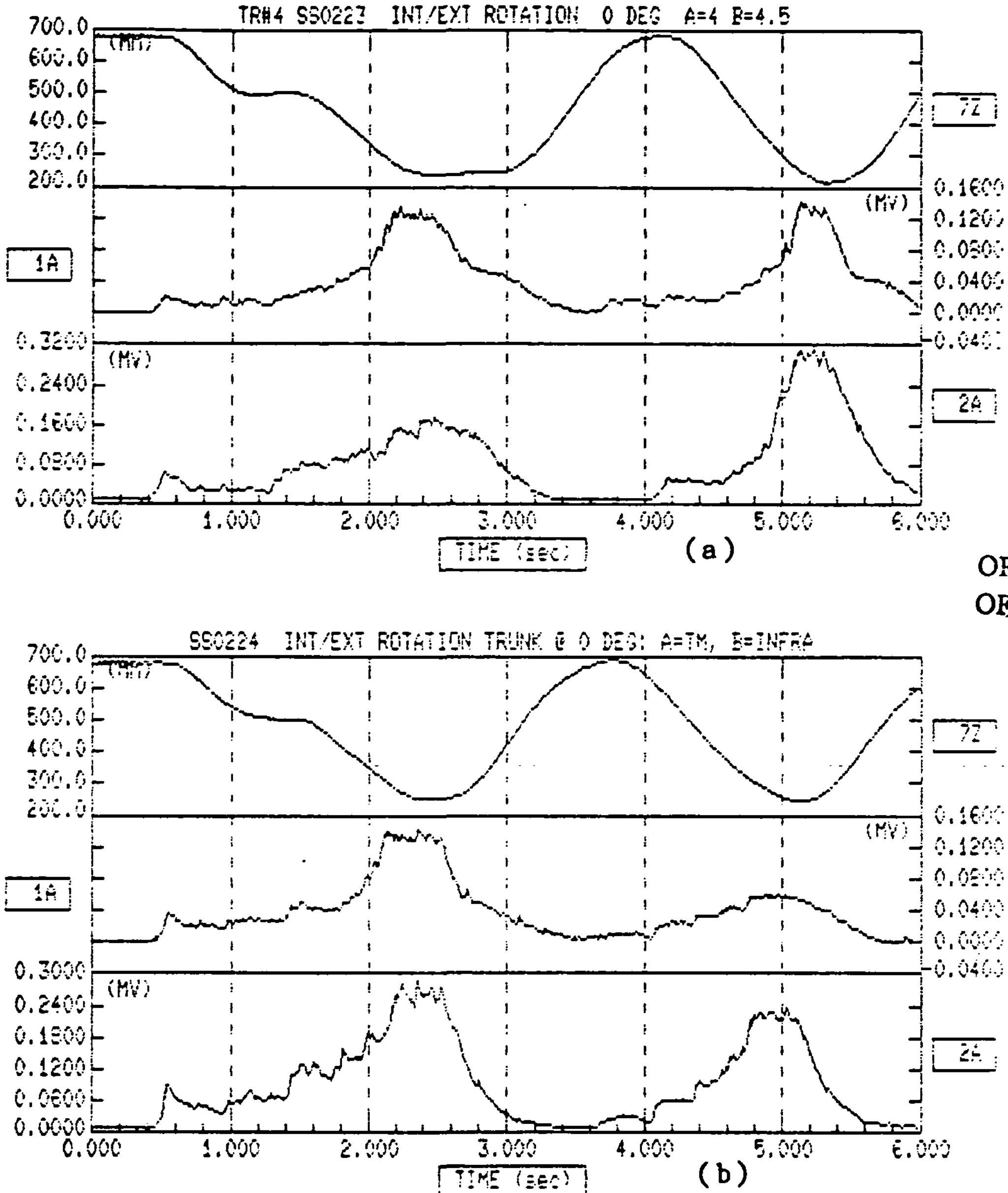


Figure 22. Internal/external rotation of the humerus in the transverse plane about a vertical axis.

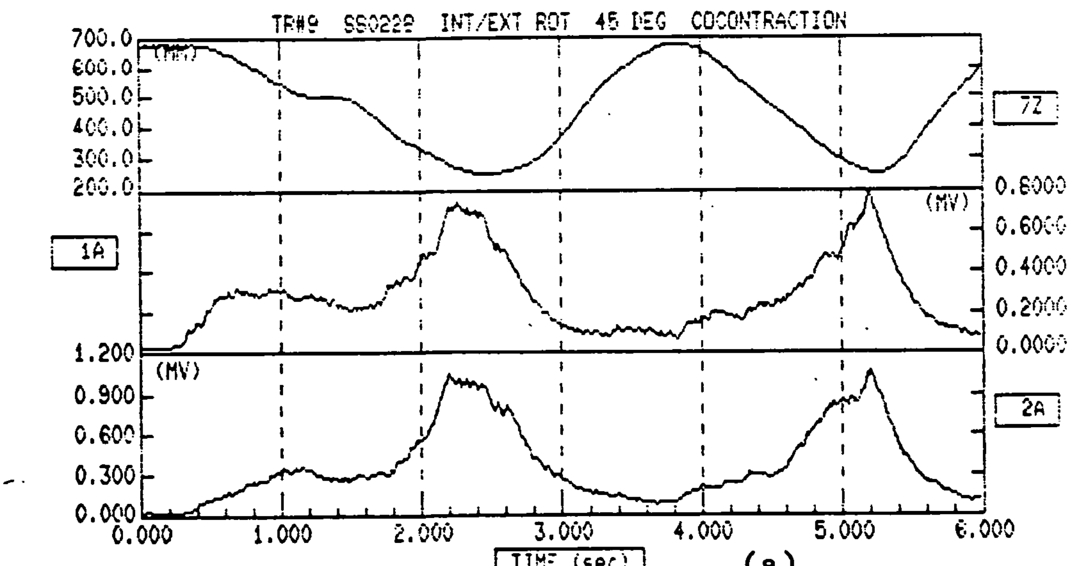


Figure 23. Internal/external rotation of the humerus in the transverse plane about a vertical axis.

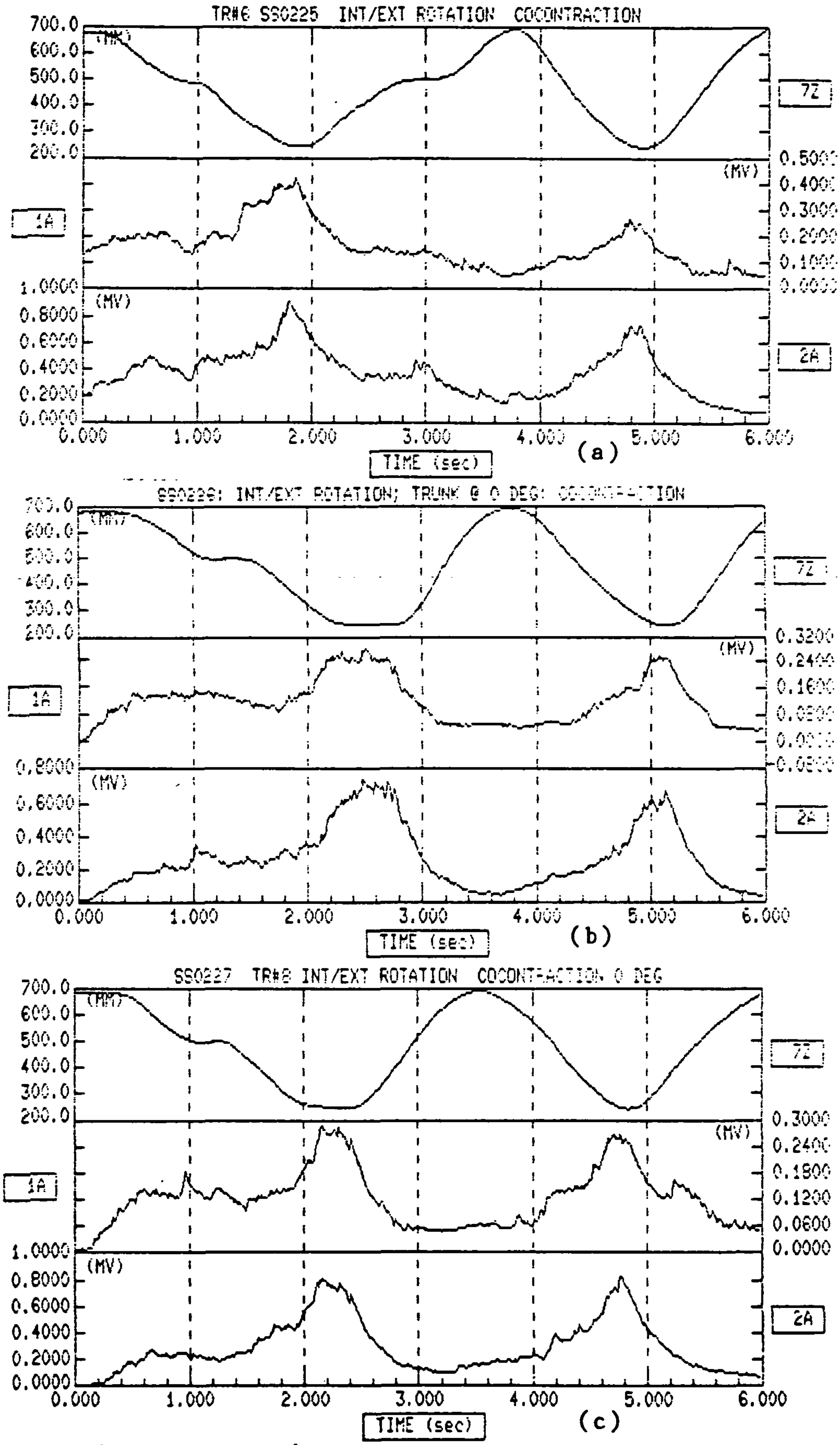


Figure 24. Internal/external rotation of the humerus in the transverse plane about a vertical axis.

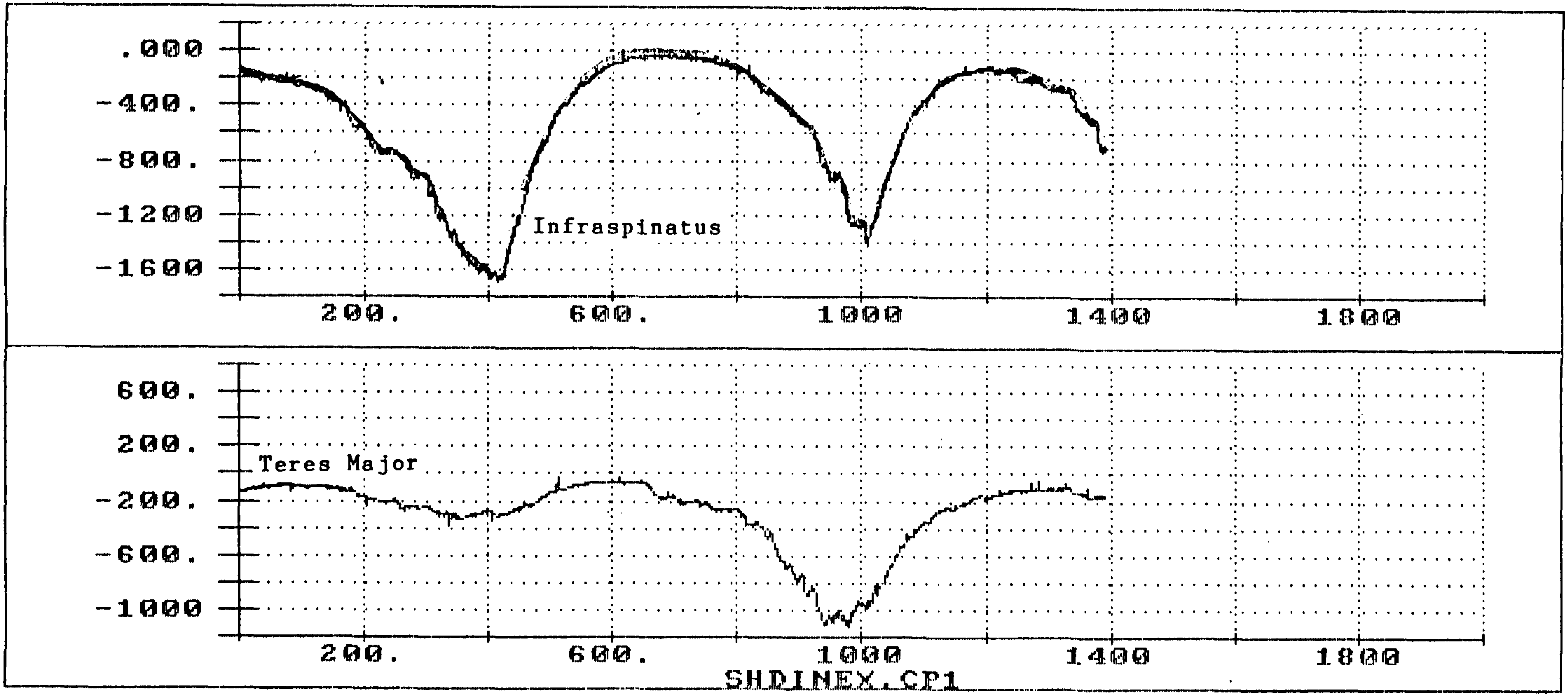


Figure 25a. INTERNAL & EXTERNAL ROTATION AT THE SHOULDER
Transverse Plane

MOVEMENT SPEED: Slow SAMPLING RATE 333 Samples/Sec/Channel

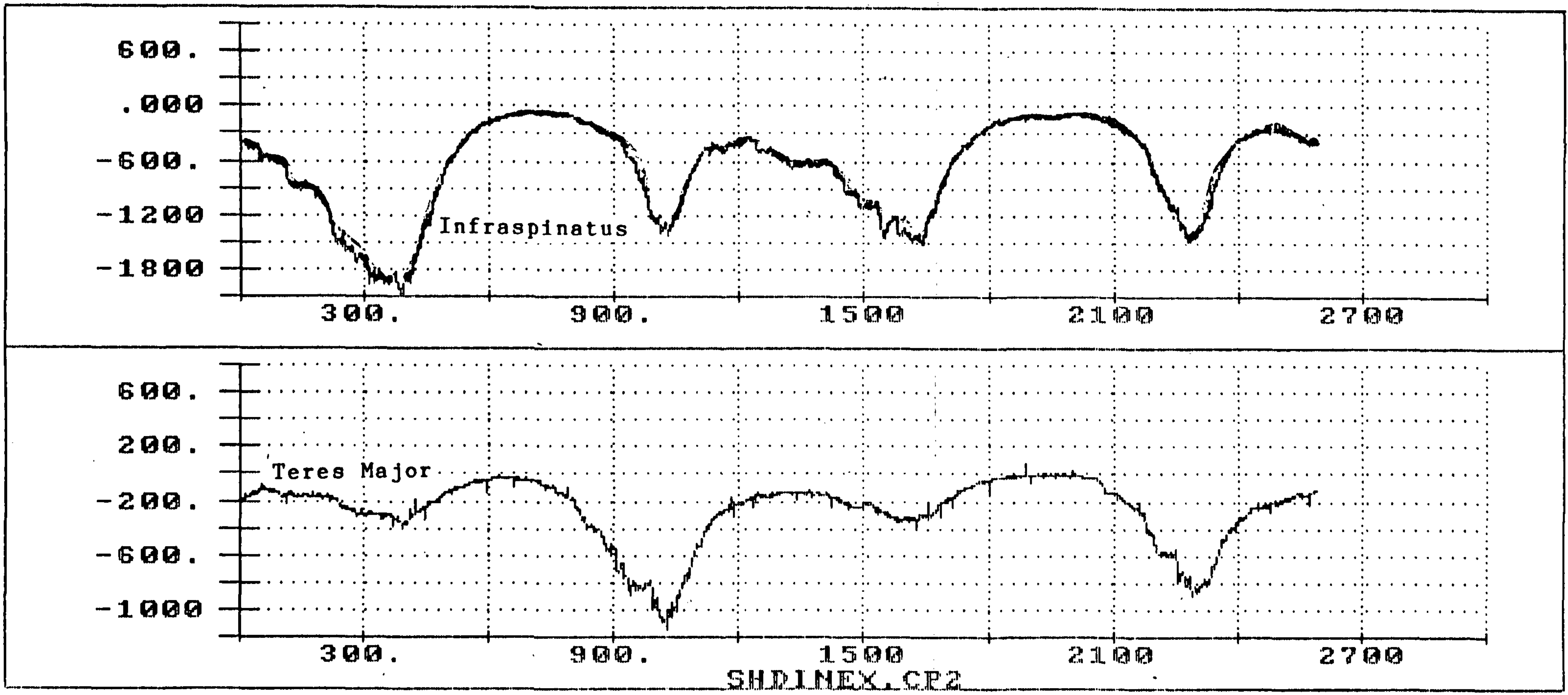
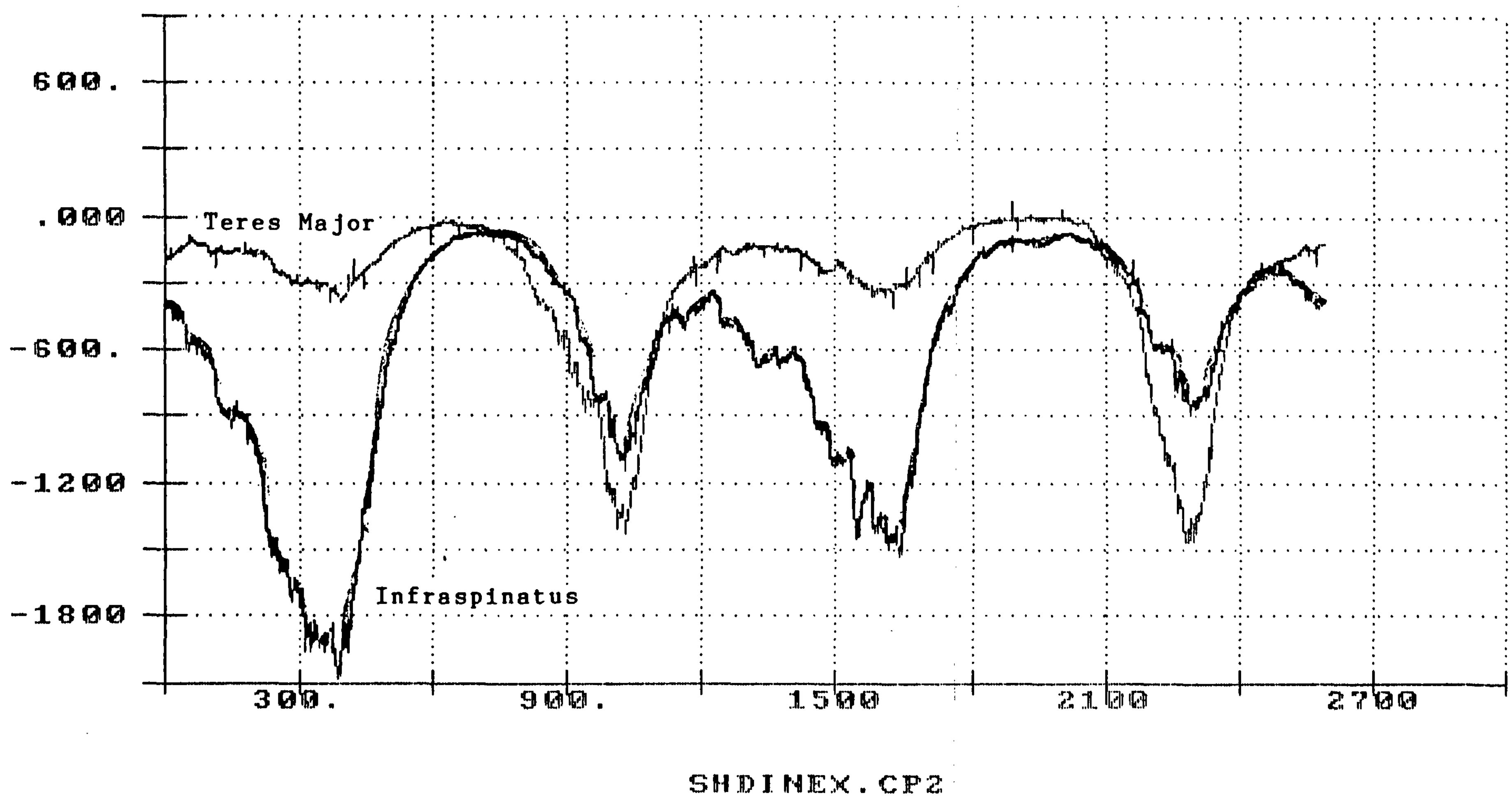


Figure 25b. INTERNAL & EXTERNAL ROTATION AT THE SHOULDER
Transverse Plane

MOVEMENT SPEED: Slow SAMPLING RATE 333 Samples/Sec/Channel



<u>Figure 25c.</u> INTERNAL & EXTERNAL ROTATION AT THE SHOULDER
Transverse Plane

MOVEMENT SPEED: Slow SAMPLING RATE 333 Samples/Sec/Channel

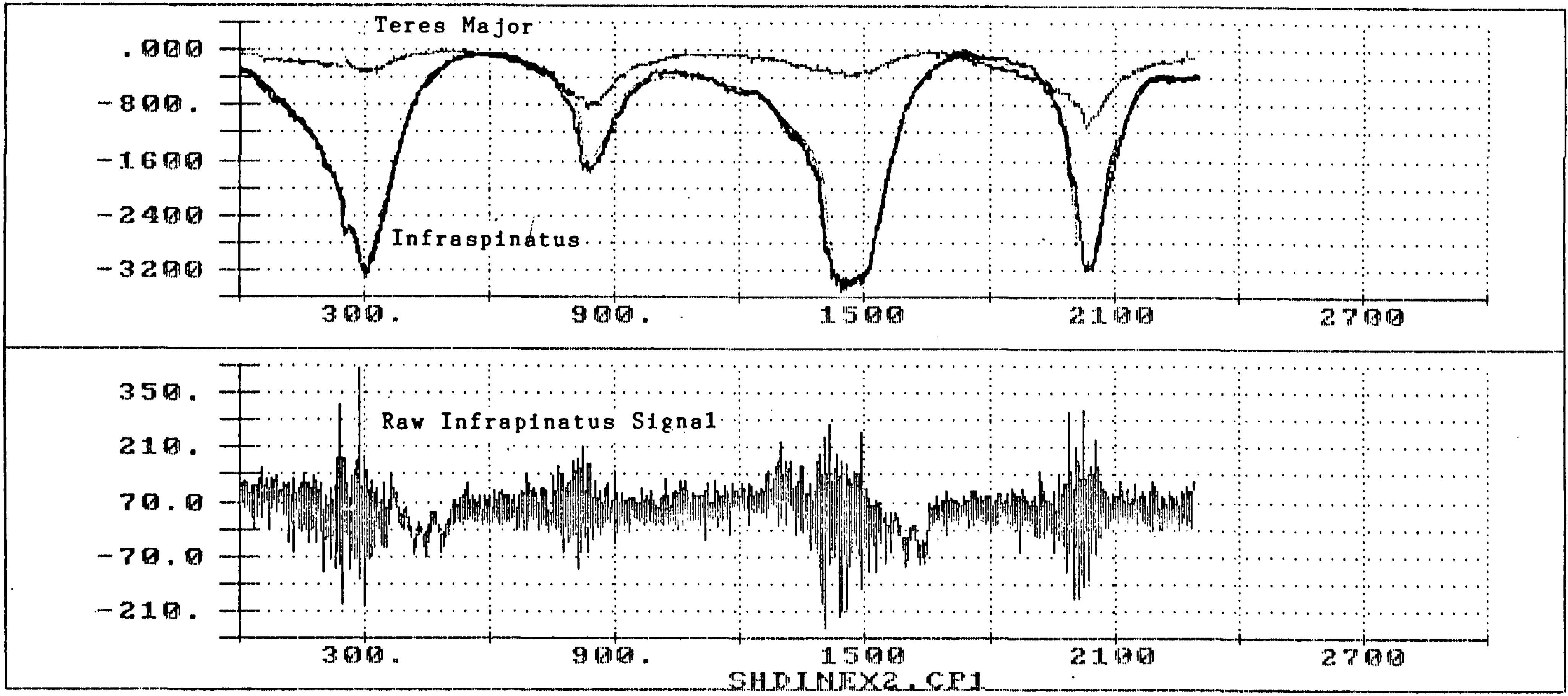


Figure 26a. **INTERNAL & EXTERNAL ROTATION AT THE SHOULDER**
Transverse Plane

MOVEMENT SPEED: Slow SAMPLING RATE 333 Samples/Sec/Channel

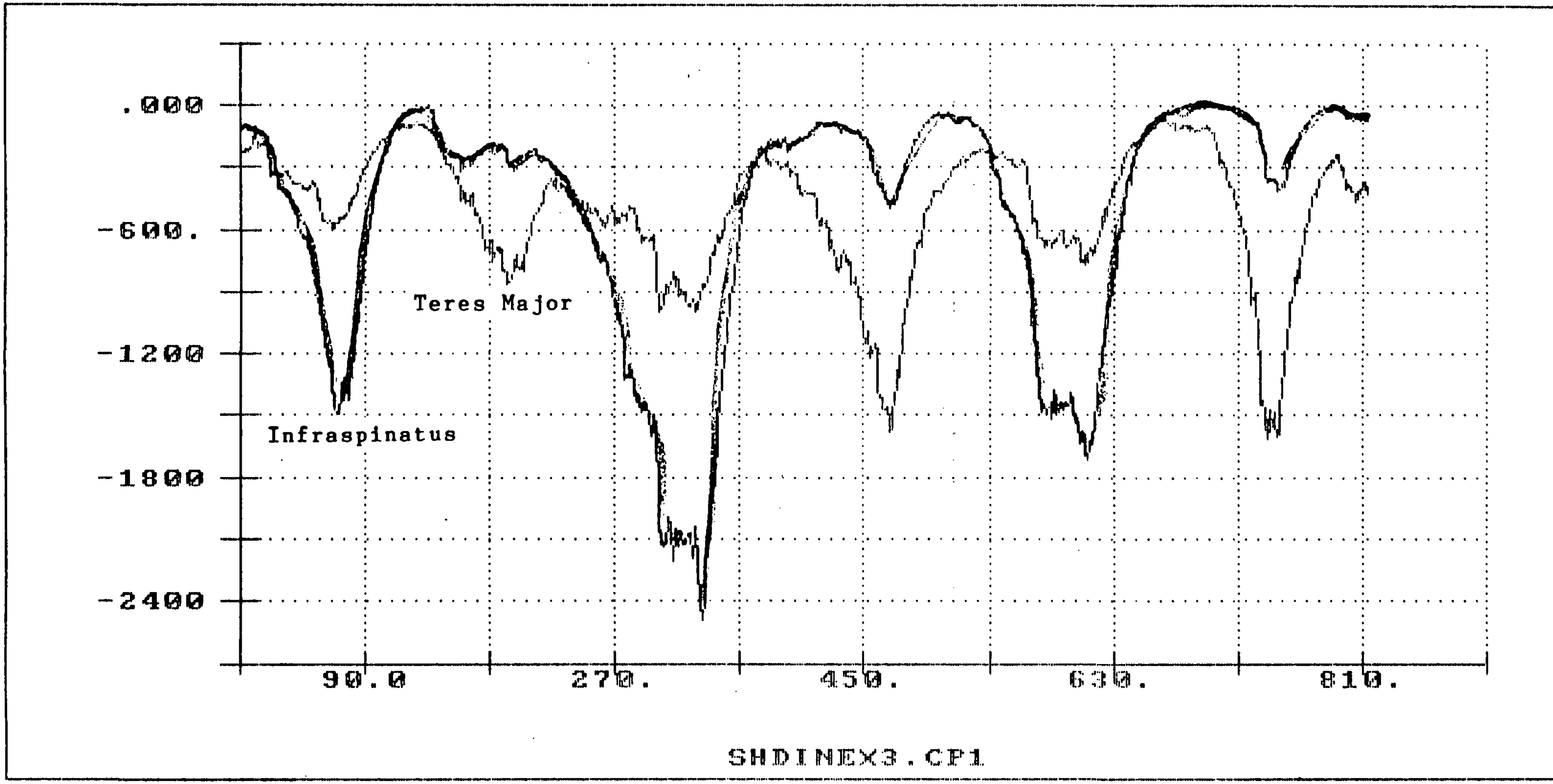


Figure 27a. INTERNAL & EXTERNAL ROTATION AT THE SHOULDER
Cocontraction in the Transverse Plane

MOVEMENT SPEED: Slow SAMPLING RATE: 66.6 Samples/Sec/Channel

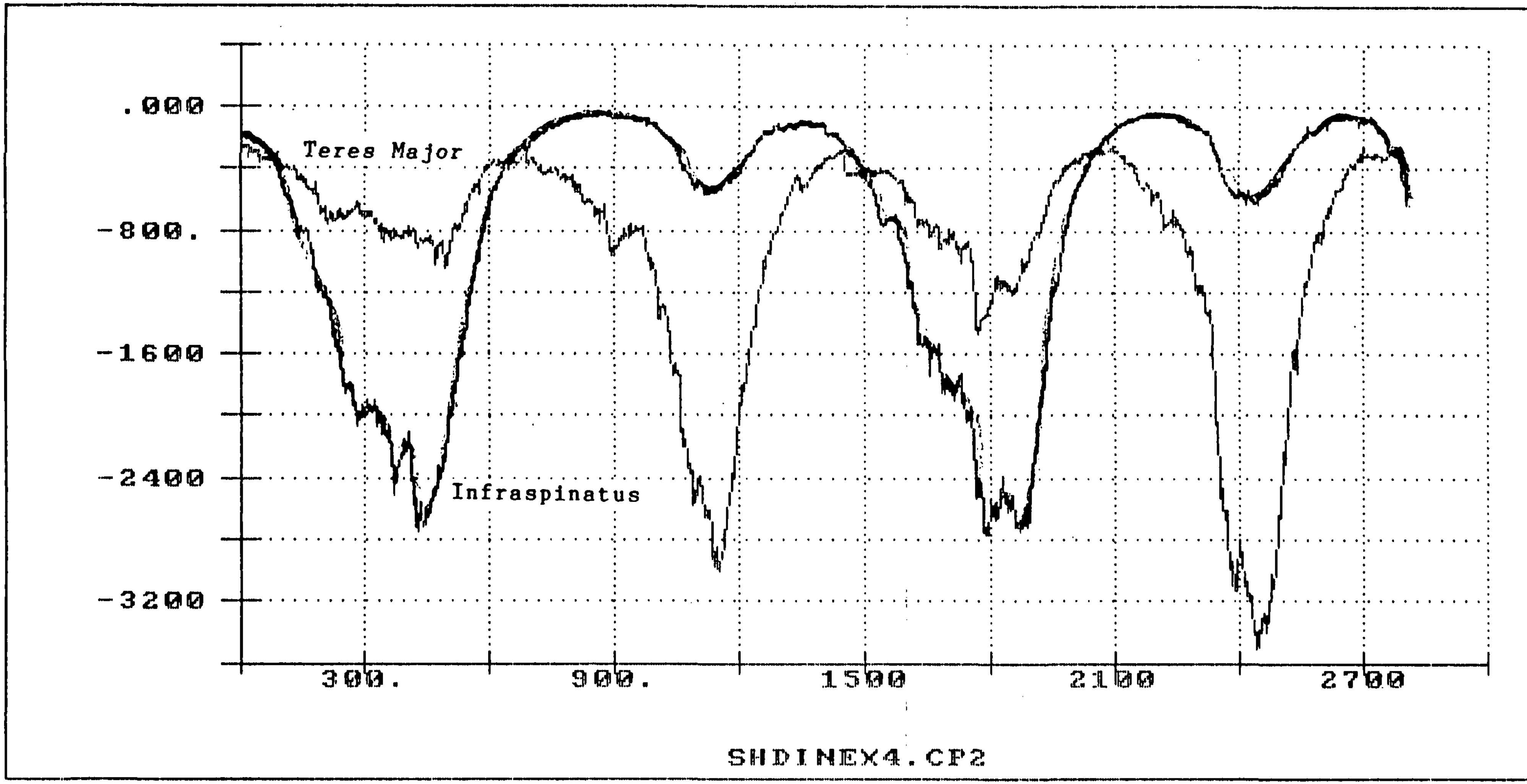


Figure 28a. INTERNAL & EXTERNAL ROTATION AT THE SHOULDER
Cocontraction in the Transverse Plane

MOVEMENT SPEED: Slow SAMPLING RATE: 333 Samples/Sec/Channel

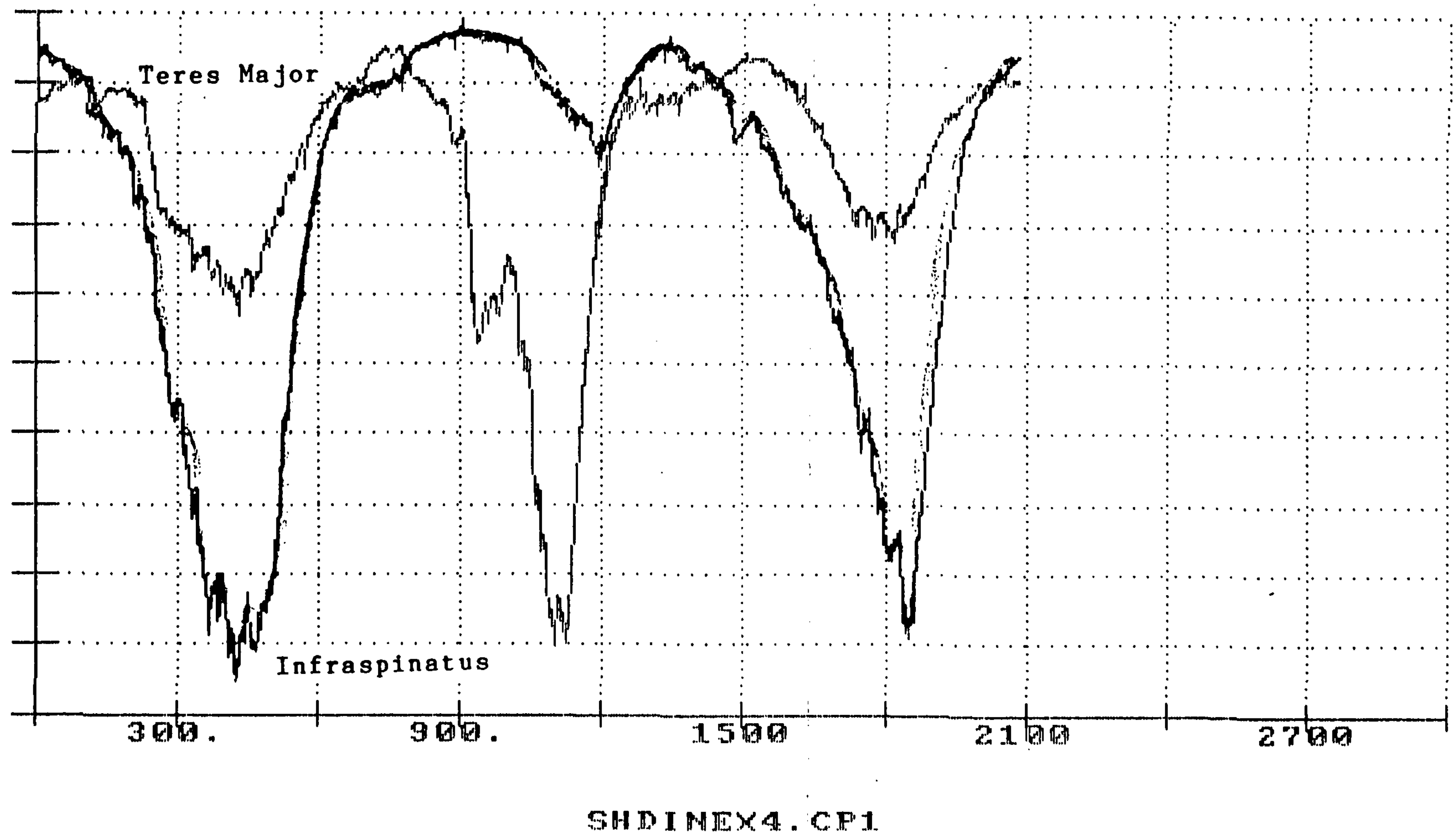


Figure D28b. **INTERNAL & EXTERNAL ROTATION AT THE SHOULDER**
Cocontraction in the Transverse Plane

MOVEMENT SPEED: Slow SAMPLING RATE: 333 Samples/Sec/Channel

2.1.6 Internal/External Rotation of the Humerus; Transverse Plane, Vertical Axis

Special conditions: With and without cocontraction; Intersegmental shoulder angles of 45° and 0° (Phase I only)

EMG: anterior deltoid and pectoralis major

Description: Position 1: The subject's forearm was flexed 90° at the elbow joint. With this forearm position, the subject was placed such that the longitudinal axis of the humerus was colinear with the axis of rotation for a mechanical arm. That is, the elbow was fixed on top of, and coincident with, the rotary axis of the mechanical arm. In this position, drawing the hand toward the body was indicative of internal humeral rotation, and swinging the hand away from the body marked external humeral rotation. The intersegmental angle between the humerus and the line of the trunk was as close to 0° as possible. Position 2: The humerus was flexed approximately 45° creating a 45° intersegmental angle with the trunk. To maintain hand contact with the mechanical arm, the intersegmental angle at the elbow was relaxed to an angle greater than 90°.

Figures: D29 a,b, trunk 45° no cocontraction: D30 a,b, trunk 0° no cocontraction: D31 a,b, trunk 45° cocontraction: D32 a,b, trunk 0° cocontraction. Top strip chart (7Z) = displacement representing a change in humeral rotation angle. Peaks (e.g. 700 mm) indicate maximum internal rotation; valleys (e.g. 250 mm) indicate maximum external rotation. Second strip chart (1A) = EMG recording from the anterior deltoid. Third strip chart (2A) = EMG recording from the pectoralis major.

Observations:

Little success was achieved in identifying the teres major as an internal rotator of the humerus. The anterior deltoid was considered a possible source for internal rotation signals as it is considered to operate in all humeral flexion tasks and during inward rotation (Luttgens & Wells, 1982). One caution, however, is that the line of pull of the anterior fibers may allow them to act only under circumstances of maximum external rotation.

Like the deltoid, certain parts of the pectoralis major are considered to act during internal rotation. In particular, the clavicular portion of the pectoralis major acts to flex, horizontally flex, and inwardly rotate the humerus. However, again we are faced with a situation in which the muscle may act to inwardly rotate the humerus only against resistance (Scheving & Pauly, cited in Basmajian, 1979).

In Figures 29a,b and 30a,b internal/external rotation of the humerus was performed with 45° and 0° of trunk flexion respectively. Both the anterior deltoid and the pectoralis major displayed similar activity patterns, however both patterns showed peaks corresponding with maximum external rotation. Since both muscles are described as conditional inward rotators of the humerus, the peak activity displayed at the extreme end of external rotation may have been caused by a passive stretch. The degree of shoulder flexion did not appear to affect the myoelectric activity of the anterior deltoid or the pectoralis major.

When the internal/external humeral rotation movement at 45° of shoulder flexion was accompanied by cocontraction (Figures 31a,b) the activity level of both muscles increased. The anterior deltoid activity still peaked with maximum external rotation, but the pectoralis major showed a slight peak with internal rotation. Pectoralis major activity also peaked as the first external rotation movement was initiated. A change in the shoulder flexion angle to 0° did not appear to alter the activity of the pectoralis major (Figures 32a,b). However, the anterior deltoid activity pattern clearly corresponded with internal rotation of the humerus. The anterior deltoid appeared to initiate internal rotation from the maximal externally rotated position and to continue acting as an internal rotator until maximal internal rotation was reached.

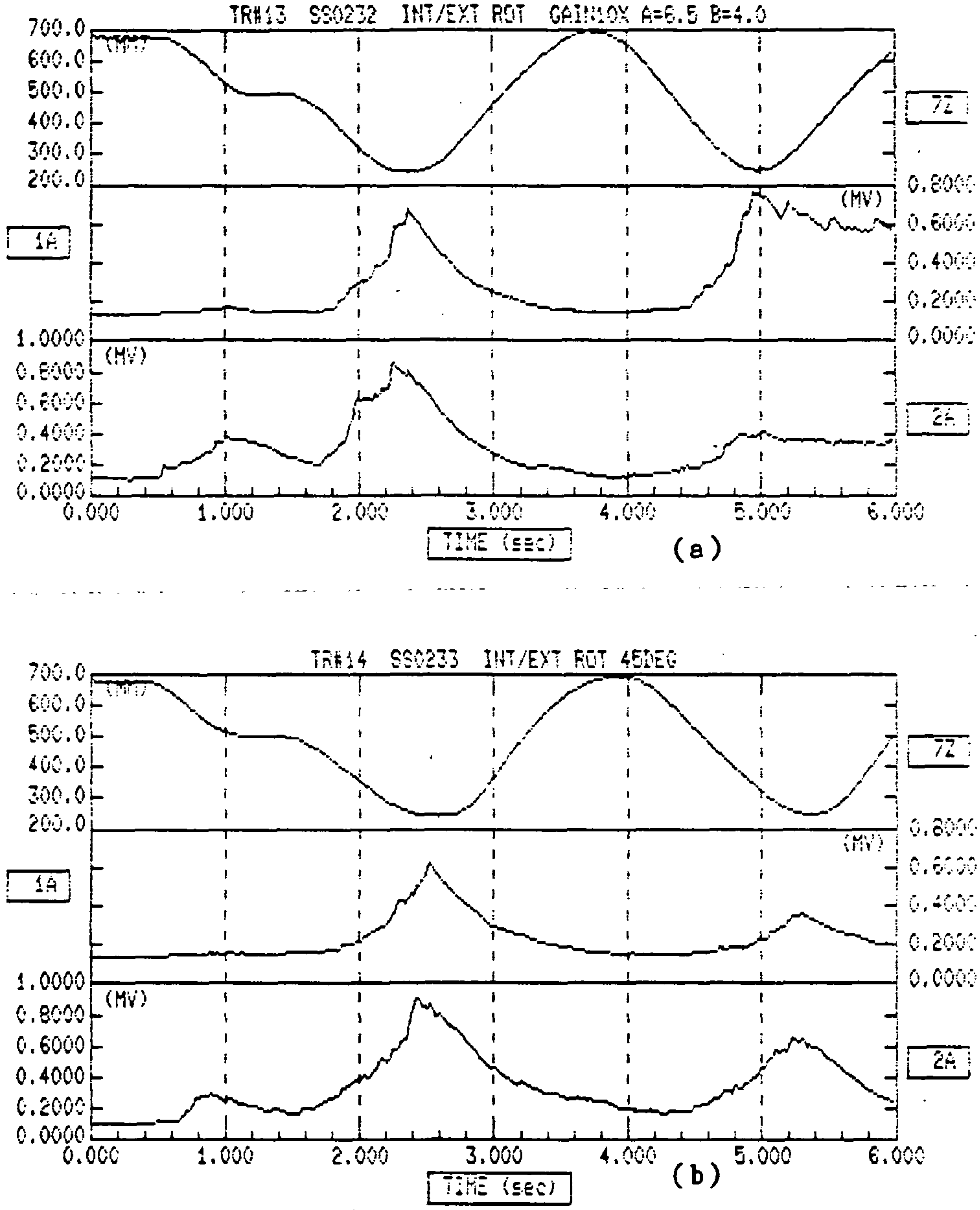


Figure 29. Internal/external rotation of the humerus in the transverse plane about a vertical axis.

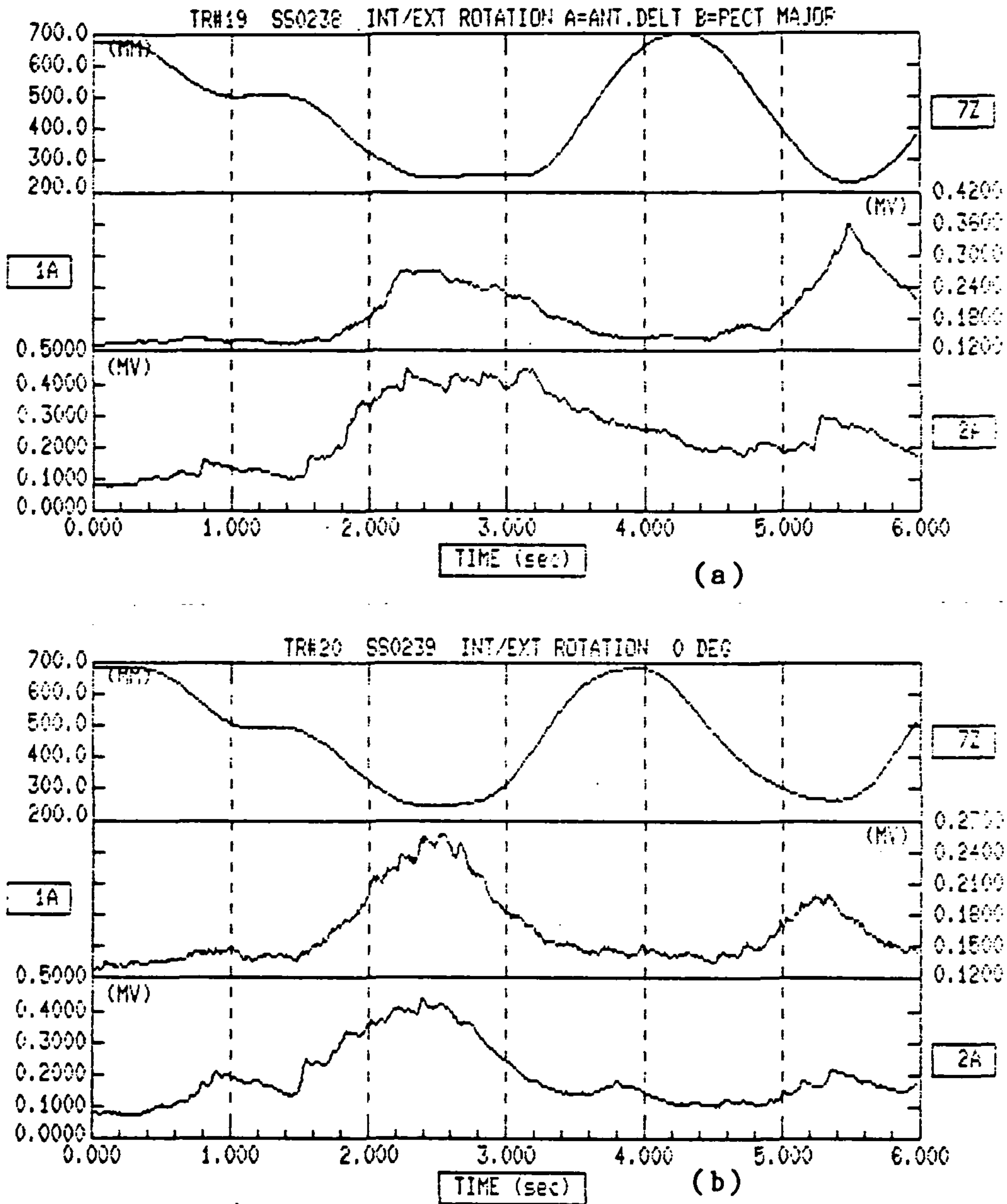
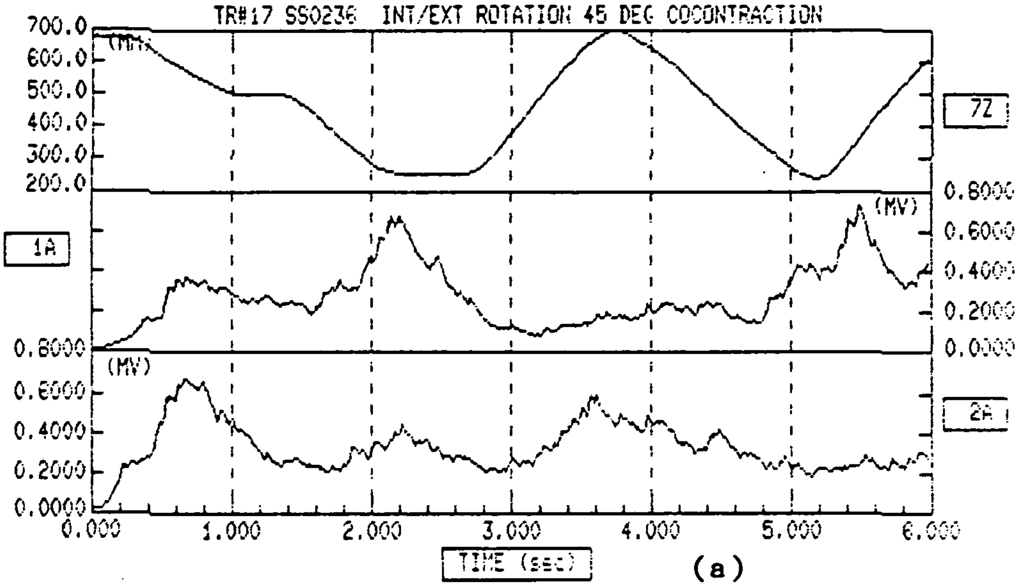
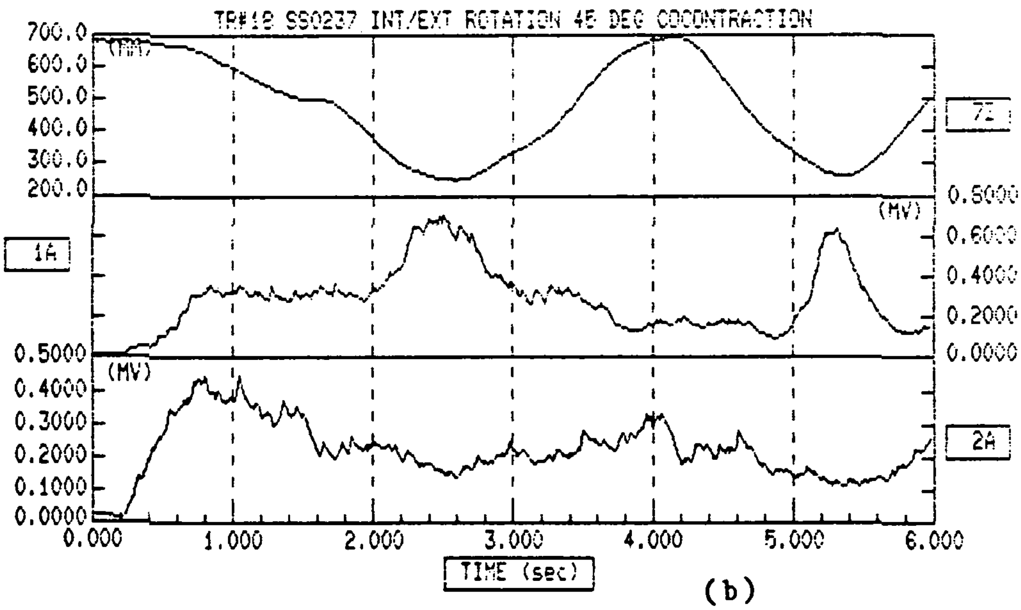


Figure 30. Internal/external rotation of the humerus in the transverse plane about a vertical axis.



(a)



(b)

Figure 31. Internal/external rotation of the humerus in the transverse plane about a vertical axis.

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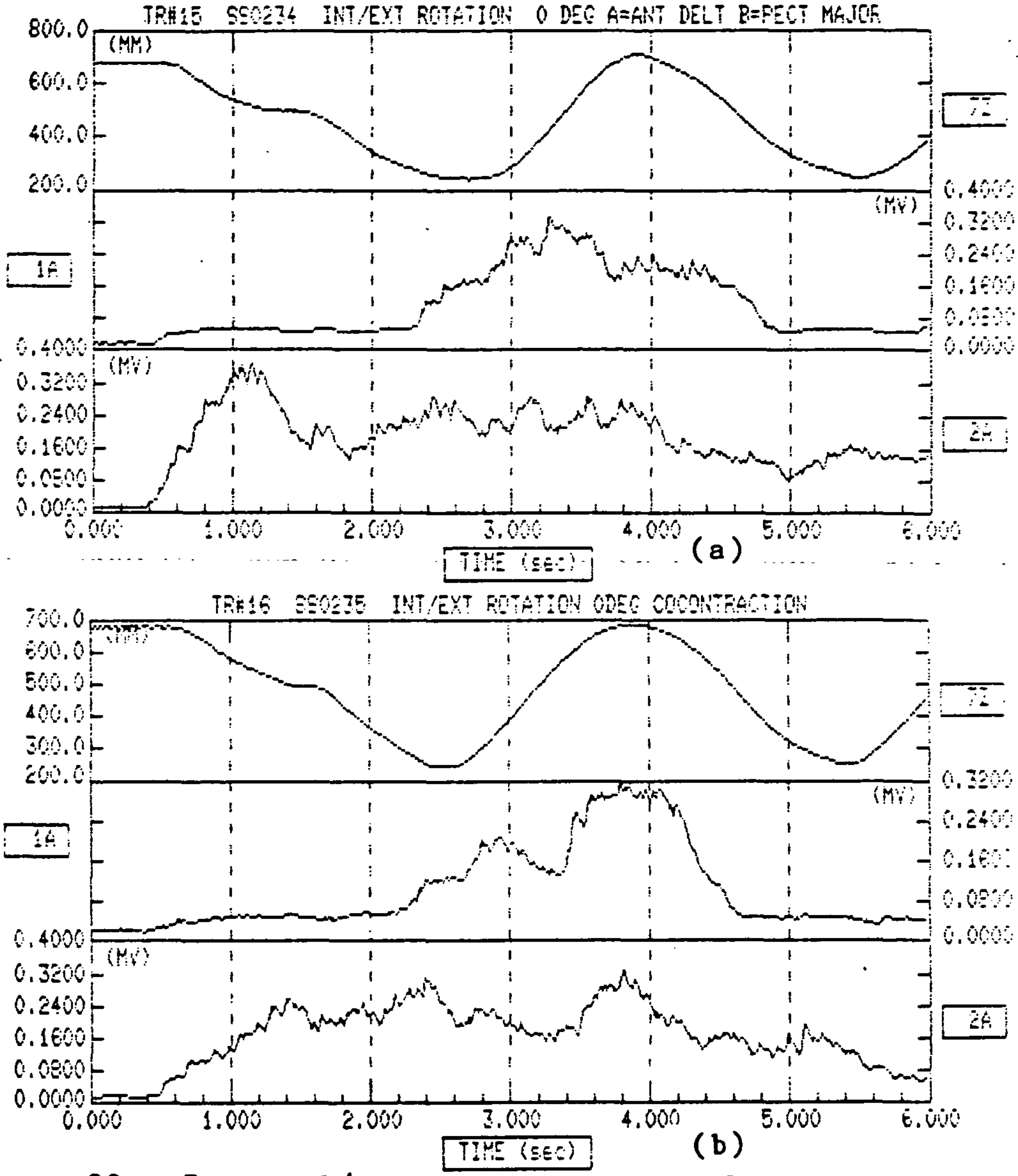


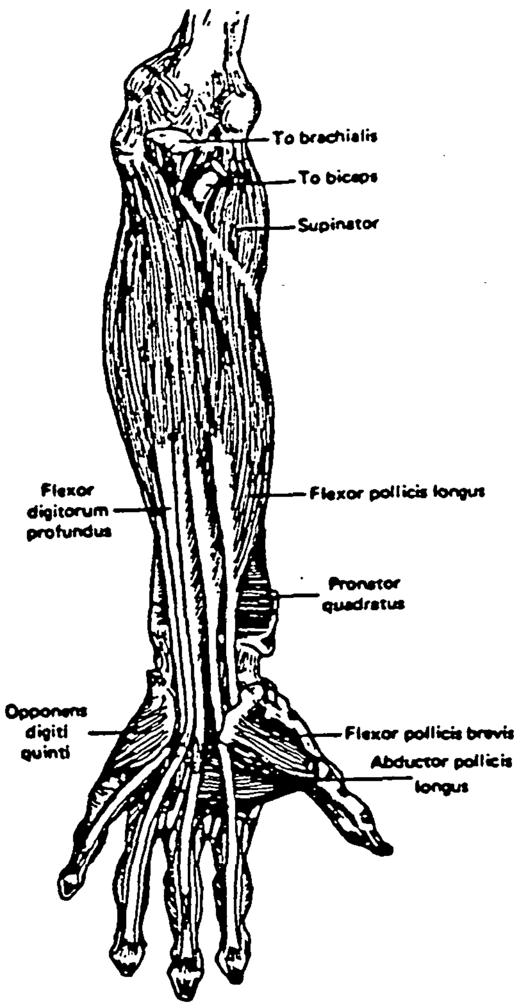
<u>Figure 32.</u> Internal/external rotation of the humerus in the transverse plane about a vertical axis.

Wrist Flexion/Extension and Grip Movements

3.0 Anatomical Considerations

A gripping motion, generally performed with a slight degree of wrist extension, requires flexion across the interphalangeal and metacarpal joints. The muscles responsible for the gripping action are located in the forearm, with long tendons running distally to the fingers. More specifically, these finger and wrist flexors originate from the medial epicondyle of the humerus. This flexor group includes the flexor digitorum profundus, flexor digitorum superficialis, flexor pollicis longus, flexor carpi ulnaris, flexor carpi radialis, and the palmaris longus. As a group, these muscles are responsible for creating the grip. Recording EMG activity during the grip comes not from any individual muscle, but is a global signal from the flexor group (Figure 9).

Those muscles responsible for release of the grip, or extension of the wrist and fingers have a common origin on the lateral epicondyle of the humerus. This extensor group includes the extensor carpi radialis brevis, extensor carpi radialis longus, extensor carpi ulnaris, and the extensor digitorum (Figure 10). Like the flexor group, the EMG extensor signal comes from a group of muscles rather than any single muscle.



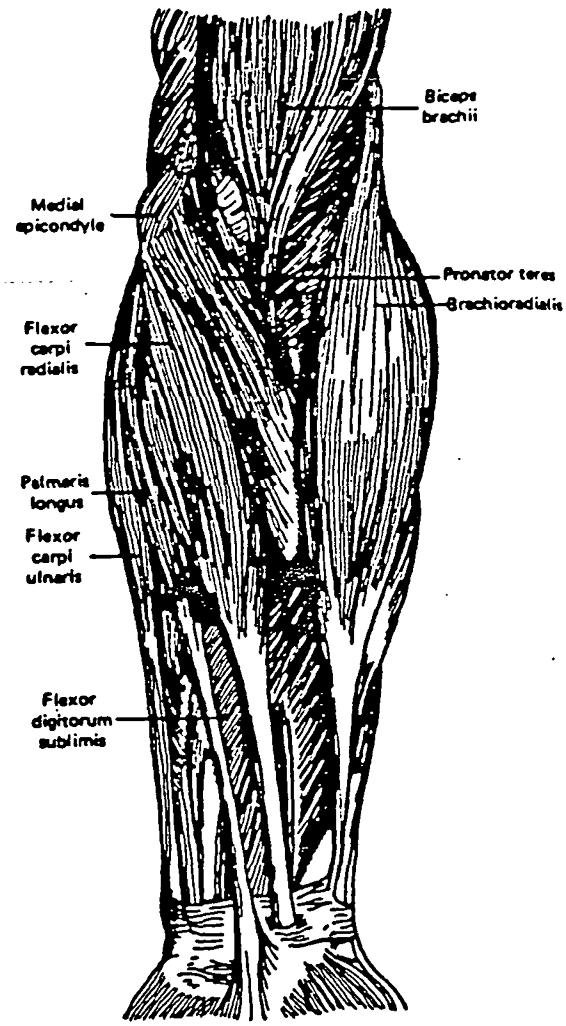


Figure 9. Anterior view of the left forearm and hand muscles: (a) deep muscles, (b) superficial muscles. (Adapted from Kinesiology: The Science of Movement (p. 82) by J. Piscopo and J. A. Baley, 1981, New York: Wiley.)

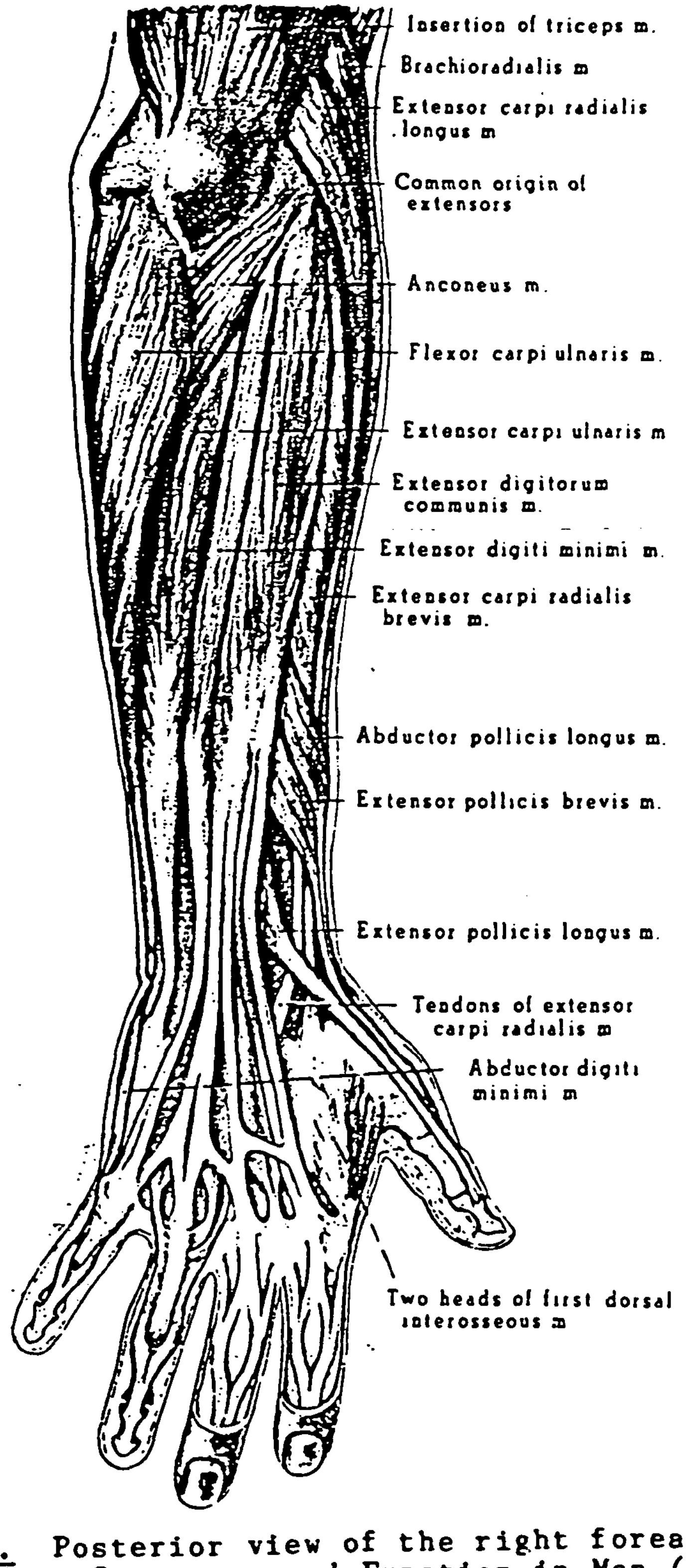


Figure 10. Posterior view of the right forearm and hand. (Adapted from Structure and Function in Man (p. 160) by S. W. Jacob and C. A. Francone, 1974, Philadelphia: W. B. Saunders Company.)

This global EMG recording is a function of methodology and anatomy. The body is a volume conductor of electrical signals. Given the close spatial arrangement of the flexor (or extensor) muscles, surface electrodes are generally incapable of distinguishing among the muscles - presuming of course that only a select number of the flexors were to act during the movement. Thus the EMG record may contain activity from numerous muscles used to perform a similar function.

3.1 Wrist Flexion/Extension and Grasping Data

3.1.1 Grasping

Special conditions: With and without cocontraction; supported and unsupported forearm (Phase I only).

EMG: flexor and extensor groups

Description: The forearm was held in a flexed position such that the elbow angle approximated 90°. The fingers were held straight and the thumb moved in opposition to the fingers in a pincer movement. The EMG signal was recorded from locations approximating the flexor group (distal to the medial epicondyle) and the extensor group (distal to the lateral epicondyle, anterior surface of the forearm).

Figures: D33 a,b,c;
Top strip chart (5Y) = displacement representing a change in grip opening. Peaks (e.g. 740 mm) indicate maximum closure of the grip. Minimum values (640 mm) indicate maximum opening of the grip. Second strip chart (1A) = EMG recording from the flexors. Third strip chart (2A) = EMG recording from the extensors.

Observations:

In Figure D33a, extensor activity seemed well correlated with opening the grip. The flexor activity seemed poorly differentiated. In response to the poor flexor recording, the electrodes were moved to a location more medial on the forearm. Figures D33b,c although still somewhat noisey, showed much greater definition in activation of the flexors versus the extensors. Trials 33b and 33c showed good phasic patterns for the two antagonist muscle groups.

While good correlation between muscle activation and position data was evident, one must be reminded that the grasping motion was being done in isolation. Previous tests have already alluded to the difficulty of identifying specific muscle action in multi-segmented, coordinated action.

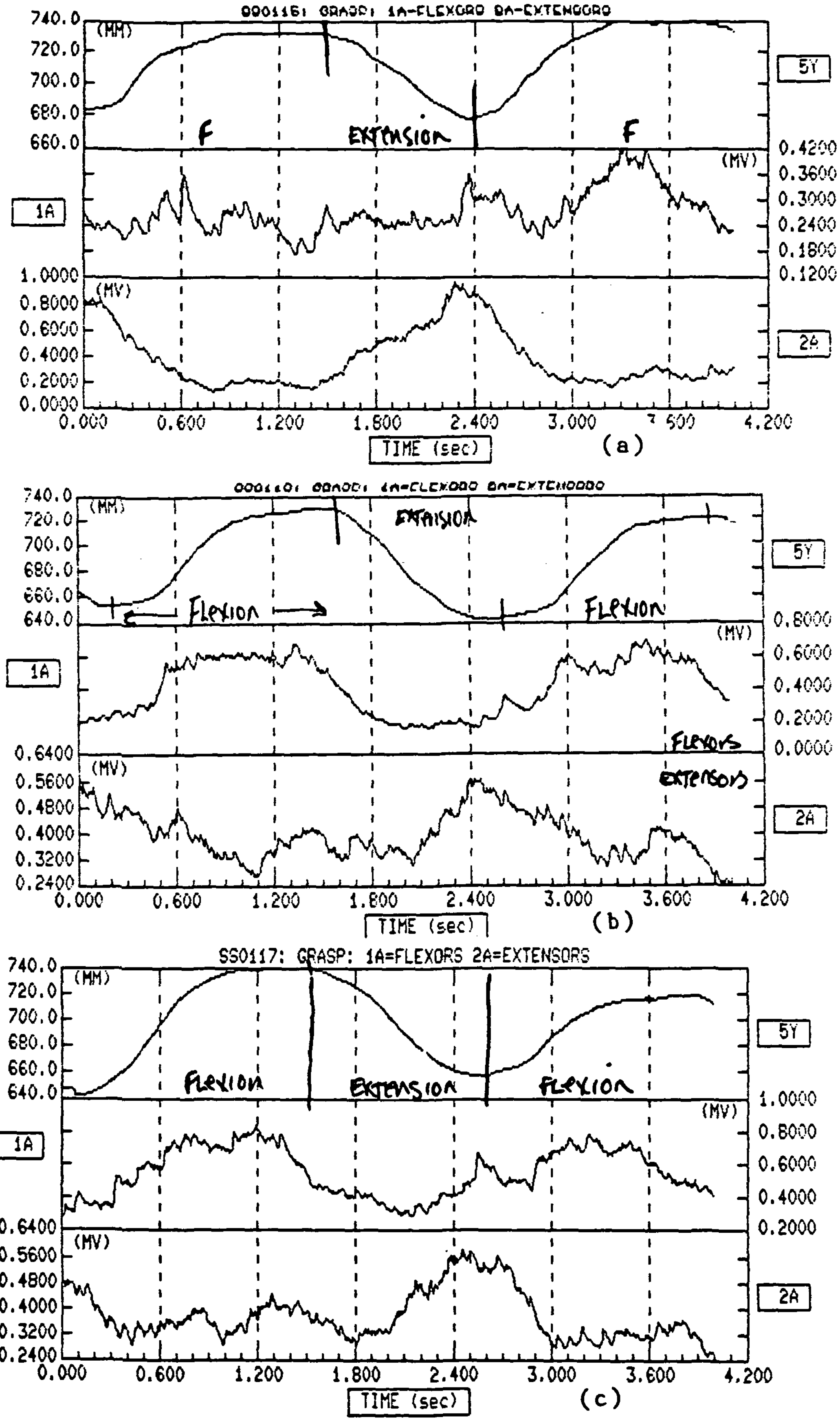


Figure 33. Grasping

3.1.2 Wrist Flexion/Extension; Sagittal Plane

Special conditions: Accelerated movement with an isometric contraction at joint reversals; Flexion only with isometric contraction at joint reversal; (Phase II only)

EMG: flexor and extensor groups

Description: Task 1: Initial position; subject seated with arm relaxed at the side in FAP. From this position the wrist was rapidly extended, approximately 45°, held in an isometric contraction at full extension, then rapidly flexed, approximately 45° and held in an isometric contraction at full flexion. This action was repeated. Task 2: From the same initial position the wrist was flexed approximately 45°, held in an isometric contraction at full flexion, then returned to FAP. This action was repeated several times.

Figures: D34 a,b; flexion/extension: D35 a,b,c,d; flexion only. The EMG record for both the flexors and extensors is shown in the top graphs of D34a,b. The bottom graphs of these figures = displacement representing a change in the wrist angle (peaks indicate maximum flexion; valleys indicate maximum extension). EMG activity of the wrist flexors is shown in the top graphs of D35a,c and the bottom graphs of D35b,d. Displacement representing a change in the wrist angle is shown in the bottom graphs of D35a,c (peaks indicate maximum flexion; valleys indicate a return to FAP) Raw EMG wrist flexor data is shown in the bottom graphs of D35b,d.

Observations:

Wrist flexion EMG activity correlated well with the wrist flexion movement (Figures D34a,b). There was a sharp peak in activity, as the wrist was rapidly flexed, which tapered off as the wrist was held in an isometric contraction at maximum flexion. During rapid wrist extension, there was an increase in EMG wrist extensor activity, but there also was low level flexor activity. Both muscle groups had elevated activity during the isometric contraction in the maximally extended position.

In the flexion only task, EMG activity of the wrist flexors clearly peaked as the wrist was rapidly flexed, and gradually tapered off with the isometric contraction and return to FAP (Figures D35a,c). The raw EMG wrist flexor data showed distinctive bursts of activity with rapid flexion (Figures D35b,d). In both tasks, a rapid wrist flexion movement clearly demonstrated a relationship with the displacement graph. Thus, perhaps this movement could be used as a "trigger movement", a movement performed by the robot operator which elicits a different yet similar movement in the robot. For example, since the grasping data and the forearm pronation/supination data to be presented later, did not clearly demonstrate phasic activity in all cases, perhaps a rapid wrist flexion movement by the robot operator could be used to create a grasping movement or forearm pronation/supination in the robot.

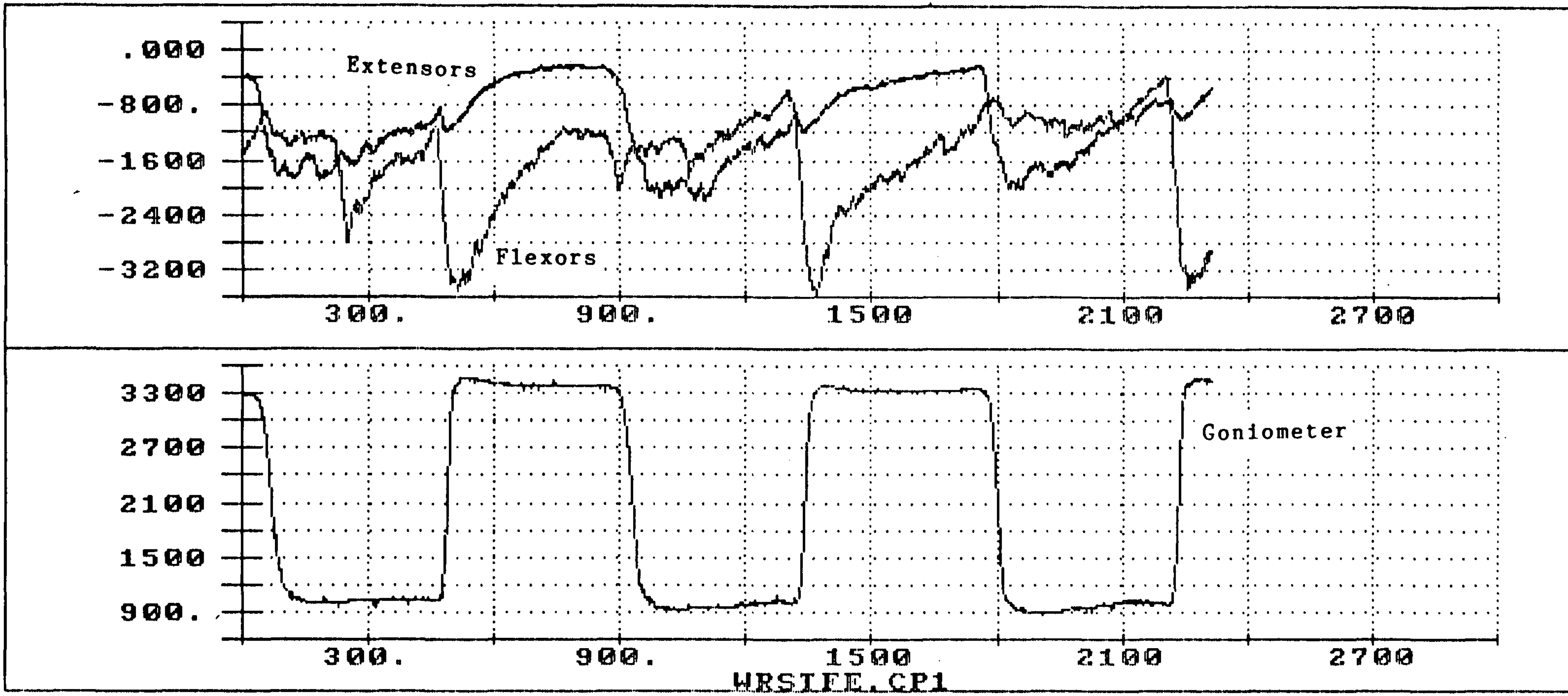


Figure 34a. WRIST FLEXION & EXTENSION IN THE SAGITTAL PLANE
Accelerated with Hold

MOVEMENT SPEED: Fast SAMPLING RATE: 300 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

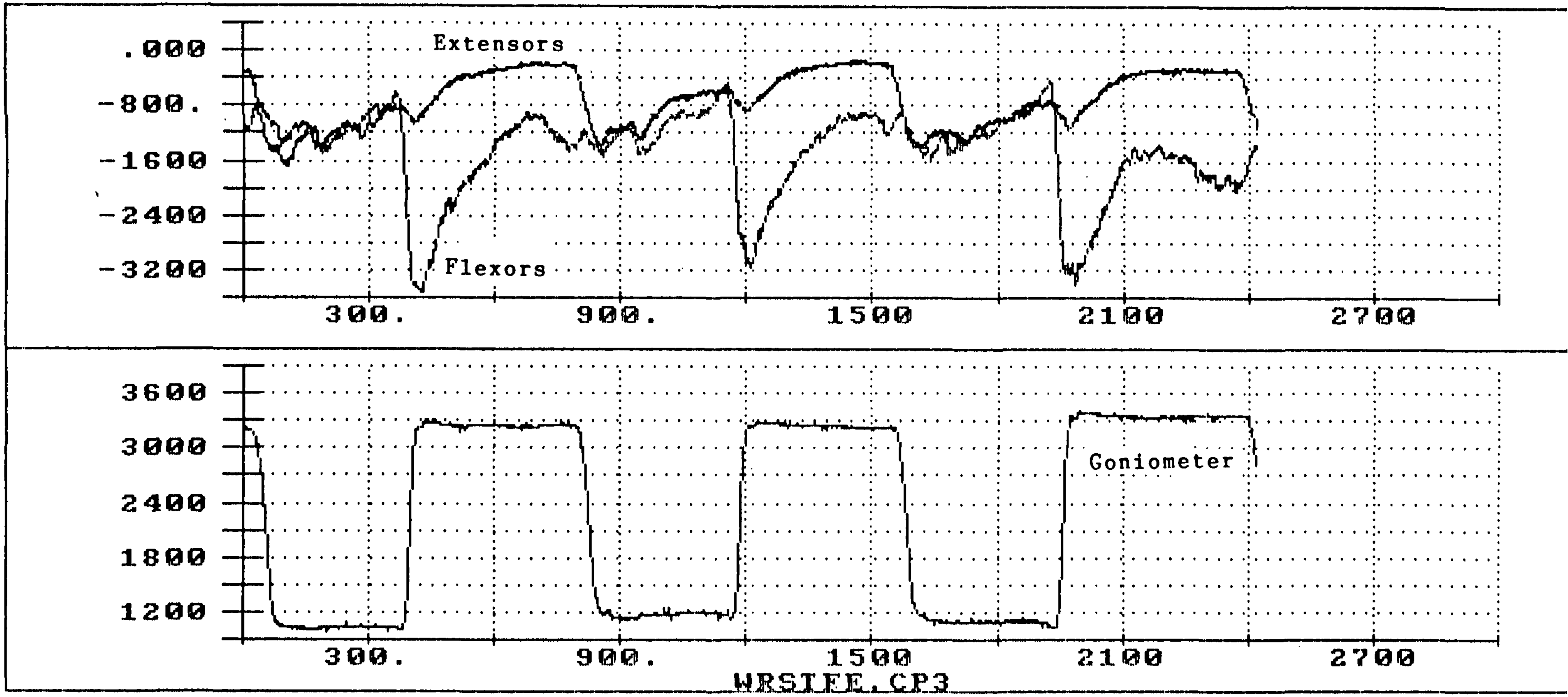


Figure 34b. WRIST FLEXION & EXTENSION IN THE SAGITTAL PLANE
Accelerated with Hold

MOVEMENT SPEED: Fast SAMPLING RATE: 300 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

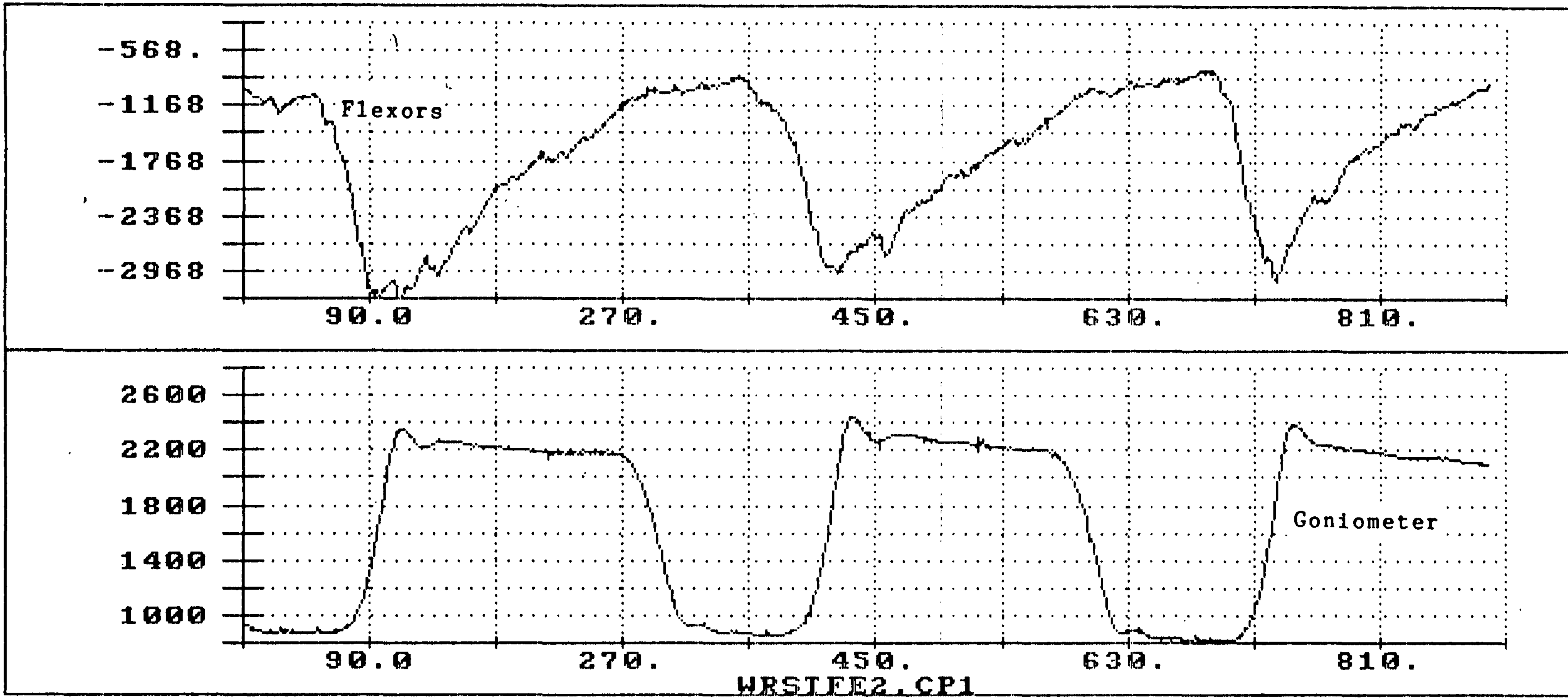


Figure 35a. WRIST EXTENSION IN THE SAGITTAL PLANE
Fast with no Hold

MOVEMENT SPEED: Fast SAMPLING RATE: 400 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion to Neutral
Decreasing Signal Magnitude -- Elbow Extension

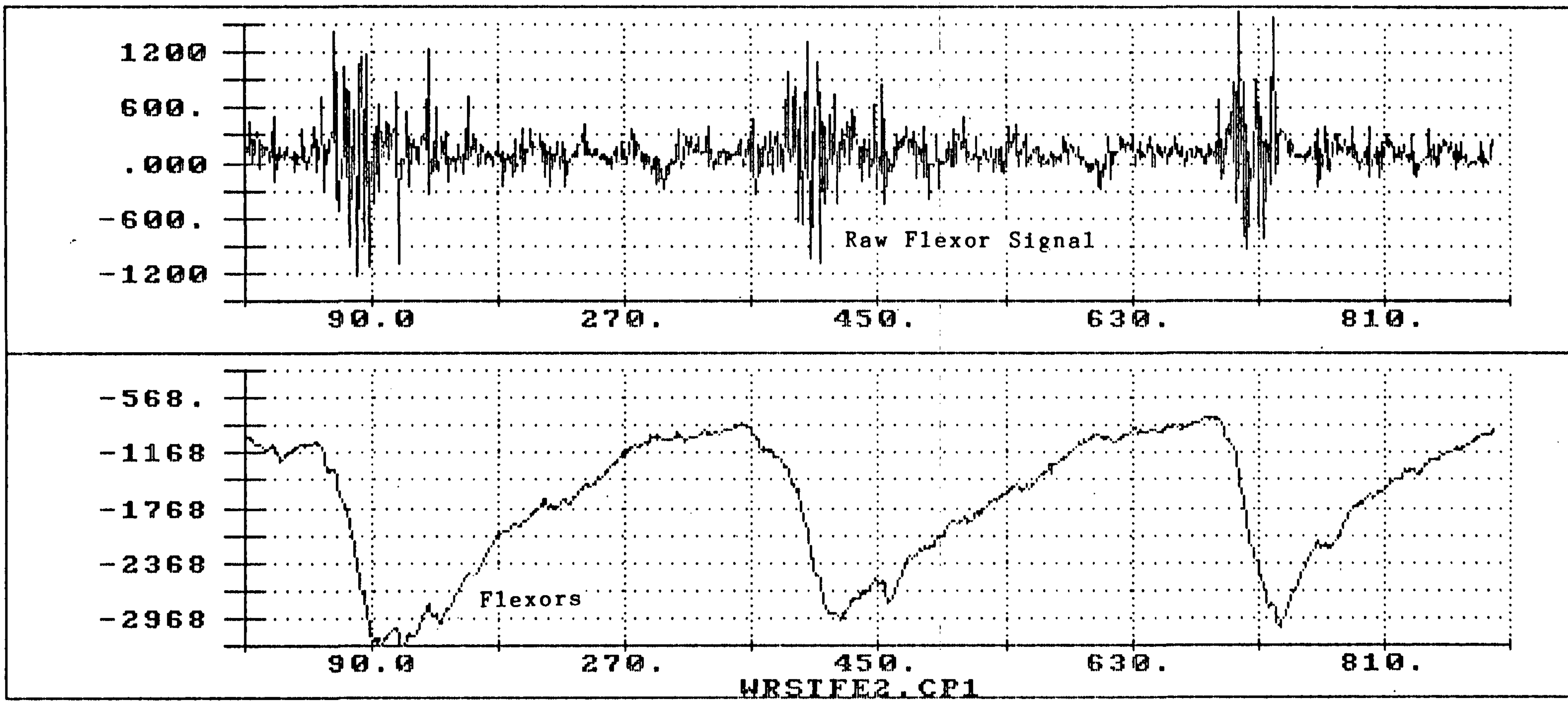


Figure 35b. WRIST EXTENSION IN THE SAGITTAL PLANE
Fast with no Hold

MOVEMENT SPEED: Fast SAMPLING RATE: 400 Samples/Sec/Channel

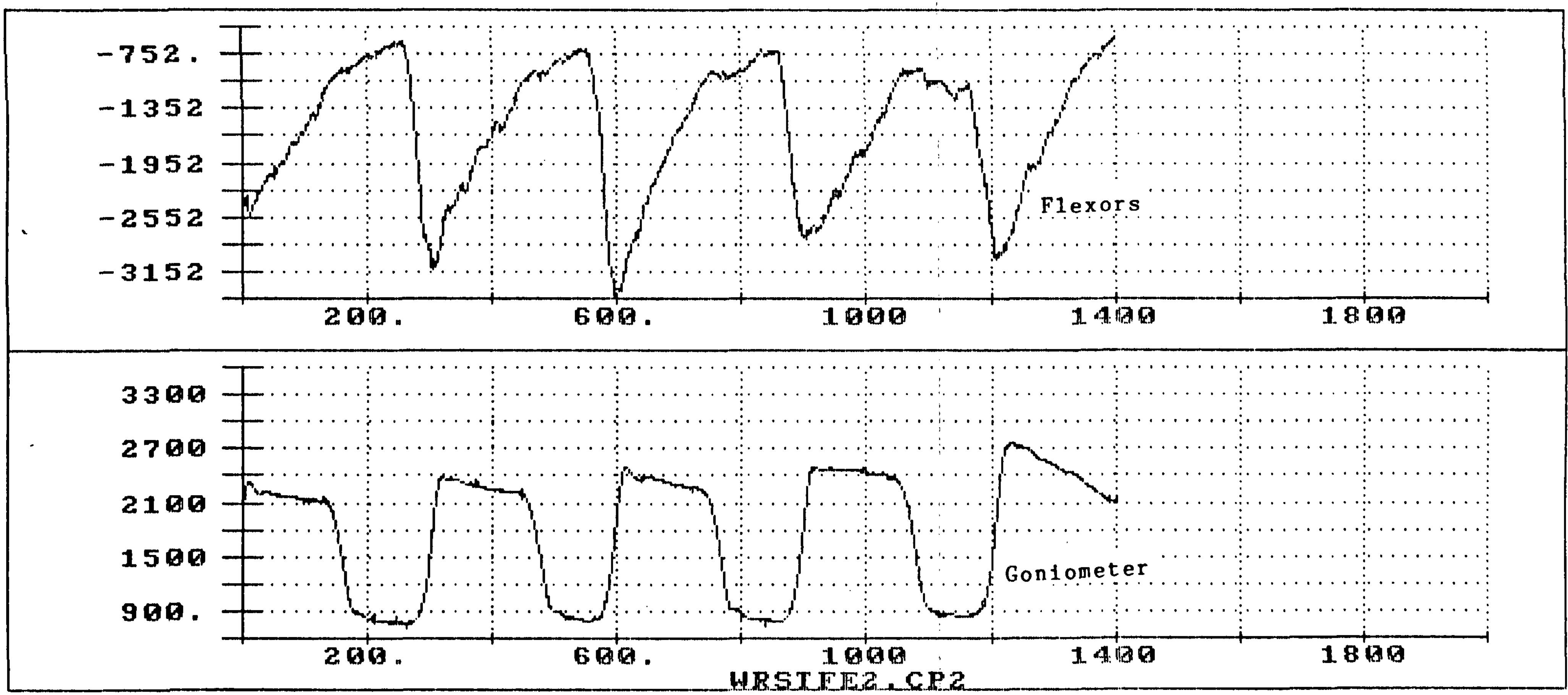


Figure 35c. WRIST EXTENSION IN THE SAGITTAL PLANE
Fast with no Hold

MOVEMENT SPEED: Fast SAMPLING RATE: 400 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion to Neutral
Decreasing Signal Magnitude -- Elbow Extension

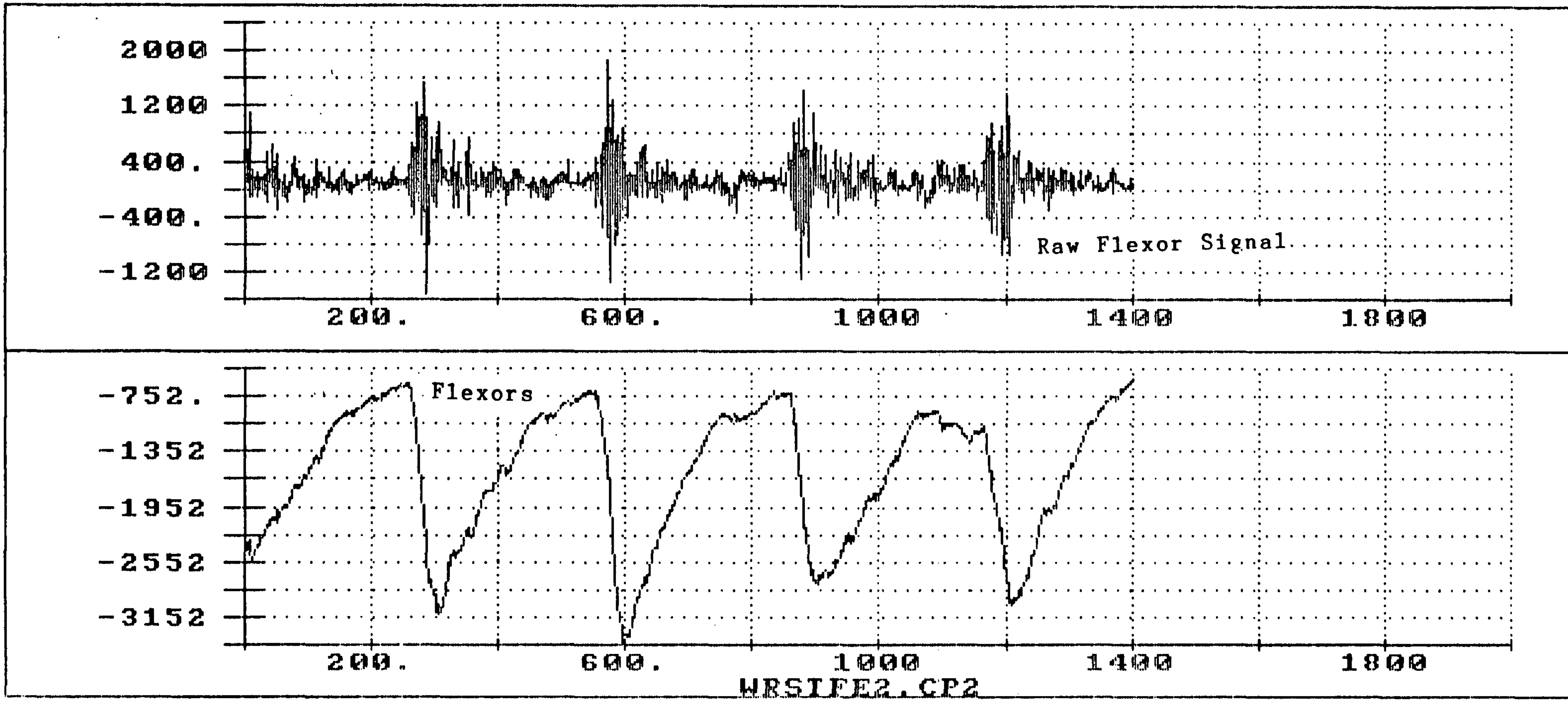


Figure 35d. WRIST EXTENSION IN THE SAGITTAL PLANE
Fast with no Hold

MOVEMENT SPEED: Fast SAMPLING RATE: 400 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion to Neutral
Decreasing Signal Magnitude -- Elbow Extension

3.1.3 Wrist Flexion/Extension; Transverse Plane

Special conditions: Fast and slow movement speeds (Phase II only)

EMG: flexor and extensor groups

Description: Initial position; subject seated with arm flexed to create a 90° intersegmental angle at the elbow. The bilateral axis for wrist flexion was placed co-linear with the goniometer axis of rotation (i.e. the wrist was fixed on top of the rotary axis of the goniometer). In this position, hand movement toward the body was indicative of wrist flexion and hand movement away from the body marked wrist extension. The entire movement consisted of wrist flexion (approximately 60°), then extension to neutral position and approximately 45° beyond that position.

Figures: D36 a; fast: D37 a,b; slow.
The EMG record for both the flexors and extensors is shown in D37a and the top graph of D36a. Figure D37b and the bottom graph of D36a = displacement representing a change in the wrist angle (peaks indicate maximum flexion; valleys indicate maximum extension).

Observations:

Since both of these movements were conducted in the transverse plane, increased wrist extensor activity and decreased wrist flexor activity were expected with wrist extension. Decreased wrist extensor activity and increased wrist flexor activity were expected with wrist flexion. Movement at both speeds clearly reflected these patterns, despite the slower sampling rates used (Figures D36a, D37a,b). (It is possible that the muscles were firing at frequencies that were adequately detected by the sampling rates.) Perhaps wrist flexion/extension movements in the horizontal plane would be better trigger movements for forearm pronation/supination.

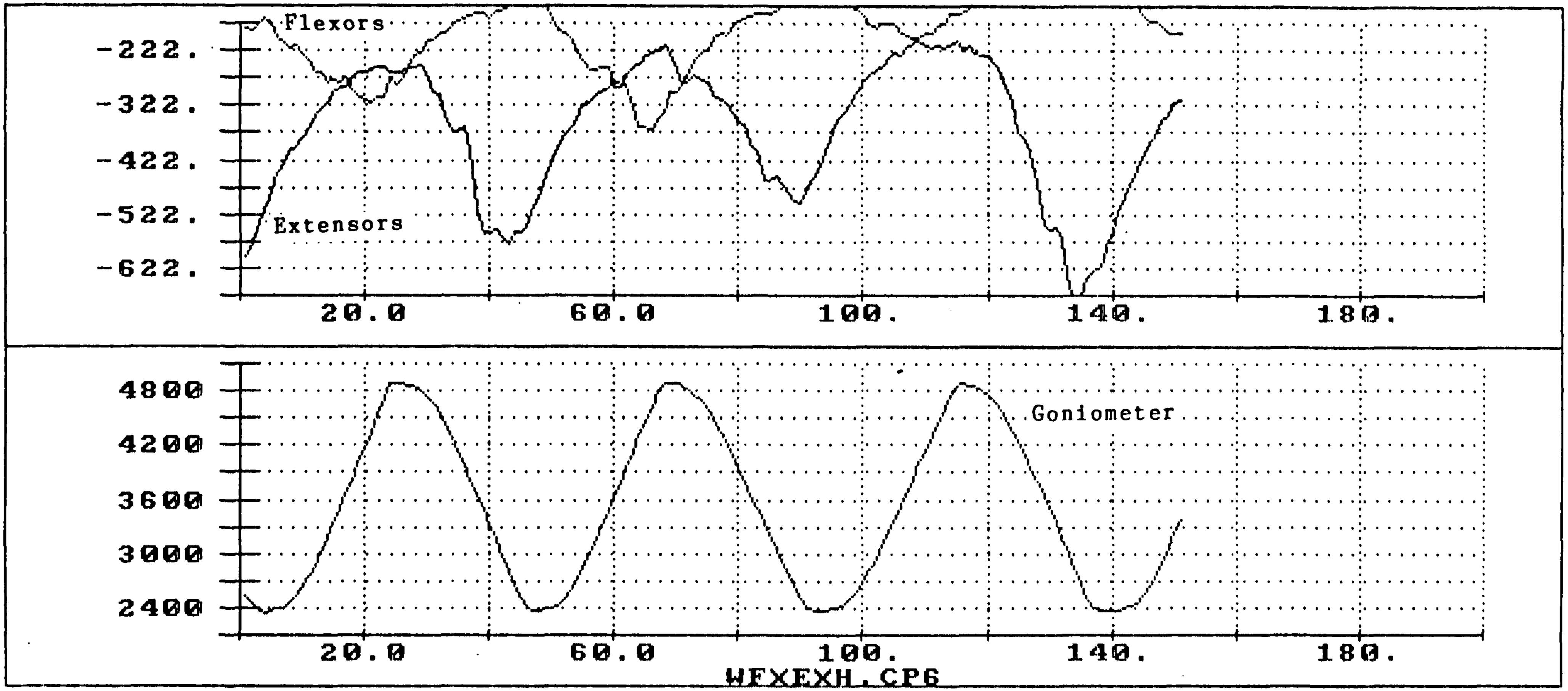


Figure 36a. **WRIST FLEXION & EXTENSION IN THE TRANSVERSE PLANE**

MOVEMENT SPEED: Fast SAMPLING RATE: 80 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Wrist Flexion
Decreasing Signal Magnitude -- Wrist Extension

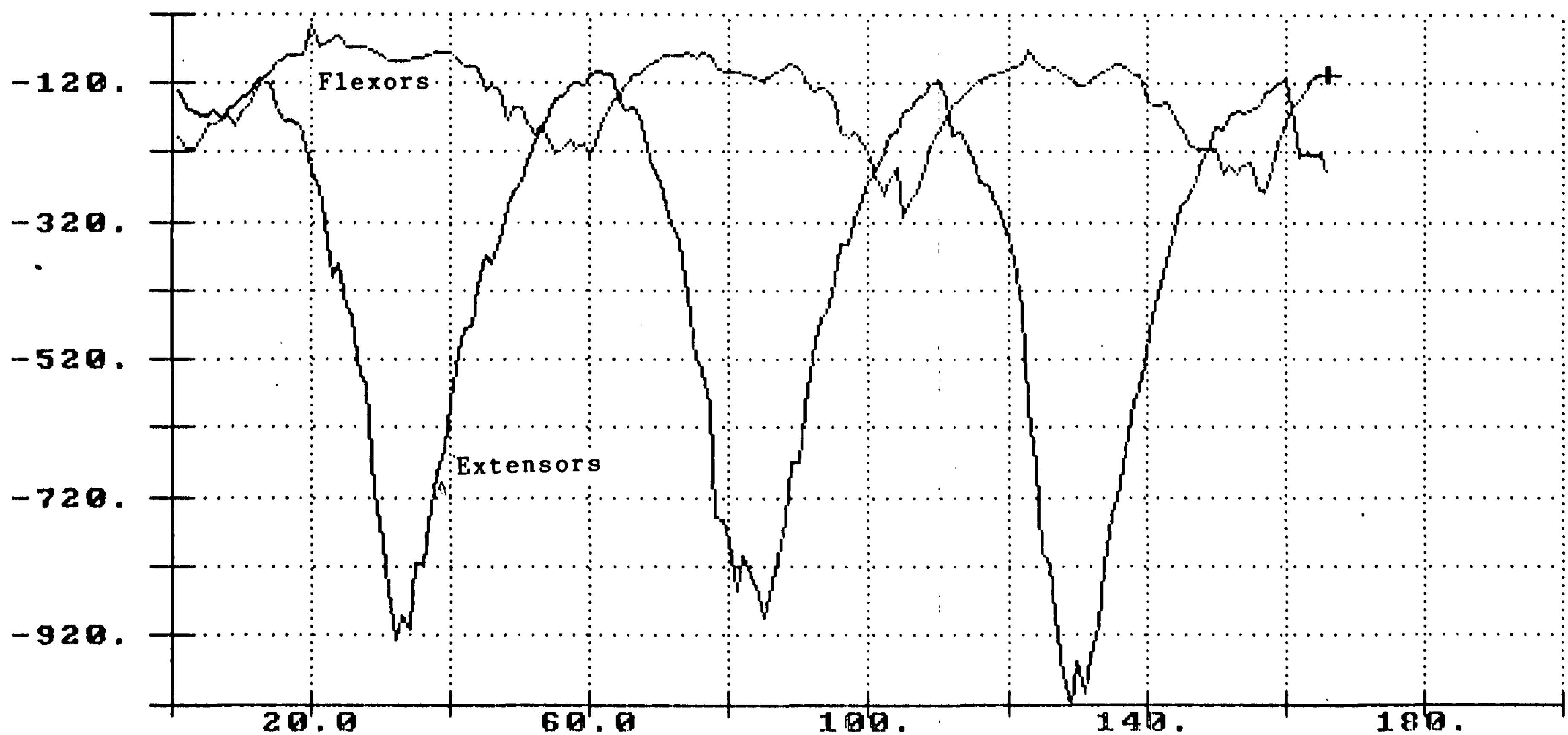


Figure 37a. WRIST FLEXION & EXTENSION IN THE TRANSVERSE PLANE

MOVEMENT SPEED: Slow SAMPLING RATE: 40 Samples/Sec/Channel

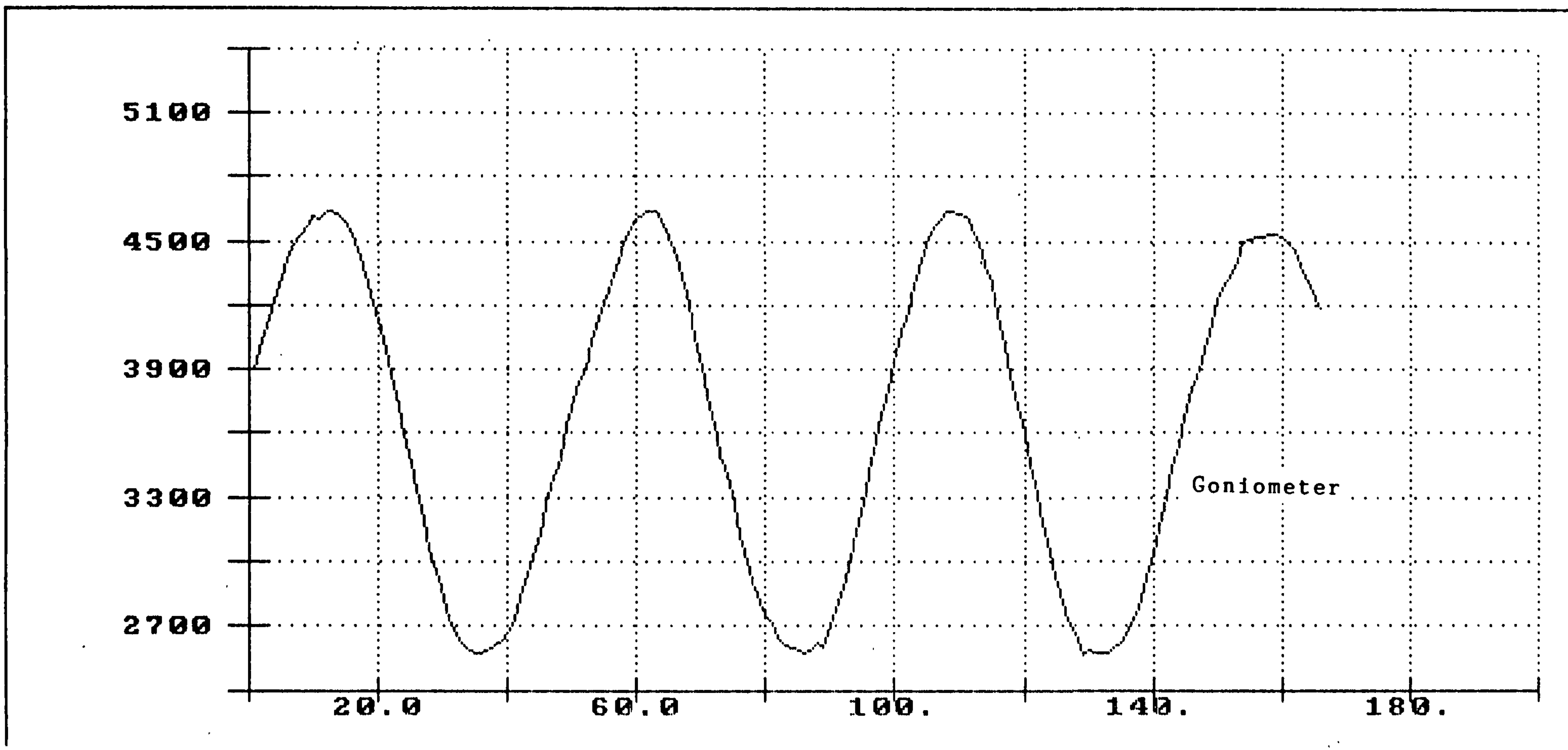


Figure 37b. **WRIST FLEXION & EXTENSION IN THE TRANSVERSE PLANE**

MOVEMENT SPEED: Slow SAMPLING RATE: 40 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Wrist Flexion
Decreasing Signal Magnitude -- Wrist Extension

Radioulnar Pronation/Supination

4.0 Anatomical Considerations

Pronation and supination are movements that result from the rotation of the radius about a fixed ulna (refer to Figure 11). The effect of pronation is to put the hand in a palm-down position, whereas supination places the hand in a palm-up position.

The muscles responsible for supination and pronation are listed below:

Action	Prime Mover	Assisted by
Supination	Supinator	Biceps brachii
Pronation	Pronator quadratus Pronator teres	

It is important to note the topographical arrangement of the pronator and supinator muscles. Although the pronator teres is a superficial muscle of the forearm, it lies in proximity to the flexor muscles responsible for the grip. Obtaining a clean EMG signal from the pronator teres, distinct from the flexor group is hampered by this arrangement. The pronator quadratus is a deep muscle in the distal forearm, and thus inaccessible for direct EMG recording from surface electrodes.

The supinator is also a deep muscle of the forearm (proximal end). Although the prime mover for supination of

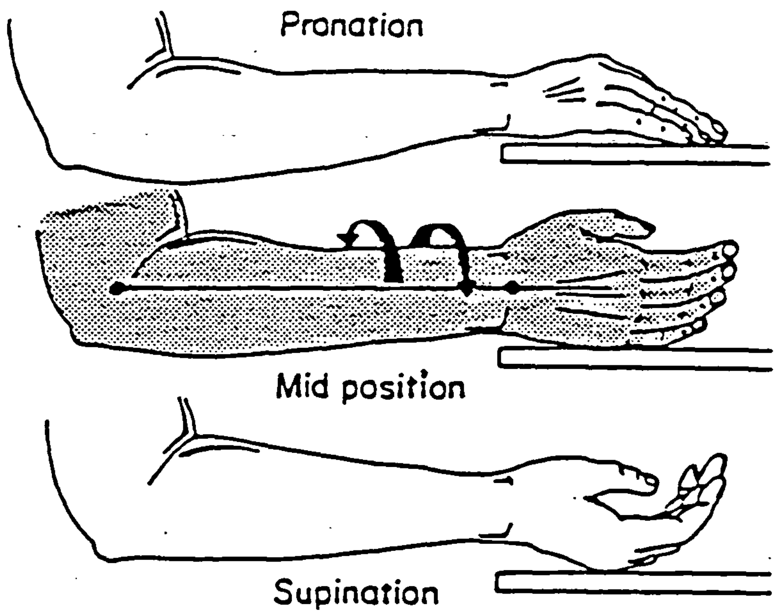


Figure 11. **Pronation and supination of the forearm.** (Adapted from Kinesiology Fundamentals of Motion Descripition (p. 75) by D. L. Kelley, 1971, New Jersey: Prentice-Hall.)

the forearm, it is covered in large part by the extensor muscle group. Thus the EMG signal from the supinator is compromised by any concurrent activity from the wrist and finger extensors. The difficulty of separating flexion and extension signals from pronation and supination will be pointed out during discussion of the data.

4.1 Pronation/Supination Data

4.1.1 Forearm Pronation/Supination Movement About the Long Axis of the Forearm (flexed to 90°).

Special conditions: With and without cocontraction; (Phase I only)

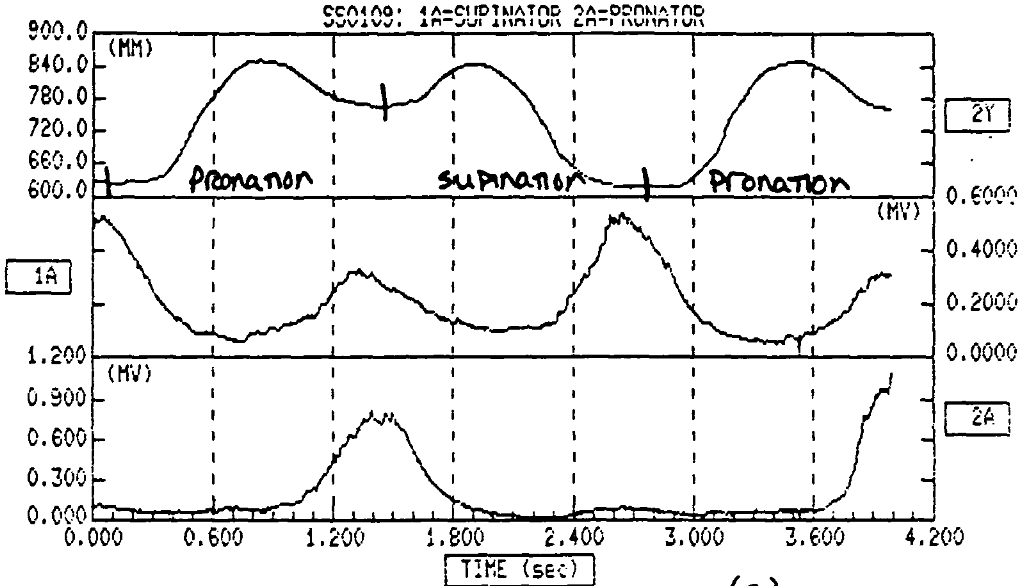
EMG: supinator and pronator teres

Description: The forearm was flexed to create a 90° intersegmental angle at the elbow. To facilitate obtaining position information about pronation and supination, a ruler was placed in the hand and the LEDs were attached to each end of the ruler. The vertical displacement of the upper LED was plotted as indicative of rotation. The subject started in a fully supinated position, rotated to full pronation and returned to the starting position. This sequence was repeated throughout the trial. The EMG signal was recorded from locations approximating the supinator and the pronator teres.

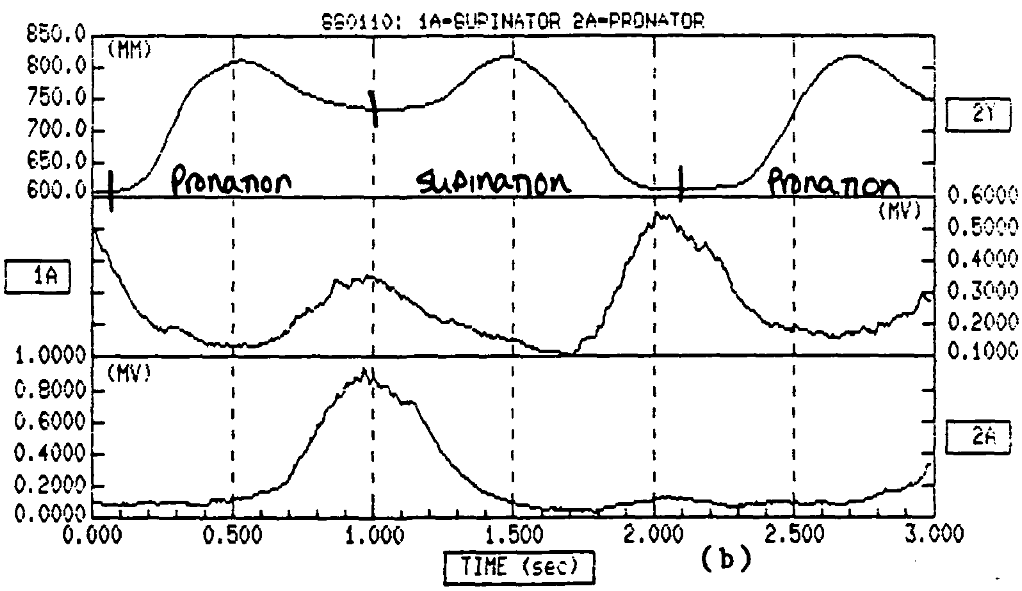
Figures: D38 a,b;
Top strip chart (2Y) = displacement representing a change in rotation angle. Peaks (e.g. 800 mm) indicate a neutral forearm position. The small valley between peaks represents the move from a neutral forearm position to maximum pronation. Minimum values (e.g. 600 mm) indicate maximum supination. Second strip chart (1A) = EMG recording from the supinator. Third strip chart (2A) = EMG recording from the pronator teres.

Observations:

In Figure D38a,b the supinator appeared active at full supination but its activity dropped off quickly as the forearm was pronated. The pronator teres peaked at the extremes of pronated motion, but showed little activity the first 90° of rotation. While the pronator showed a peak, the supinator also showed a small peak in activity (1.4 sec). This supinator peak may have less to do with activity of the supinator and reflect flexor activity. At the extremes of supination, the supinator showed a strong peak. But like the pronator, supinator activity was observed mostly at the extremes of motion.



(a)



(b)

Figure 38. Pronation/supination of the forearm.

4.1.2 Forearm Pronation/Supination: Movement About the Long Axis of the Forearm (flexed to 90°)

Special conditions: With and without cocontraction; (Phase I only).

EMG: supinator and biceps brachii

Description: The forearm was flexed to create a 90° intersegmental angle at the elbow. To facilitate obtaining position information about pronation and supination, a ruler was placed in the hand and the LEDs were attached to each end of the ruler. The vertical displacement of the upper LED was plotted as indicative of rotation. Subject started in a fully supinated position, rotated to full pronation and returned to the starting position. This sequence was repeated throughout the trial. The EMG signal was recorded from locations approximating the supinator and the belly of the biceps brachii.

Figures: D39 a,b;
Top strip chart (2Y) = displacement representing a change in rotation angle. Peaks (e.g. 800 mm) indicate a neutral forearm position. The small valley between peaks represents the move from a neutral forearm position to maximum pronation. Minimum values (600 mm) indicate maximum supination. Second strip chart (1A) = EMG recording from the supinator. Third strip chart (2A) = EMG recording from the biceps brachii.

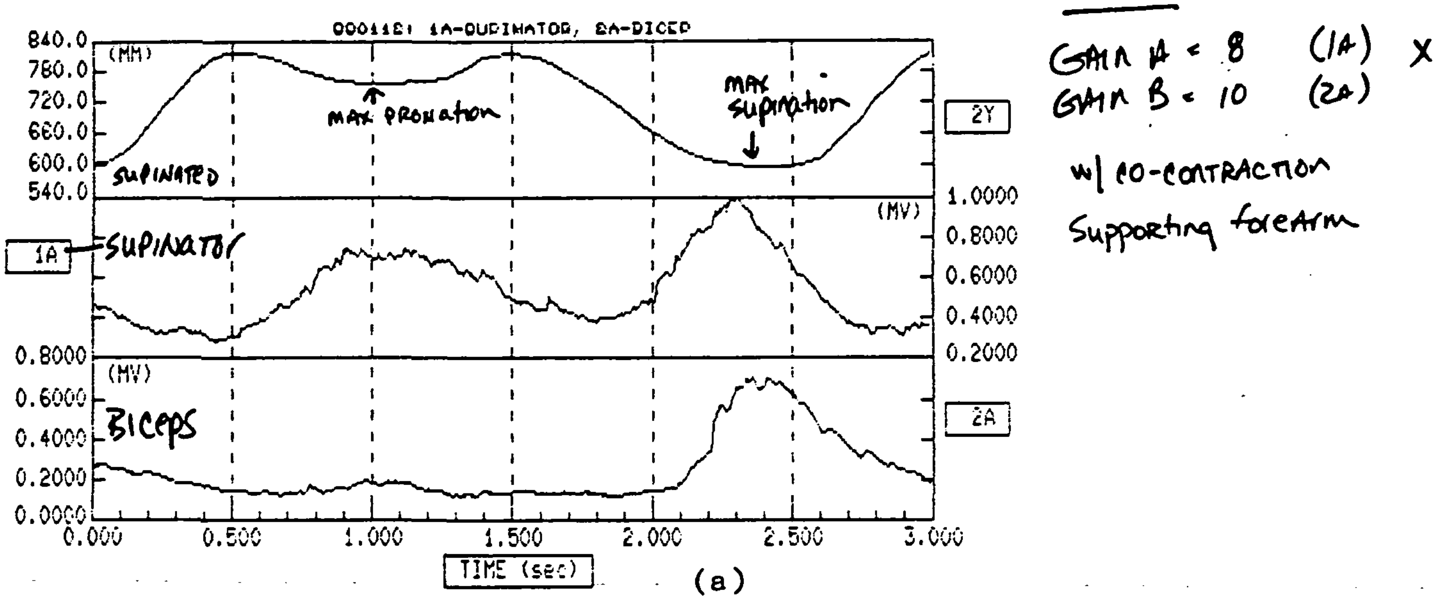
Observations:

The biceps is known to assist in supination due to its angle of pull on the radius. If the supinator is accurately marked by the recording electrodes, then supinator and biceps activity should coincide.

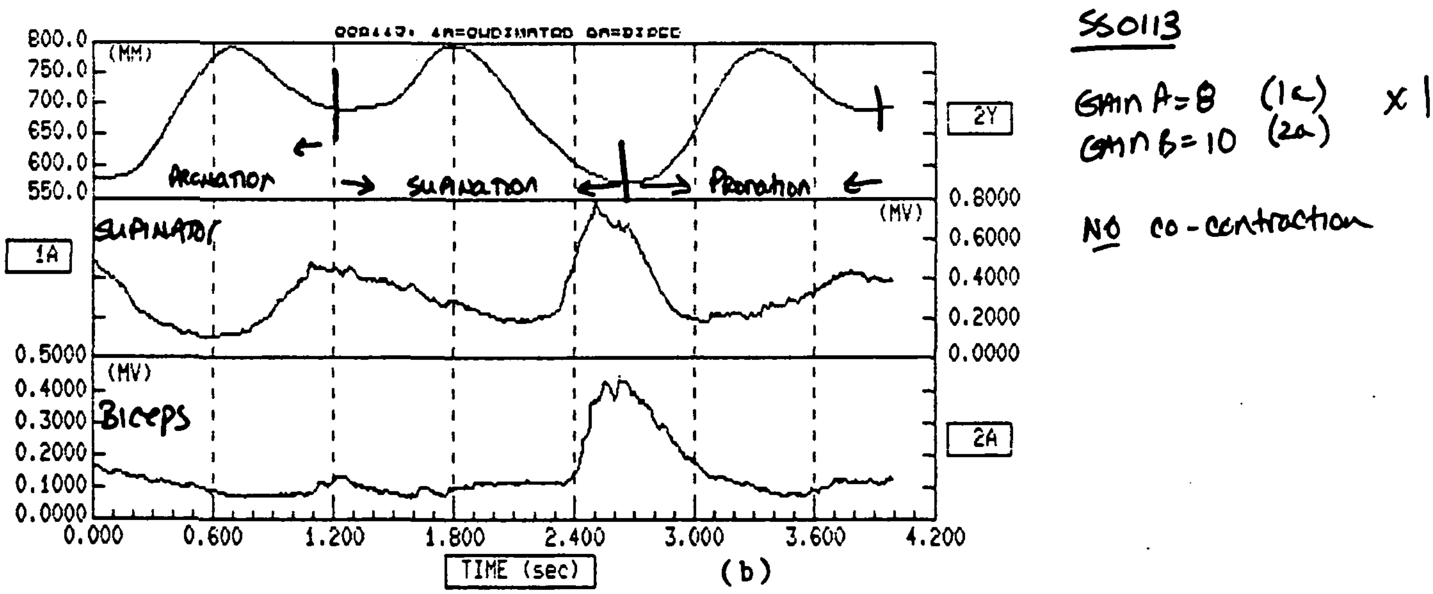
In Figure D39a,b the in-phase relationship between activation of the supinator and the biceps brachii is shown. Again, the activation is predominant at the extremes of motion.

While supinator activity may be accessible to surface recording, the problem of contaminating the signal with finger and wrist flexor activity persists. Also, we see that biceps activation may be induced not only in the control of the forearm flexion angle, but also in forearm rotation.

Pronation | Supination
EMG: Supinator
Biceps



(a)



(b)

Figure 39. Pronation/supination of the forearm.

Finger Movements

5.0 Anatomical Considerations

Numerous muscles exist within the human hand, providing great dexterity. Since many of these small muscles lie deep within the hand, investigation of their functions through surface electrodes was not feasiable. However, a few of the hand muscles, such as the adductor pollicus and the abductor digiti minimi are more superifical. These muscles and their corresponding movements were investigated for two reasons: it was thought that they may be used to trigger other movements (See Section 3.1.2); and later during the project it was discovered that the robot would have the capability to move each finger.

The adductor pollicus muscle, which spans from the small bones of the wrist and the third metacarpel to the first phalanx of the thumb (Figure 12) is the sole muscle responsible for thumb adduction during low force contractions (Bigland-Ritchie, 1981). This characteristic makes it a very suitable muscle for investigation. Since the adductor is a small muscle which lies within close proximity of the abductor pollicus brevis and the flexor pollicus brevis, EMG activity from these muscles may also be detected with surface electrodes. However, if the thumb remains extended and the movement takes place such that

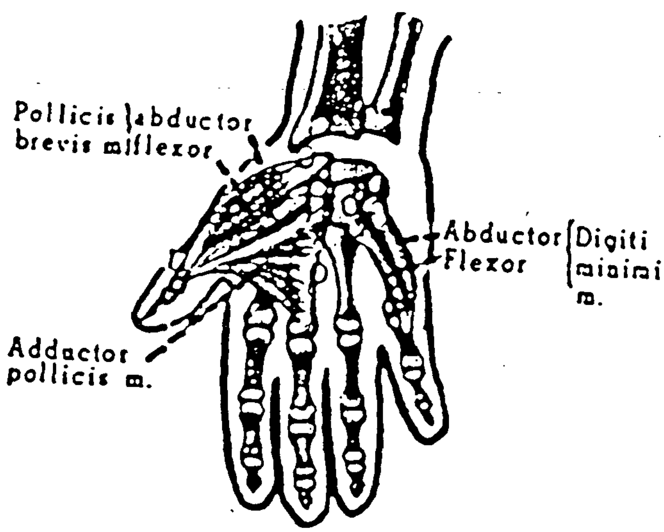


Figure 12. Anterior view of the adductor muscles of the thumb and abductor muscles of the fifth digit on the right hand. (Adapted from Structure and Function in Man (p. 163) by S. W. Jacob and C. A. Francone, 1974, Philadelphia: W. B. Saunders Company.)

gravity is the force initiating thumb abduction, the activity from these two muscles would be minimized.

The abductor digiti minimi (ADM) originates from the pisiform bone of the wrist and the flexor carpi ulnaris tendon, and inserts at the base of the proximal phalanx of the fifth digit (i.e. the pinky) (Figure 12). The ADM is not the only abductor of the pinky, but the other abductors (i.e. the interossei dorsales and opponens digiti minimi) are deeper muscles. Since the flexor digiti minimi brevis lies within close proximity to the ADM, an investigation with surface electrodes may also detect pinky flexion. However, as mentioned for thumb movement, if the pinky remains extended during an abduction task, EMG activity from the flexor muscle would be minimized.

5.1 Finger Movement Data

5.1.1 Thumb Adduction/Abduction

Special conditions: With and without cocontraction (Phase II only)

EMG: adductor pollicus

Description: Initial position; subject seated with forearm fully supinated and flexed to create a 90° inter-segmental angle at the elbow; thumb held fully extended and abducted. The movement included the full ROM (maximum thumb adduction (i.e. without thumb flexion), then maximum thumb abduction). The thumb remained extended throughout the entire ROM.

Figures: D40 a; no cocontraction; D41 a; cocontraction. The EMG record for the adductor pollicus is shown in both D40a and D41a. Unfortunately measurement of thumb dis- placement was not possible given the nature of the movement and the size of the joint compared to the size of the goniometer.

Observations:

There appeared to be a on/off pattern to the adductor pollicus activity during both tasks (Figures D40a, D41a). During the data collection process it was observed that the rise and peak in adductor pollicus activity was coincident with thumb adduction and the fall in activity with thumb abduction. This EMG activity seemed fairly distinctive, however thumb adduction without thumb flexion is not a natural movement, but one which takes some concentration and practice. Thus thumb adduction/abduction may have potential for controlling a robot, but needs further investigation.

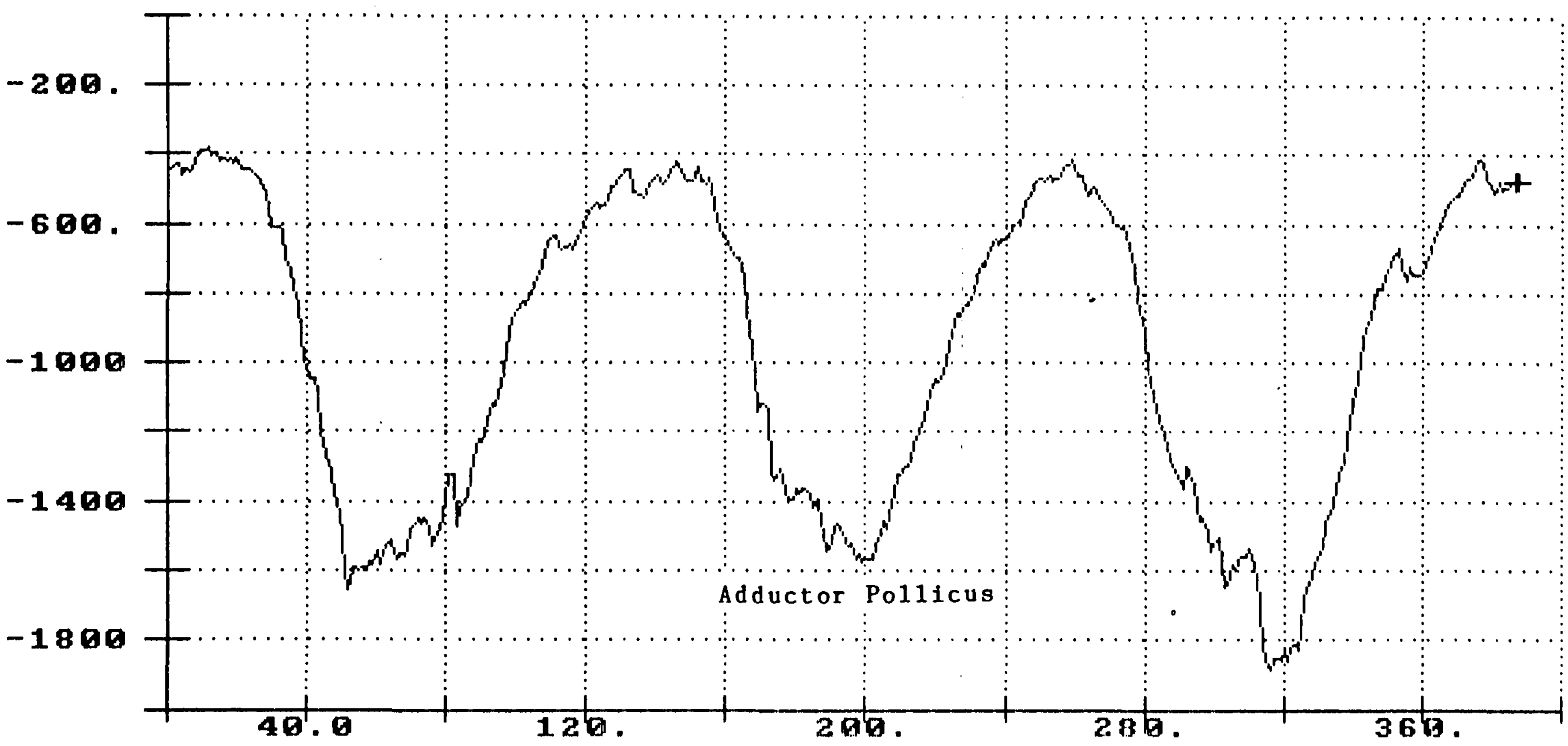


Figure D40a. **ADDUCTOR POLLICUS ABDUCTION & ADDUCTION**
"Thumb"

MOVEMENT SPEED: Medium SAMPLING RATE: 200 Samples/Sec/Channel

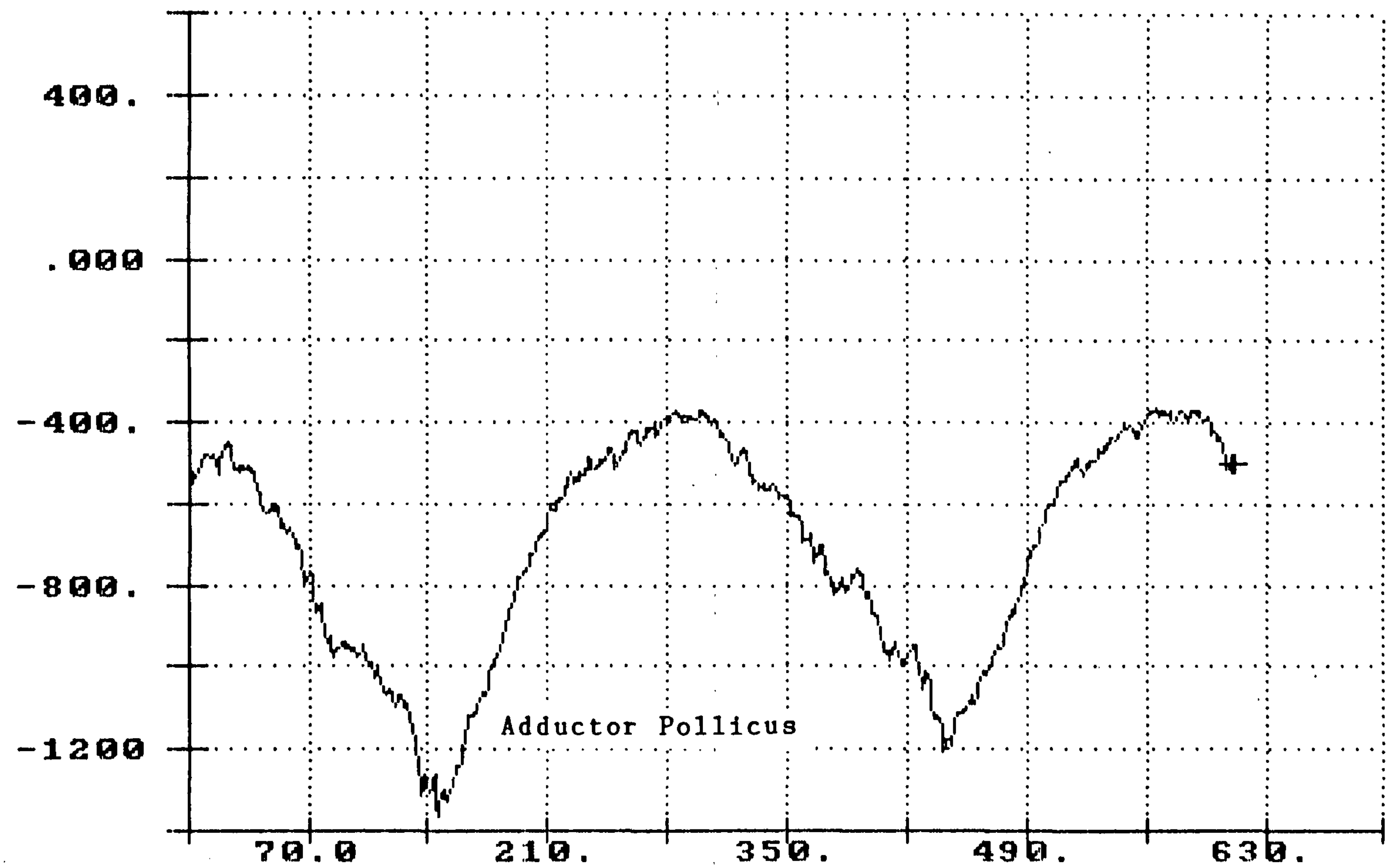


Figure D41a. ADDUCTOR POLLICUS ABDUCTION & ADDUCTION
"Thumb" with Cocontraction

MOVEMENT SPEED: Medium SAMPLING RATE: 200 Samples/Sec/Channel

5.1.2 Pinky Abduction/Adduction; Transverse Plane; Phase II Only

EMG: abductor digiti minimi

Description: Initial position; subject seated with forearm fully pronated and flexed to create a 90° inter-segmental angle at the elbow; pinky held fully extended and adducted, in contact with the fourth digit. The movement included the full ROM (maximum pinky abduction, then pinky adduction to a point where it contacted the fourth digit). The pinky remained extended throughout the entire ROM.

Figure: D42 a;
The EMG record for the abductor digiti minimi is shown in D42a. Unfortunately measurement of pinky displacement was not possible given the nature of the movement and the size of the joint compared to the size of the goniometer.

Observations:

As with the thumb adduction/abduction task, there appeared to be an on/off EMG activity pattern for the abductor digiti minimi (Figure D42a). During the data collection process it was observed that the rise and peak in activity coincided with pinky abduction and the fall in activity with pinky adduction. This movement may be more practical for controlling a robot, as it is not as difficult as thumb adduction without thumb flexion.

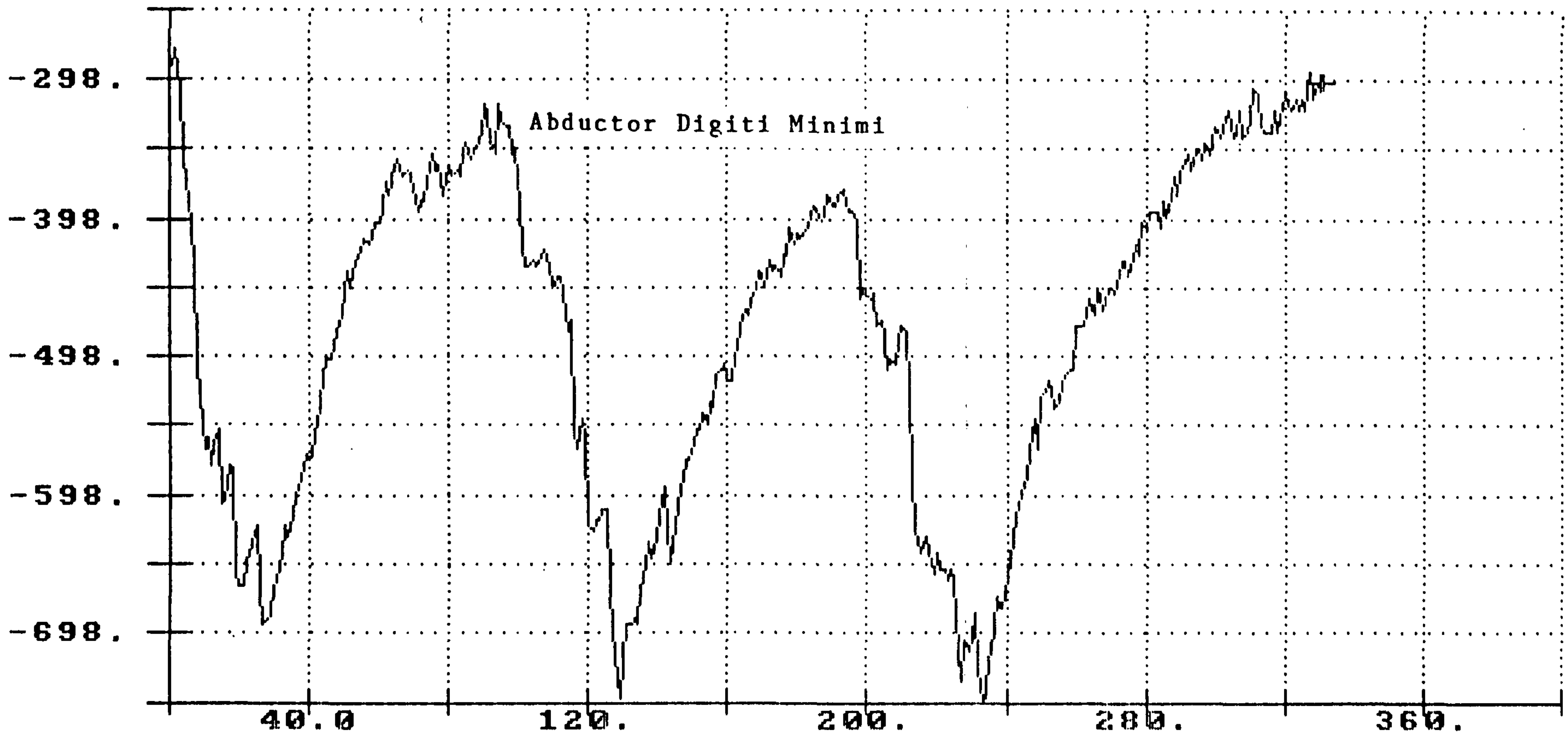


Figure D42a. **ABDUCTOR DIGITI MINIMI ABDUCTION & ADDUCTION**
"Pinky"

MOVEMENT SPEED: Medium SAMPLING RATE: 100 Samples/Sec/Channel

Reaching Movements

6.0 Anatomical Considerations

Since a two degree-of-freedom reaching movement performed in the sagittal plane involves flexion and extension of the shoulder and elbow joints, many of the anatomical considerations have been discussed in previous sections. However the action of two-joint muscles, those which cross two joints and have important functions at both, (Basmajian, 1979) needs particular mention. Working alone these muscles can not function as a one-joint muscle because they pull directly from one end to the other with all parts of the muscle contracting (Basmajian, 1979).

The two-joint muscles directly involved in the reaching task are the biceps brachii and the triceps brachii. The biceps brachii, which crosses the glenohumeral and elbow joints, may function as an agonist in elbow or shoulder flexion, but is strongest as an elbow flexor. Maximal bicep activity may be expected in a countercurrent movement (Basmajian, 1979) (i.e. shoulder flexion and elbow flexion). However in a concurrent movement such as elbow extension and shoulder flexion, little if any bicep activity may be expected providing gravity is not the force responsible for elbow extension. In order for elbow extension to occur without the force of gravity acting, the biceps must relax, thus it can not provide shoulder flexion.

The triceps brachii also crosses the glenohumeral and elbow joints, and may function as an agonist in shoulder extension or elbow extension against resistance but is strongest as an elbow extensor. Similar to the biceps, maximal triceps activity would be expected in a counter-current movement such as shoulder and elbow extension against resistance. Likewise little triceps activity would be expected in a concurrent movement such as shoulder extension and elbow flexion.

Since these data were collected on a sagittal plane reaching motion in a gravitational environment, the aforementioned activation patterns may not have been evident. However in transverse plane reaching tasks or a nongravitational environment the activation patterns of two-joint muscles should be apparent and would need to be considered for robot control.

6.1 Reaching Movement Data

6.1.1 Reaching (Forearm Flexion, then Shoulder Flexion); Sagittal Plane

Special conditions: Slow and moderate speeds

Phase I EMG: biceps brachii and anterior deltoid.
Phase II EMG: biceps brachii, triceps brachii, anterior deltoid, and posterior deltoid.

Phase I description: Initial position; subject seated, right arm hanging relaxed at the side. Right side was facing the cameras. LEDs marked the wrist, elbow and shoulder. The subject was asked to perform a reaching motion in which forearm flexion preceeded shoulder flexion. The midpoint of the movement was when the arm was fully extended at shoulder level. From this midpoint, the movement was characterized by simultaneous extension of the humerus and flexion of the forearm until the humerus was approximately in line with the trunk. Then, the forearm was extended until the arm was fully extended along the side of the body.

Phase II description: Initial position; subject standing in FSP, right arm relaxed at the side. The subject was asked to perform the reaching motion, similar to that of Phase I: elbow flexion to approximately 90°, followed by simultaneous shoulder flexion and elbow extension. The midpoint of the movement was the same as Phase I: a fully extended arm held at shoulder level. From this position the movement was completed just as it was in Phase I.

Phase I figures: D43 a; D44 a; D45 a; position-time data with EMG: D43 b; D44 b; D45 b; stick-figures of reaching. Top strip chart (1Y) = displacement representing a change in vertical position of the wrist. Peaks (e.g. 1000 mm) occur when the wrist is at shoulder level. Minimum values (e.g. 450 mm) occur when the arm is suspended at the side of the body. Second strip chart (1A) = EMG recording from the biceps brachii. The biceps was monitored as the prime forearm flexor. Third strip chart (2Y) = displacement data representing a change in the vertical position of the elbow. Maximum values (e.g. 960 mm) occur when the upper arm has been raised to shoulder level in the sagittal plane. Minimum values correspond to an upper arm position parallel to the trunk. Fourth strip chart (2A) = EMG recording from the anterior deltoid. The anterior deltoid was monitored as the prime mover in humeral flexion.

Phase II figures: D46 a,b,c,d,e,f,g; D47 a,b,c,d,e,f. EMG activity for the biceps and triceps is displayed in the top graphs of D46a,b and D47a,b. The bottom graphs of D46a and D47a display displacement representing a change in the angle at the elbow (peaks indicate maximum flexion; valleys indicate maximum extension). The bottom graphs of D46b and D47b display anterior and posterior deltoid activity. The top graphs of D46c,d and D47c display EMG activity from the biceps and anterior deltoid. The bottom graphs display triceps, posterior deltoid, and triceps and posterior deltoid activity respectively. Figures D46e and D47d display posterior deltoid activity in the top graph and anterior deltoid activity in the bottom graph. Raw EMG data is displayed in the top graphs of D46f and D47e, for the biceps, and in D46g and D47f for the triceps. The corresponding processed EMG signal is displayed in the bottom graphs for each of the aforementioned figures.

Observations:

Phase I: Biceps activity: As seen in Figure D43a, biceps activity rose with the increasing magnitude of forearm flexion. From approximately .6 to 1.8 seconds biceps activity held a relative plateau, then declined. The biceps activation pattern suggested that a flexion angle was maintained at the elbow during the .6 to 1.8 second period. However, this was not the case. When the elbow rose to shoulder level, indicated by the peak in 2Y at 1.2 seconds, the forearm was in an extended position and the wrist, elbow, and shoulder were colinear. With no flexion at the elbow one might expect that there would be no EMG activity from the biceps. As can be seen across reaching trials, this was not the case. Thus the peak plateau in biceps EMG activity did not correlate well with the forearm flexion/extension pattern evidenced in single joint movements. The fact that the biceps displayed a high activation level while the forearm was extended at the midpoint of the reach, pointed out the bi-articular nature of the biceps. This high-level activation may have had more to do with shoulder activity than elbow activity.

Anterior deltoid (2Y) activity corresponded well to the flexion/extension pattern at the shoulder. Peak deltoid activity occured just prior to maximum shoulder flexion, and declined with a slope similar to the slope of the displacement curve. As shown with single-segment tasks (shoulder flexion only) the EMG activity of the anterior deltoid corresponded well with the position-time data.

Phase II: The activity pattern of the biceps was very similar to that displayed in Phase I; peak activity was reached during initial forearm flexion, and the activity remained elevated throughout the rest of the reaching task which included forearm extension at the elbow. Bicep activity did not return to a baseline level until the movement was completed and the arm was fully extended at the side (Figures D46a, D47a). These results provide further evidence for the bi-articular nature of the biceps.

There was a gradual rise in tricep activity (Figures D46a, D47a) which peaked prior to maximum extension at the elbow, when the entire arm was fully extended with an approximate 90° angle of shoulder flexion. (Note. There were no records of changes in the shoulder angle for these trails.) Since the triceps is a two-joint muscle functional in forearm and shoulder extension against resistance, this peak may have been related to either shoulder or forearm action. However, since eccentric activity of the biceps would control forearm extension in the sagittal plane, this peak was probably related to the effort to slow shoulder flexion as the humerus reached its reversal point.

Raw EMG data for both the biceps (Figures D46f, D47e) and triceps (Figures D46g, D47f) appeared noisey. Thus the processed data, displayed in the bottom graphs of the same figures, may not have provided the true muscle signal if the noise evident in the raw data were included. These data showed the importance of a clean signal. A robot driven by this raw data would not produce very accurate limb movements.

Anterior deltoid activity rose to a single peak, which occured after the peak in biceps activity (Figures D46b,c,d, D47b,c). Since humeral displacement was not recorded, it was estimated from the displacement graph of the elbow that as in Phase I, anterior deltoid activity correlated well with shoulder flexion/extension. EMG activity from the posterior deltoid, a shoulder extensor, also was monitered. However, the large spikes evident in Figures D46d,e and D47d indicated artifact. Thus posterior deltoid activity analysis was conducted with caution. The data may have indicated that the posterior deltoid activity was initiated by a stretch during shoulder flexion, and/or functioned during shoulder extension to pull the humerus behind the trunk, as viewed from the sagittal plane.

SS0106

Gain 1A = 10
2A = 2

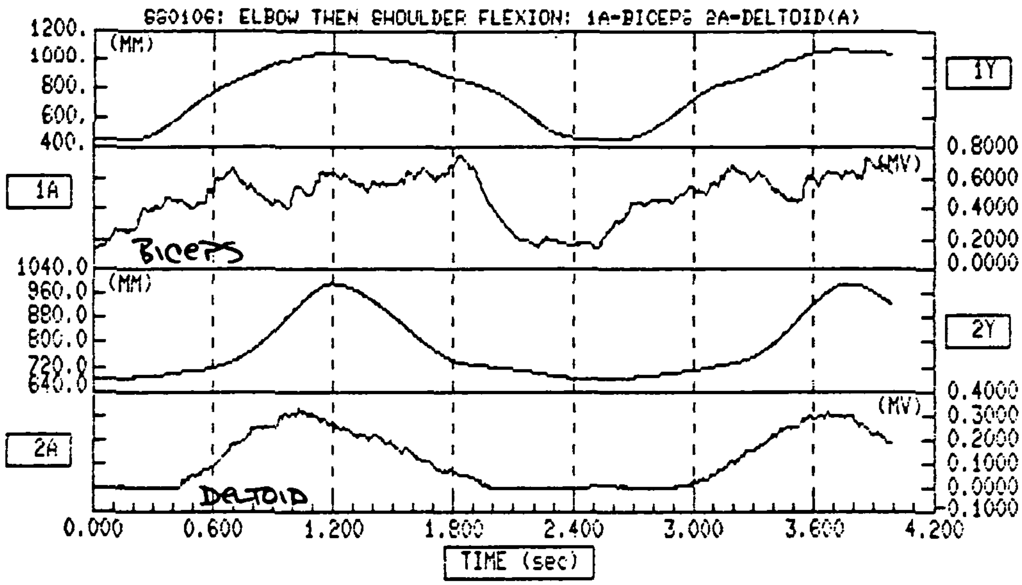
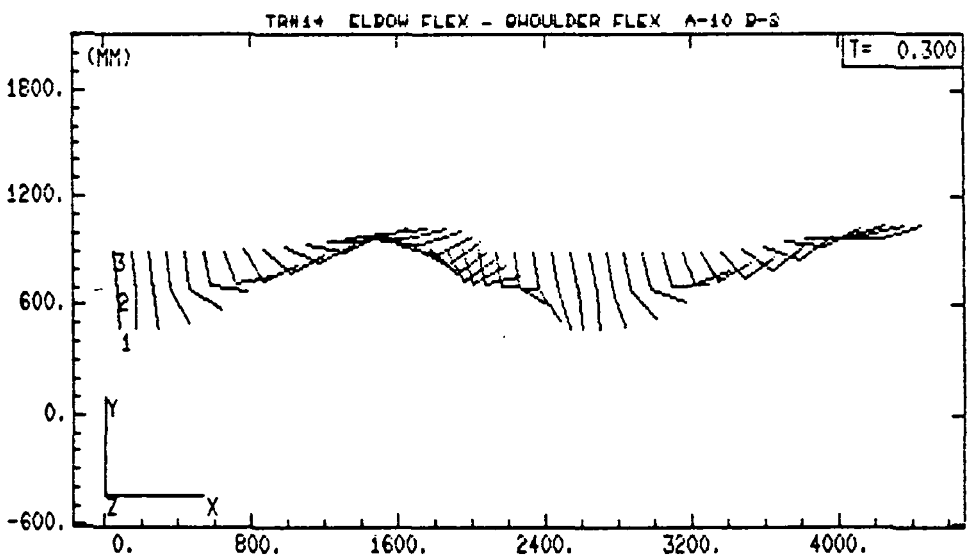


Figure D43a. Elbow flexion then shoulder flexion reaching movement in the sagittal plane.



.1 sec intervals for duration of movement

Figure D43b. Stick figure of elbow flexion then shoulder flexion reaching movement.

Elbow & Shoulder Flexion —
Reaching motion
EMG= Biceps, Deltoid

SS0107

Gain 1A = 10 x1
2A = 2

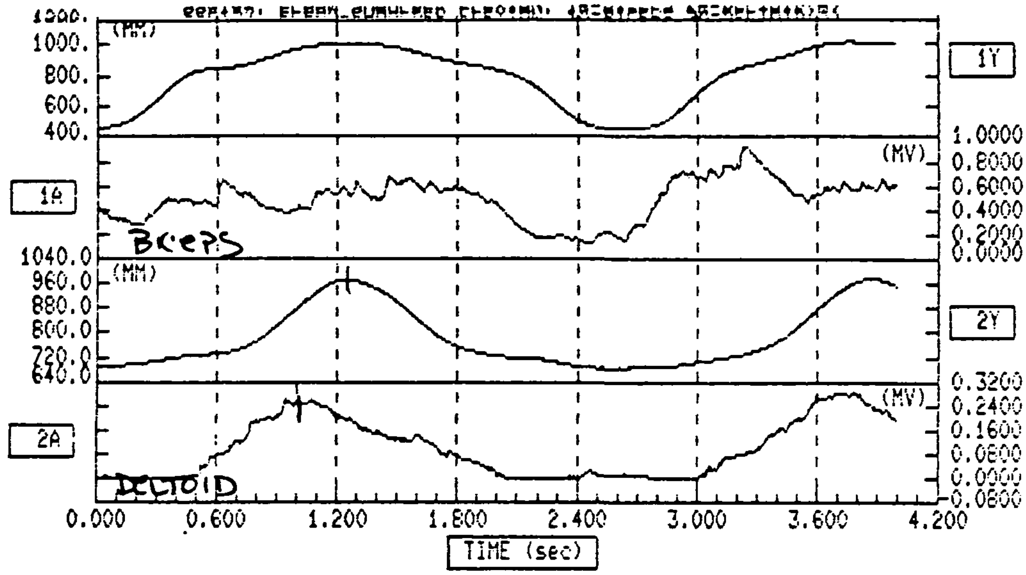


Figure D44a. Elbow flexion then shoulder flexion reaching movement in the sagittal plane.

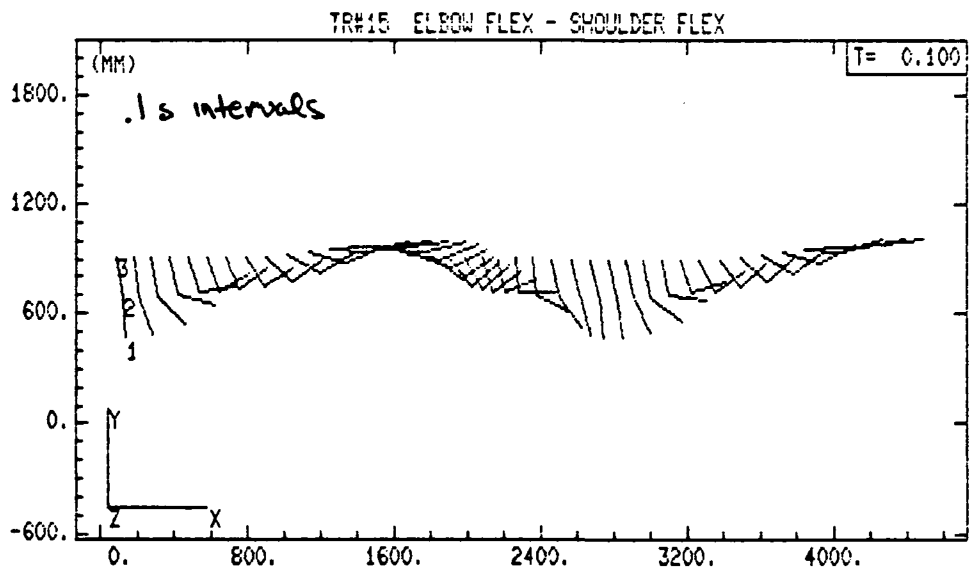


Figure D44b. Stick figure of elbow flexion then shoulder flexion reaching movement.

Elbow + Shoulder Flexion
Reaching Motion
EMG = Biceps
Deltoid (A)

SS0108
Gain 1A = 10
2A = 2

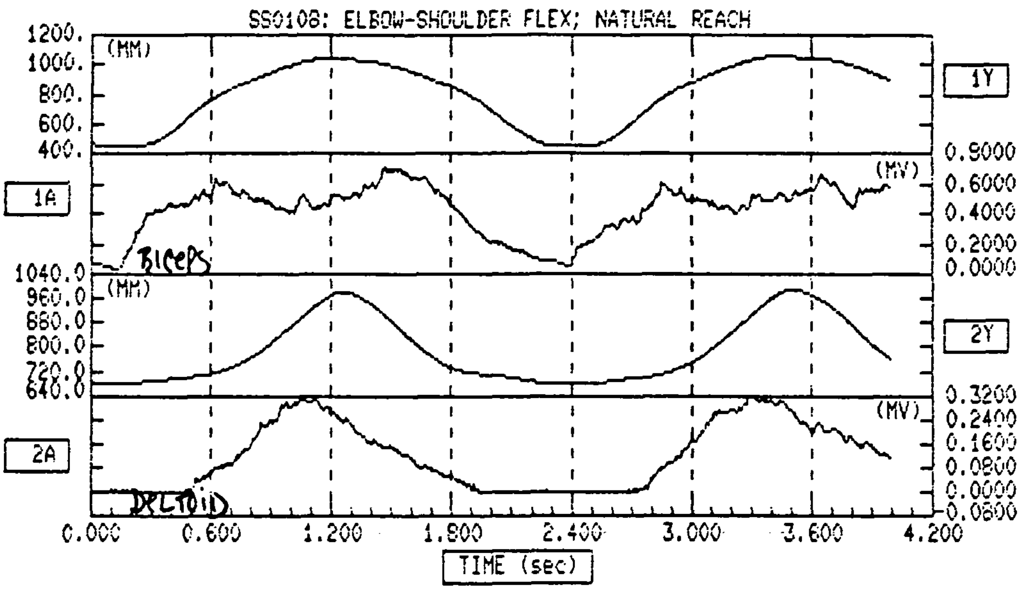


Figure D45a. Elbow flexion then shoulder flexion reaching movement in the sagittal plane.

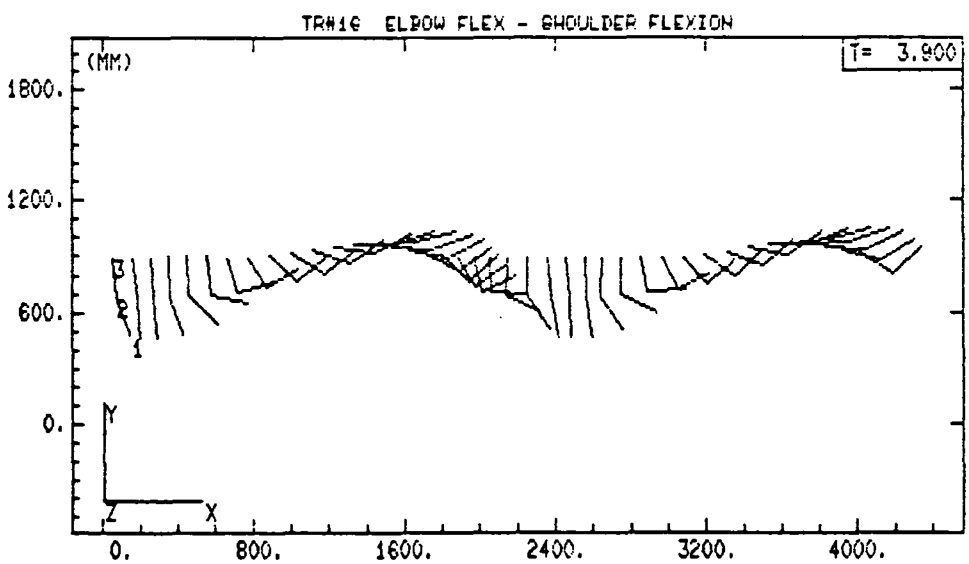


Figure D45b. Stick figure of elbow flexion then shoulder flexion reaching movement.

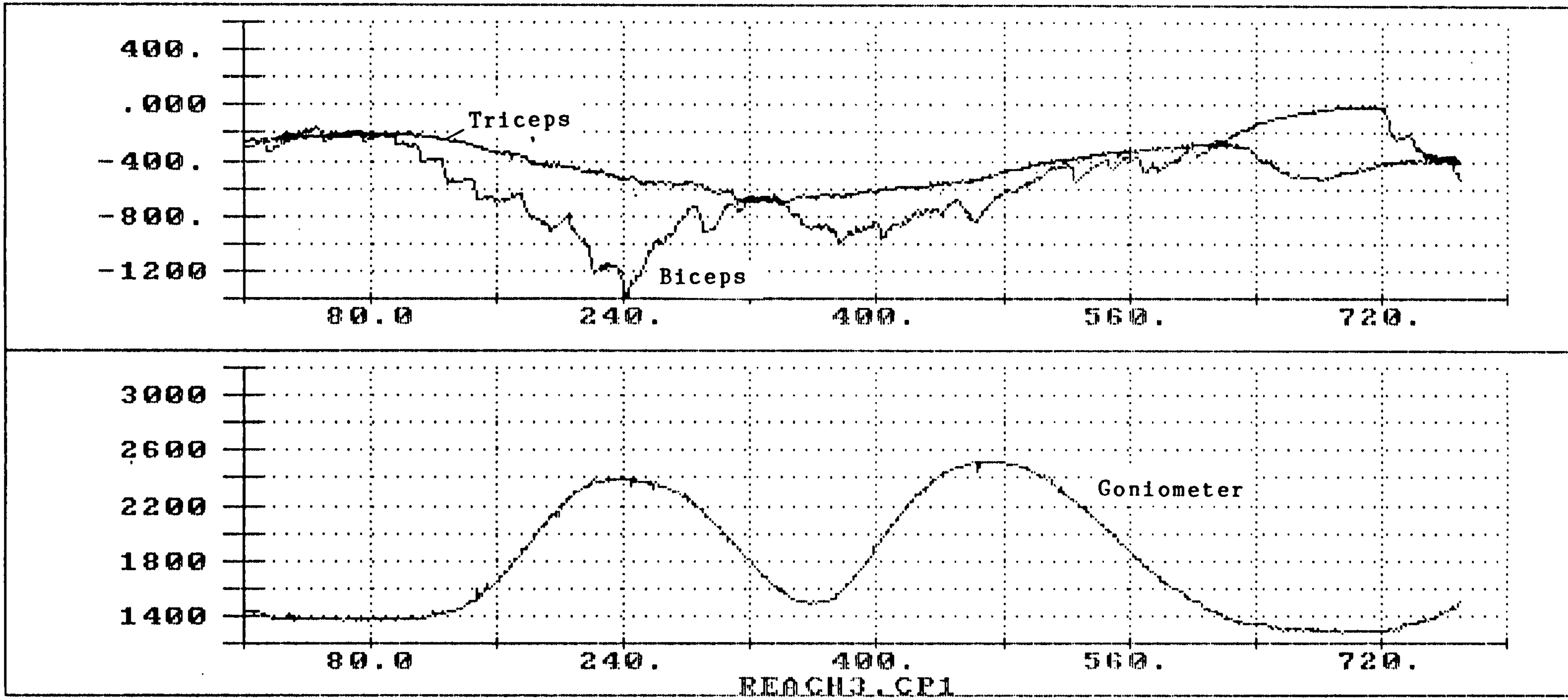


Figure D46a. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE
Elbow Movement Emphasized

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

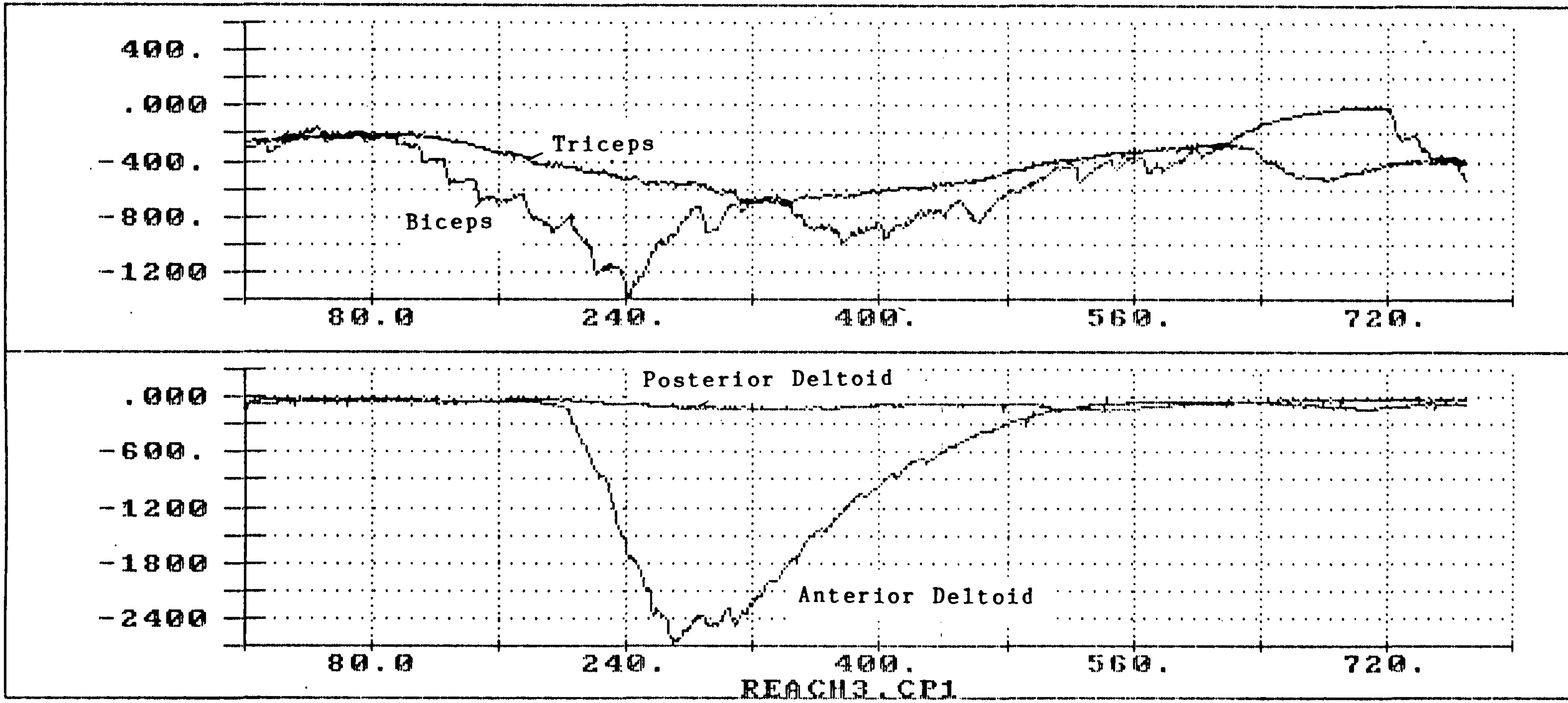


Figure D46b. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE
Elbow Movement Emphasized

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

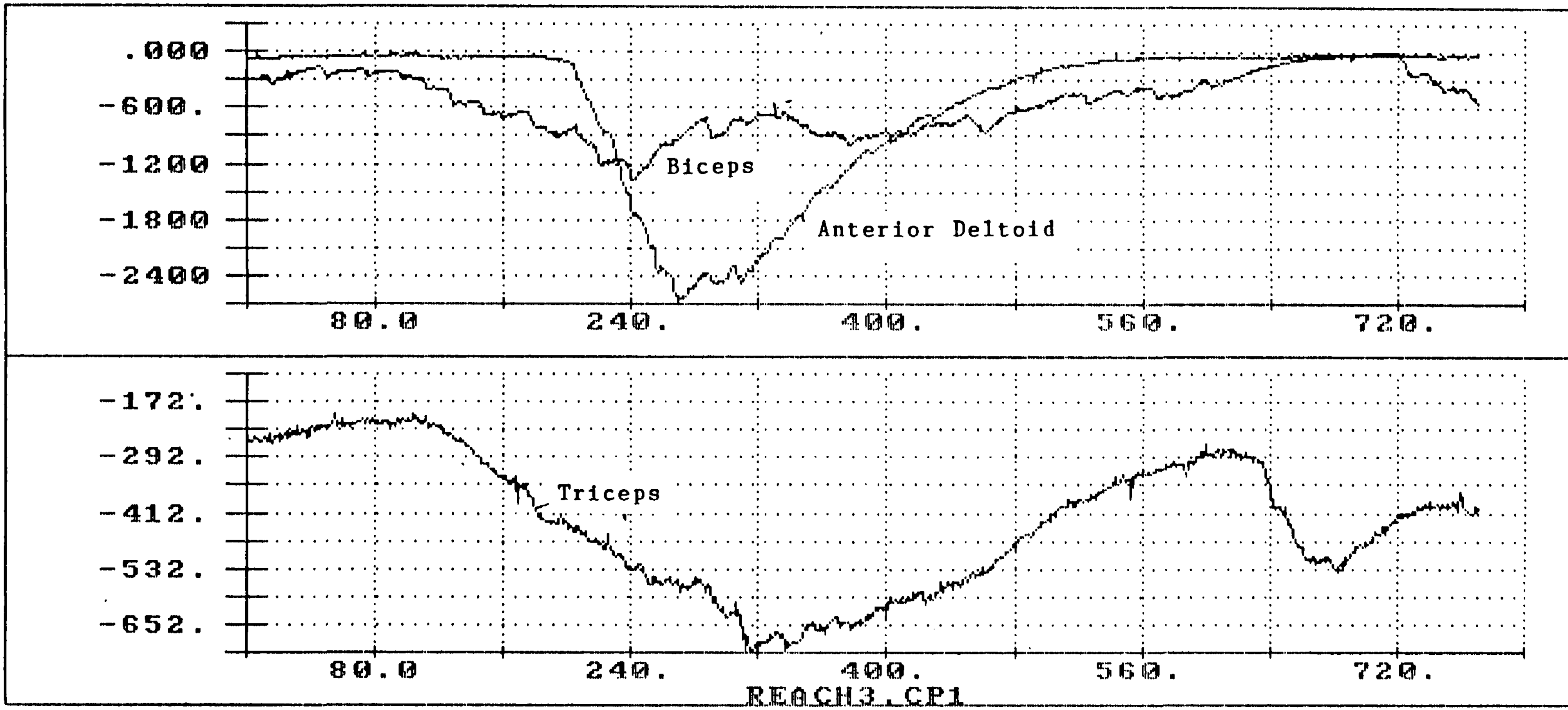


Figure D46c. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE
Elbow Movement Emphasized

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

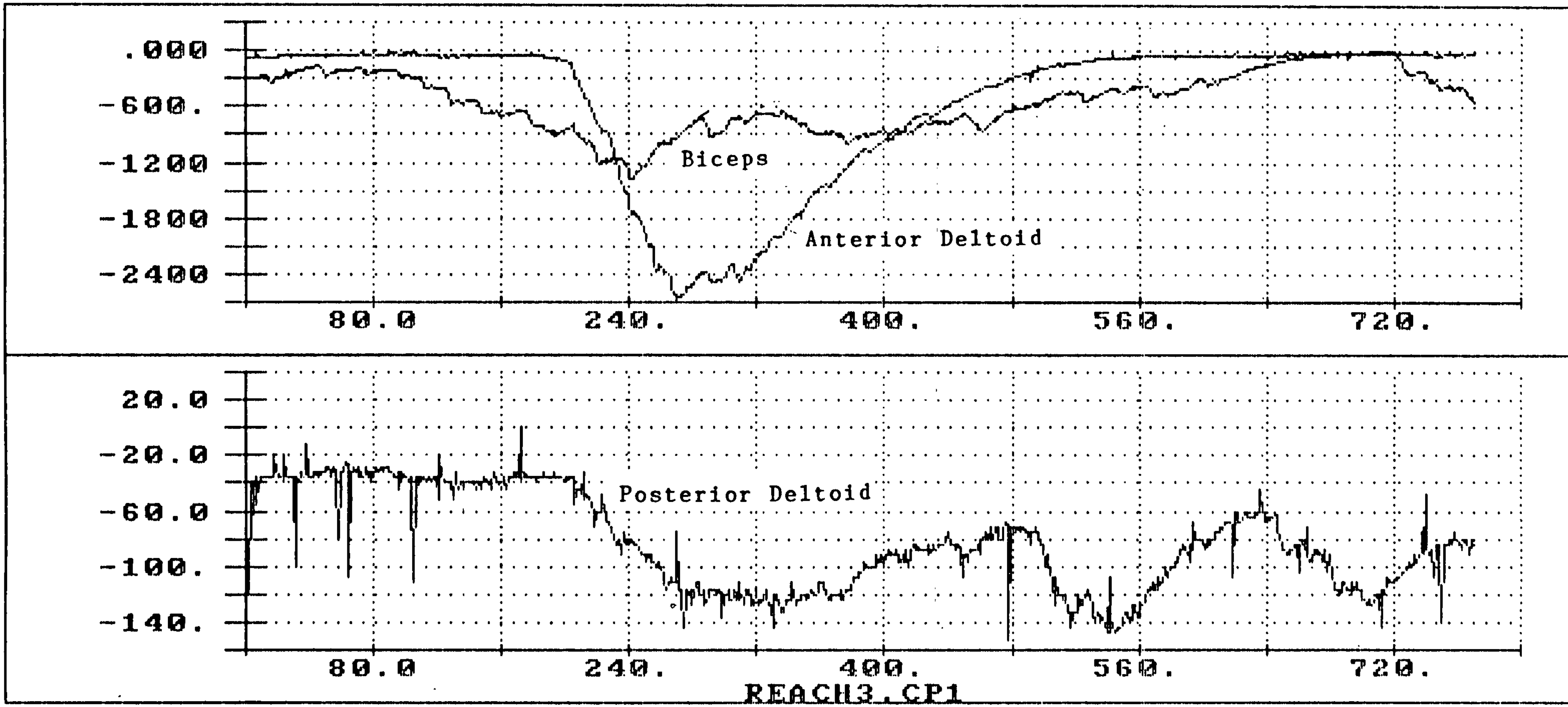


Figure D46d. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE
Elbow Movement Emphasized

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

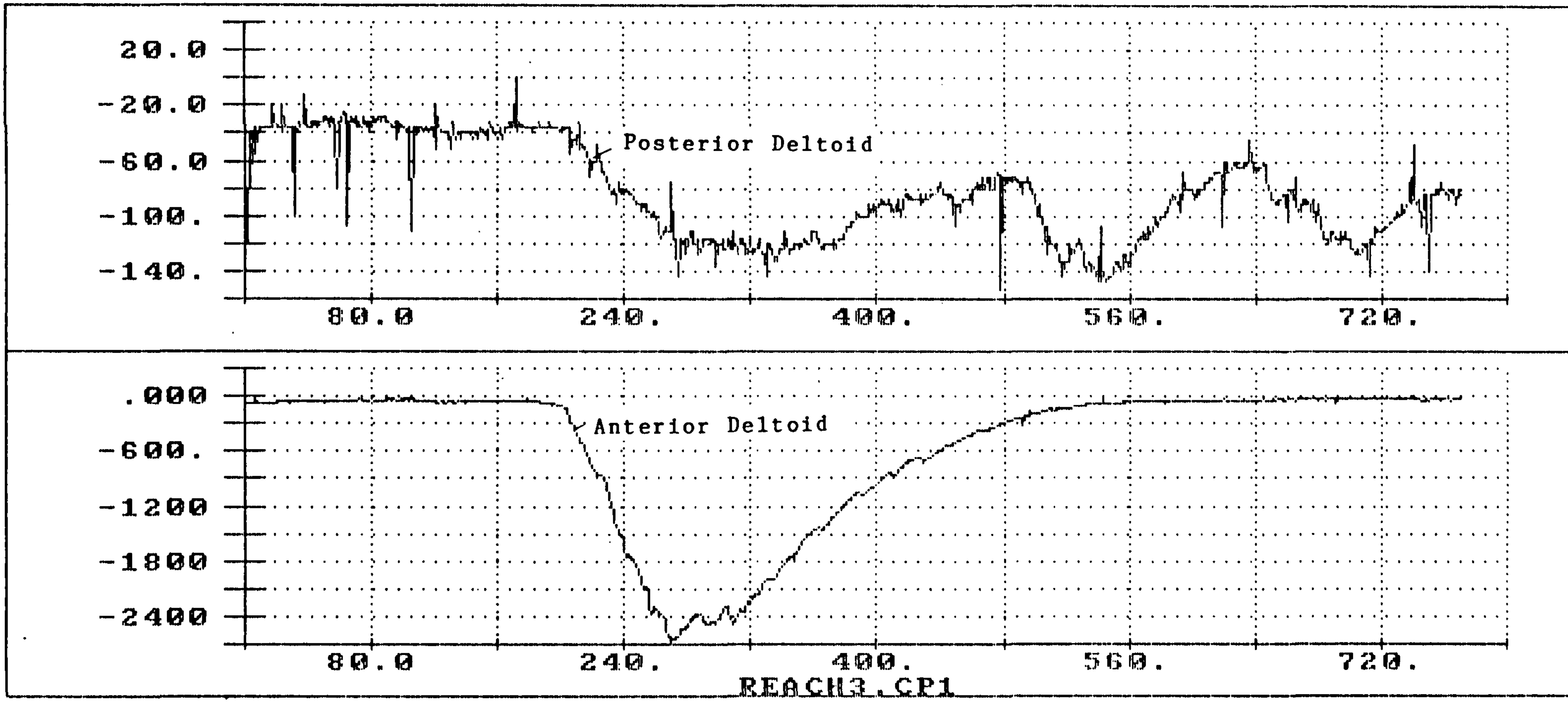


Figure D46e. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE
Elbow Movement Emphasized

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

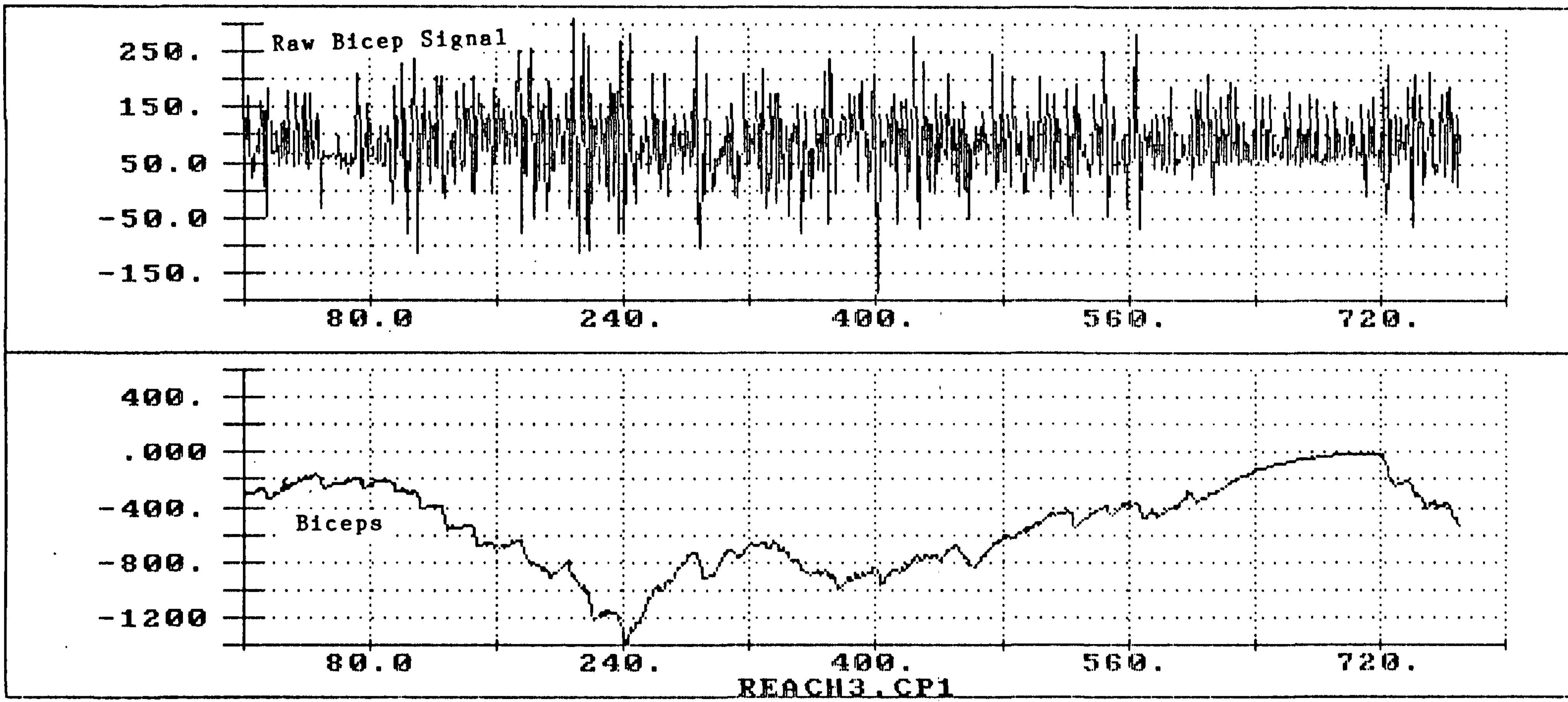


Figure D46f. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE
Elbow Movement Emphasized

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

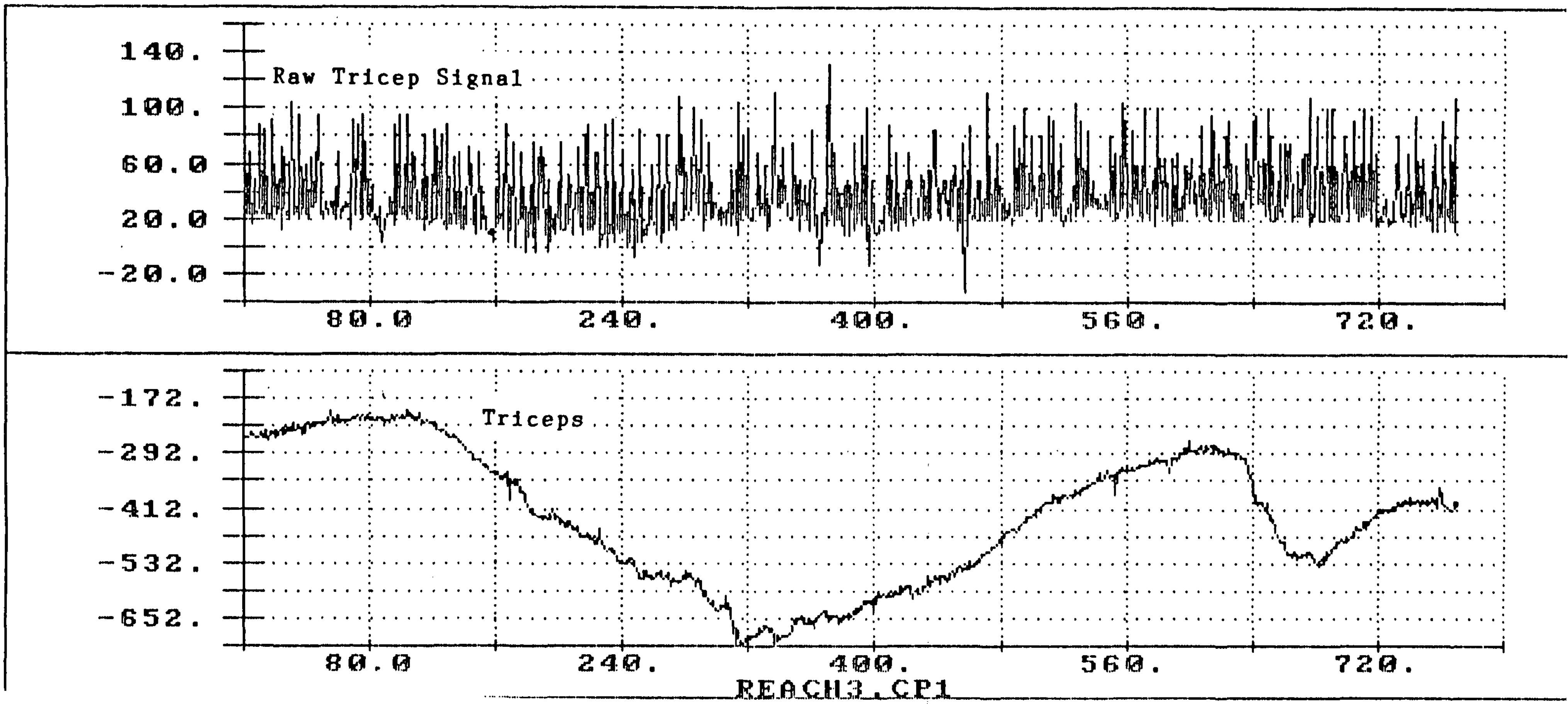


Figure D46g. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE
Elbow Movement Emphasized

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

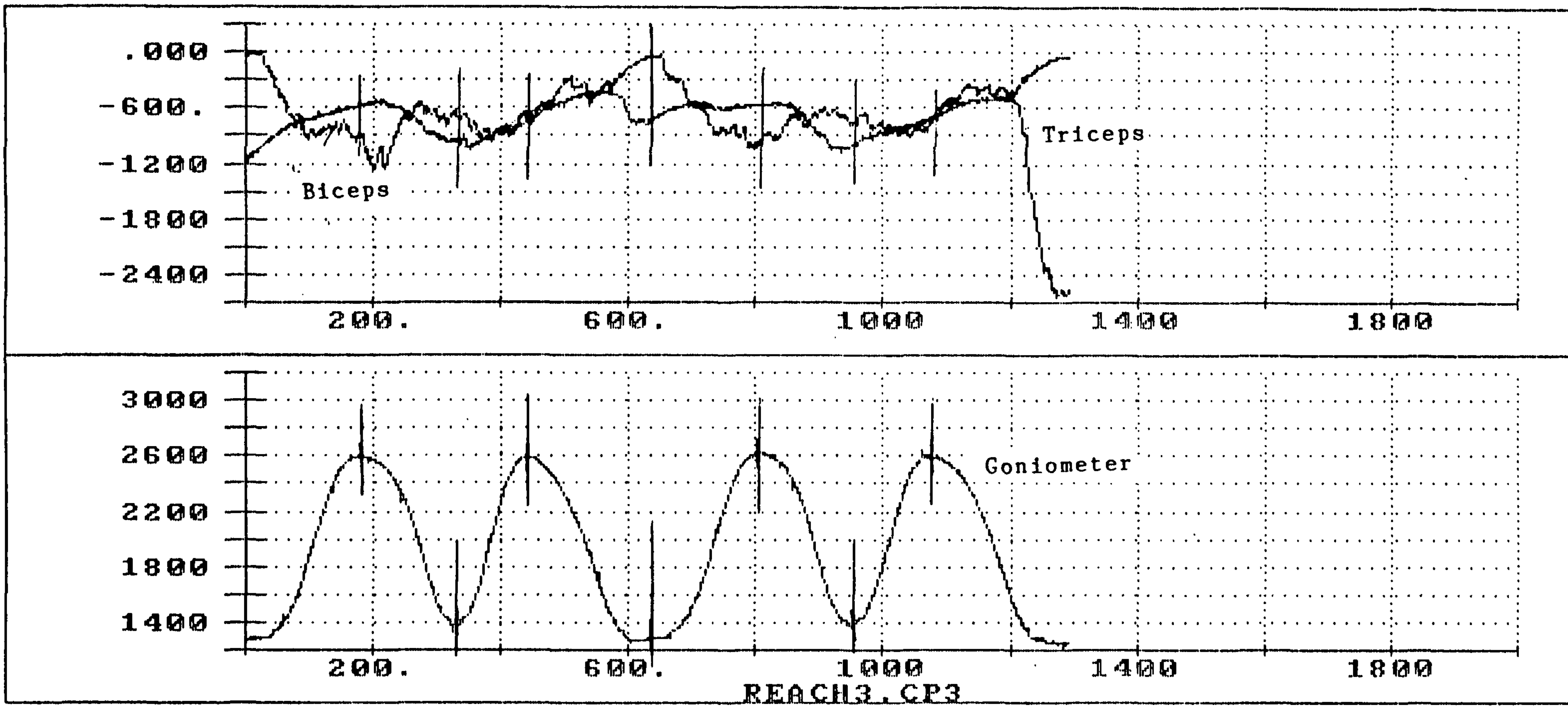


Figure D47a. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE
Elbow Movement Emphasized

MOVEMENT SPEED: Slow   SAMPLING RATE: 250 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

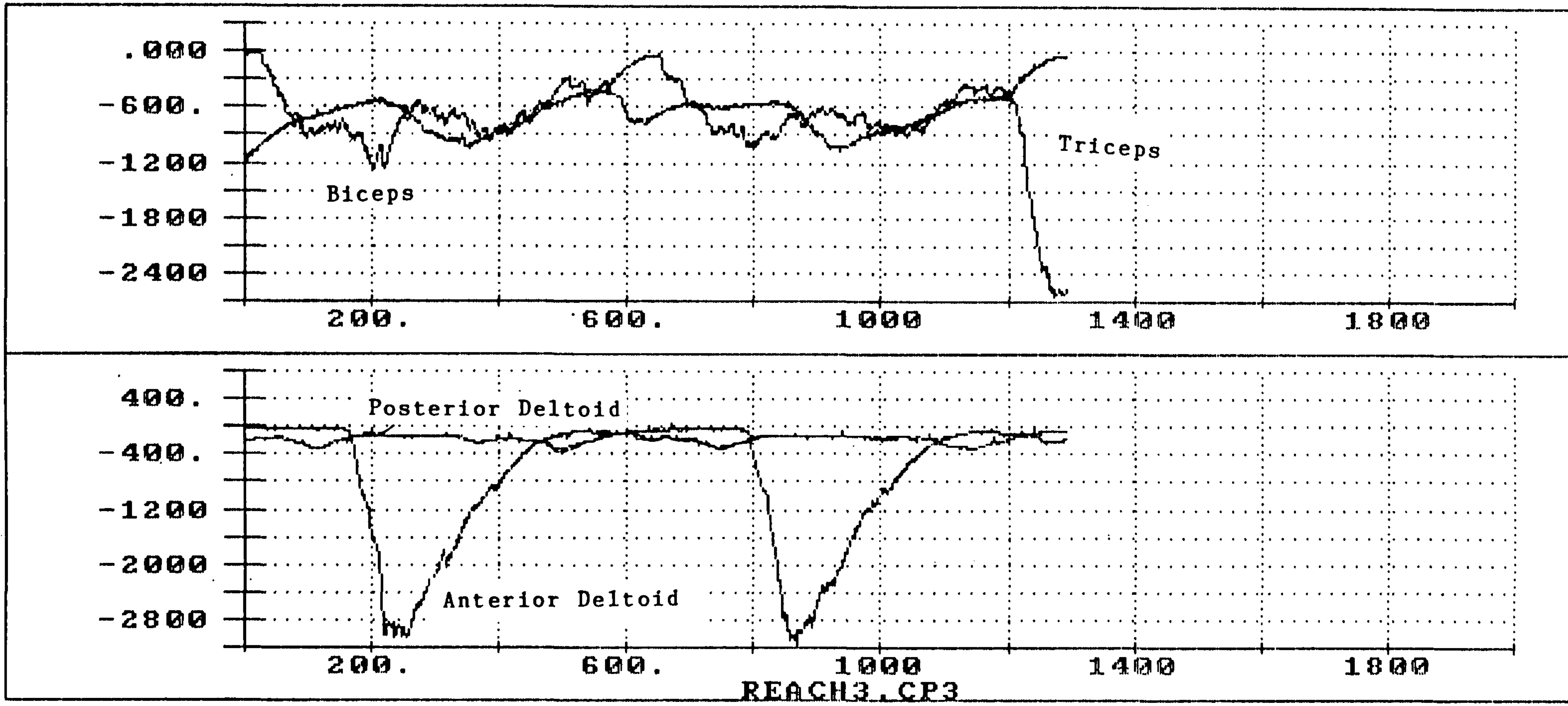


Figure D47b. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE
Elbow Movement Emphasized

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

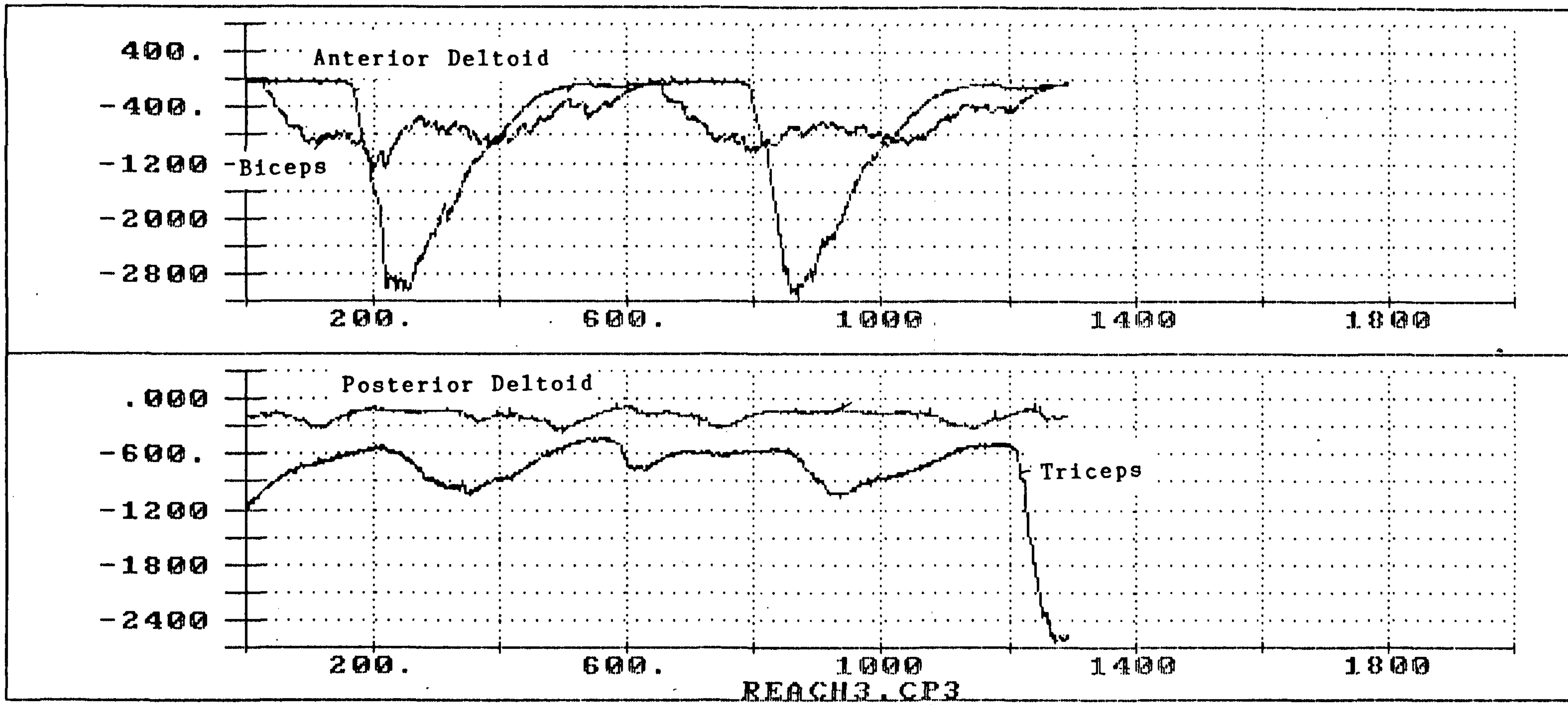


Figure D47c. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE
Elbow Movement Emphasized

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

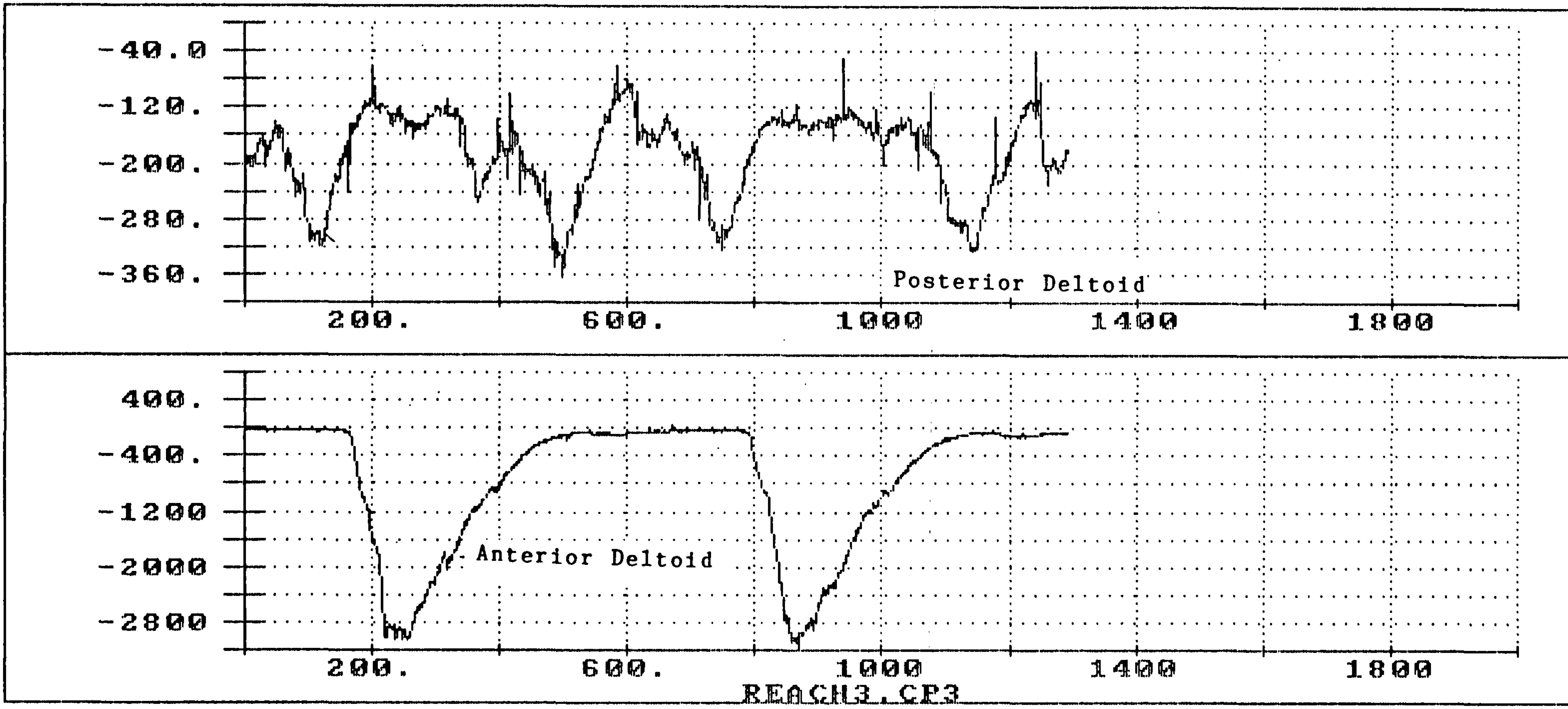


Figure D47d. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE
Elbow Movement Emphasized

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

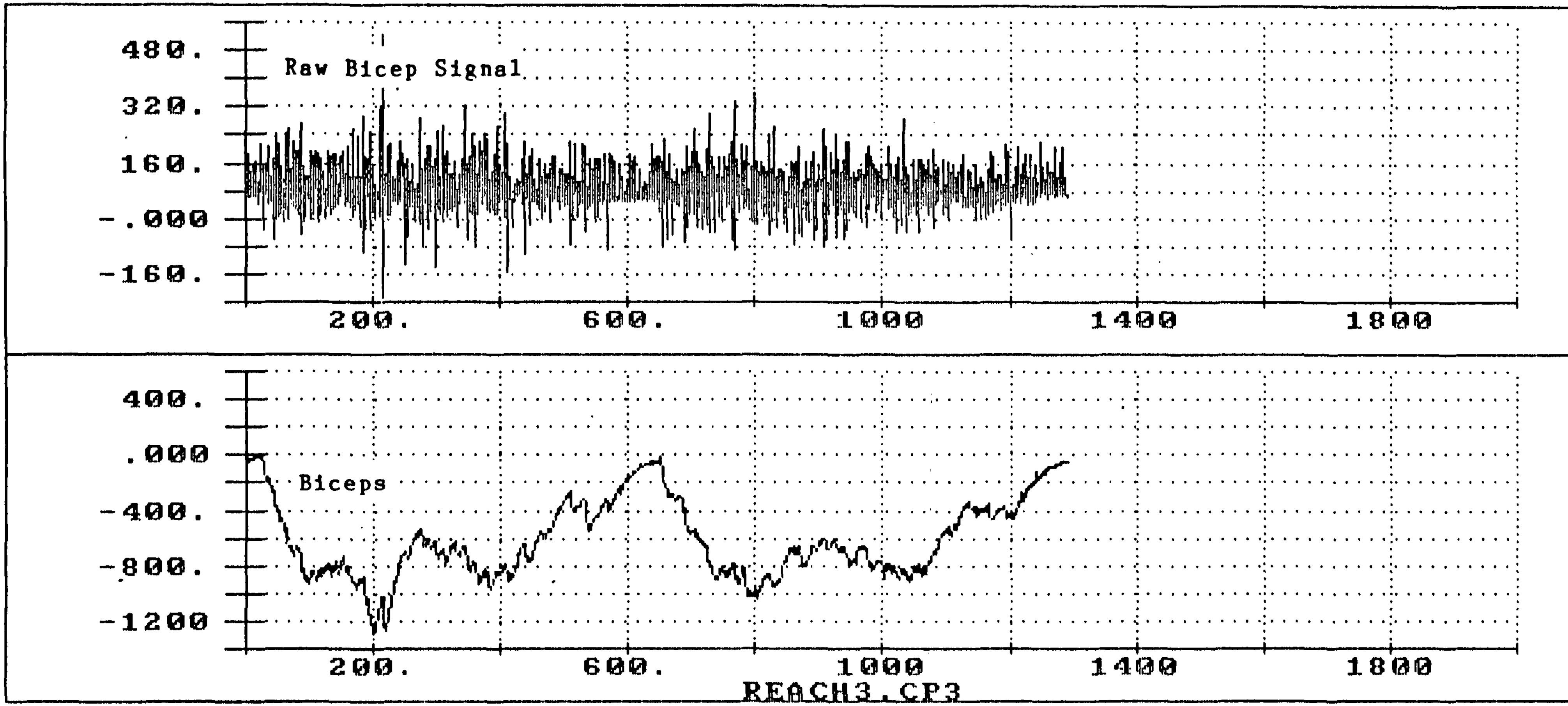


Figure D47e. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE
Elbow Movement Emphasized

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

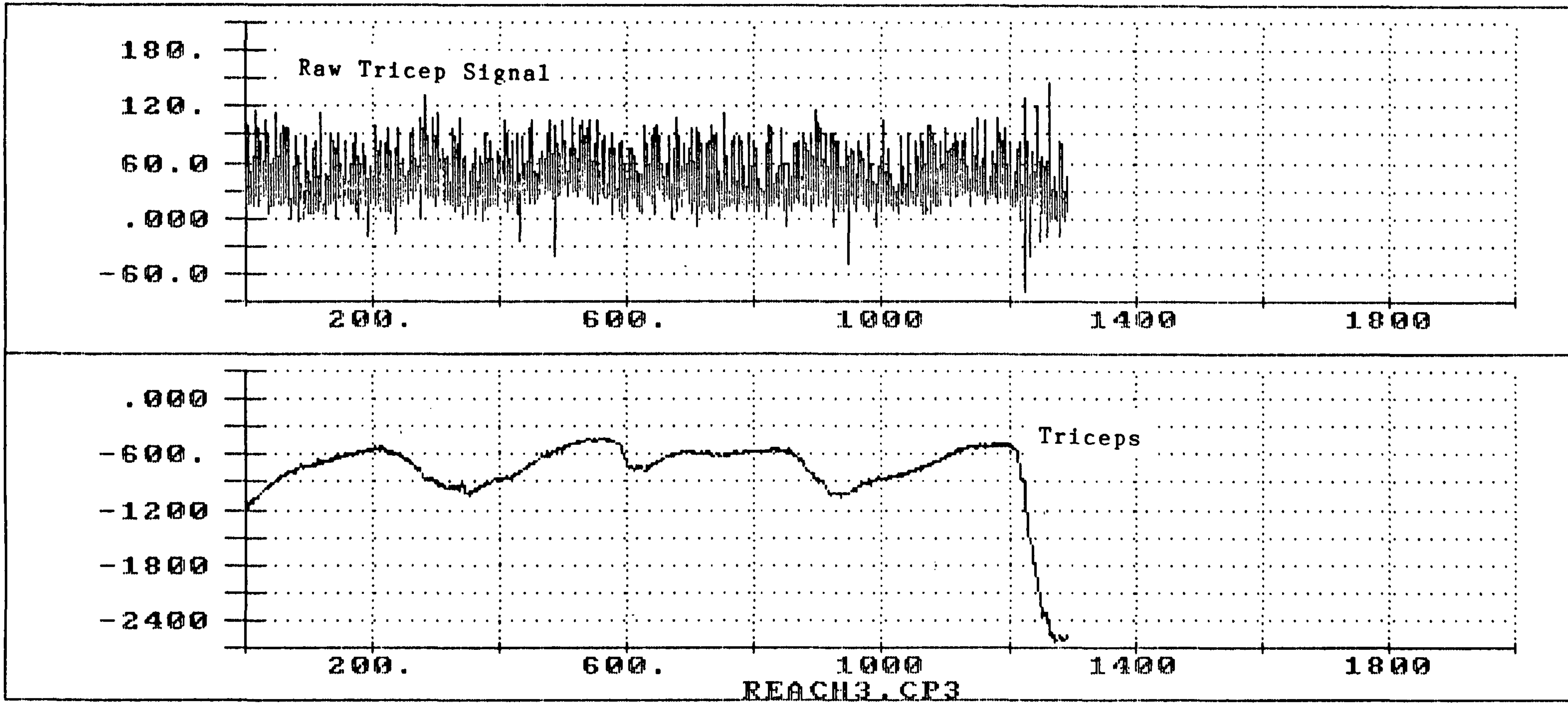


Figure D47f. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE
Elbow Movement Emphasized

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

6.1.2 Reaching (Forearm Flexion then Shoulder Flexion); Sagittal Plane

Special conditions: With and without cocontraction (Phase I only)

EMG: biceps brachii and triceps brachii

Description: Initial position; subject seated, right arm hanging relaxed at the side. Right side was facing the cameras. LEDs marked the wrist, elbow and shoulder. The subject was asked to perform a reaching motion in which forearm flexion preceeded shoulder flexion. The midpoint of the movement was when the arm was fully extended at shoulder level. From this midpoint, the movement was characterized by simultaneous extension of the humerus and flexion of the forearm until the humerus was approximately in line with the trunk. Then, the forearm was extended until the arm was fully extended along the side of the body.

Figures: D48 a,b,c; D49 a,b; D50 a,b,c; Top strip chart (3Y) = displacement representing a change in vertical position of the wrist. Peaks (e.g. 70 mm) occur when the wrist is at shoulder level. Minimum values (e.g. 20 mm) occur when the humerus is in line with the body and the forearm is at a 90° angle with respect to the humerus. Second strip chart (2Y) = displacement data representing a change in the vertical position of the elbow. Maximum values (e.g. 55 mm) occur when the upper arm has been raised to shoulder level in the sagittal plane. Minimum values (20mm) occur when the longitudinal axis of the humerus is parallel to the longitudinal axis of the trunk. Third strip chart (1A) = EMG recording from the biceps brachii. The biceps was monitored as the prime forearm flexor. Fourth strip chart (2A) = EMG recording from the triceps brachii. The triceps was monitored to determine its role in control of the extension phase and its level of activation during shoulder flexion.

Observations:

Without cocontraction, biceps activation seemed substantially reduced when compared with previous trials (Figures D43, D44, D45). Peak activation in the biceps now occurred during the recovery phase; that is, while the humerus was being returned to the side. This late biceps peak may have been related to controlling the tendency for gravity and inertia of the forearm to cause extension at the elbow. Although this late biceps peak was consistent in its phase relationship with the movement, this was clearly a much different pattern than that observed on other trials with other subjects. These kinds of intersubject differences point to potential difficulties in the design of an algorithm intended to merge the influences of multiple muscles in movement control and maintain its applicability across multiple subjects.

The triceps was not the agonist in shoulder extension since gravity was operating and there was no resistance. So the shoulder flexors controlled extension eccentrically. The triceps peak observed in these trials coincided with maximum shoulder flexion and may pertain more to countertorque slowing flexion, than to any attempt at extension control. This peak may also have been a function of an activation induced by stretch.

When the reaching action was performed under conditions of tension (intentional cocontraction) activation levels were generally increased, and biceps activity was evident much earlier in the action. As seen in Figure D48a,b,c the biceps was active in the early stages of shoulder flexion. This pattern more closely approximated that seen in earlier trials. However, the "cost" in variability was high. Note for example the variations in the triceps pattern across Figures D50a,b,c. While it may have been useful to "set" the muscles to something other than the minimum level of activation when working without resistance, control of the tension level was quite variable and not conducive to a consistent control signal.

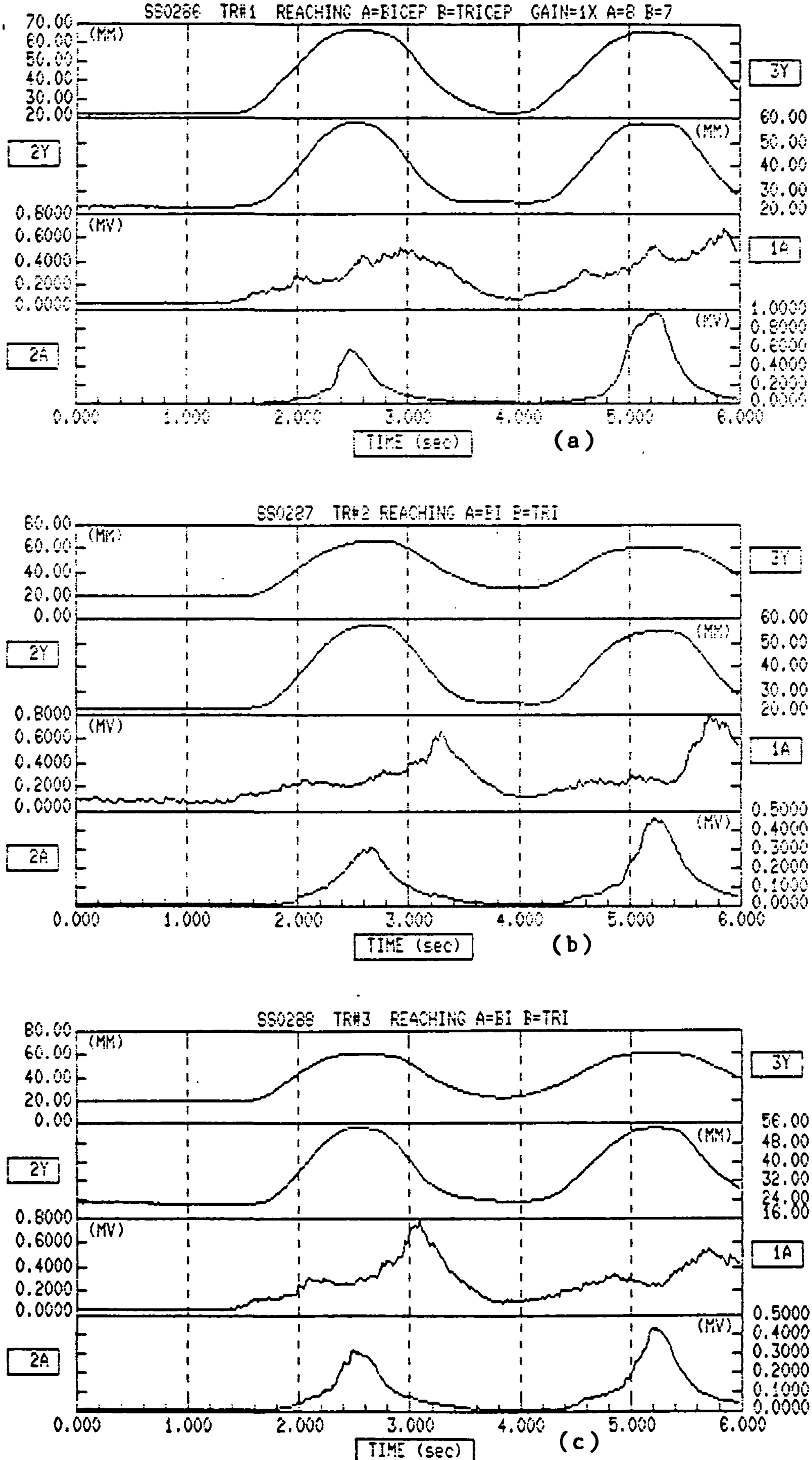


Figure D48. Elbow flexion then shoulder flexion reaching movement in the sagittal plane.

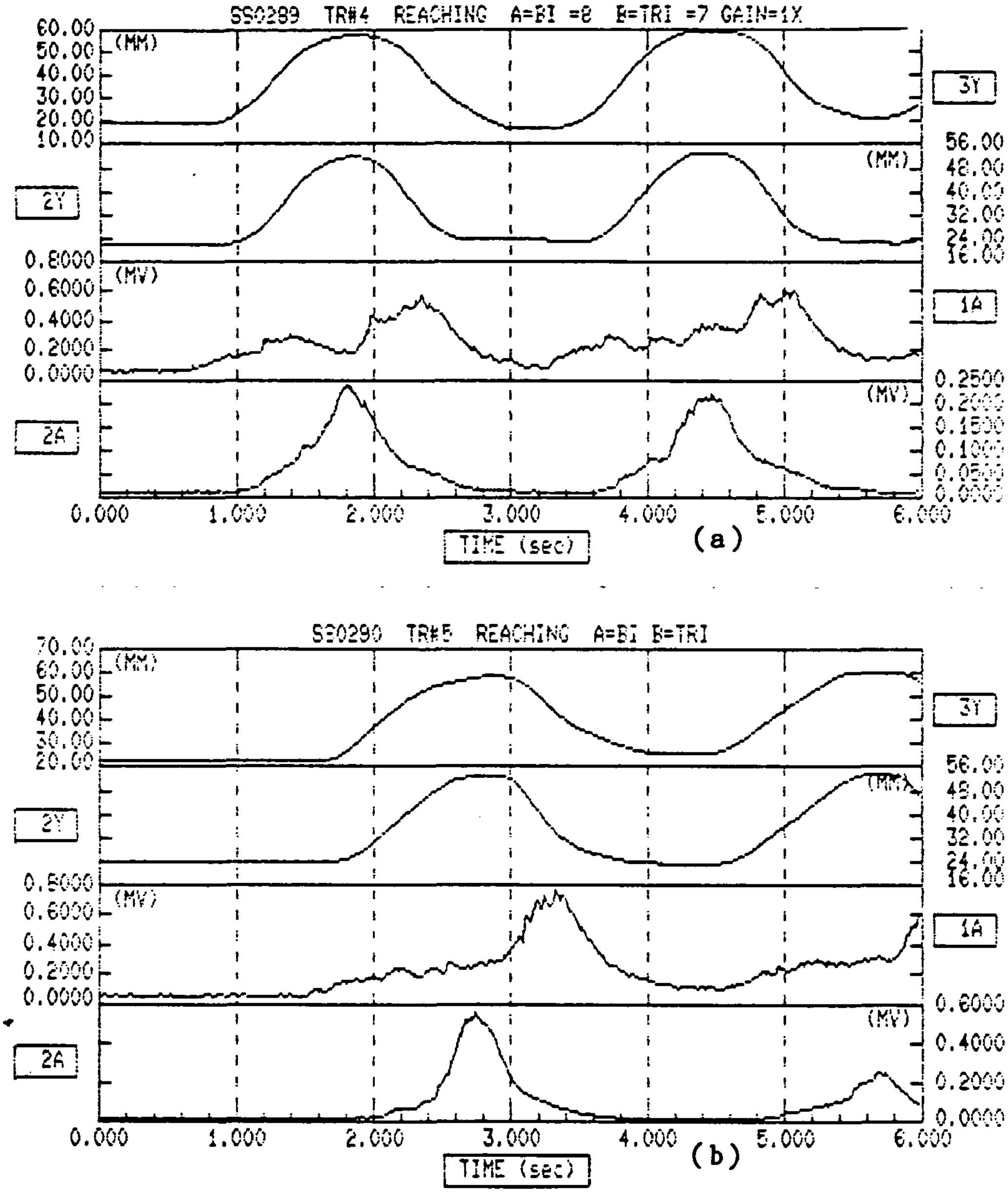


Figure D49. Elbow flexion then shoulder flexion reaching movement in the sagittal plane.

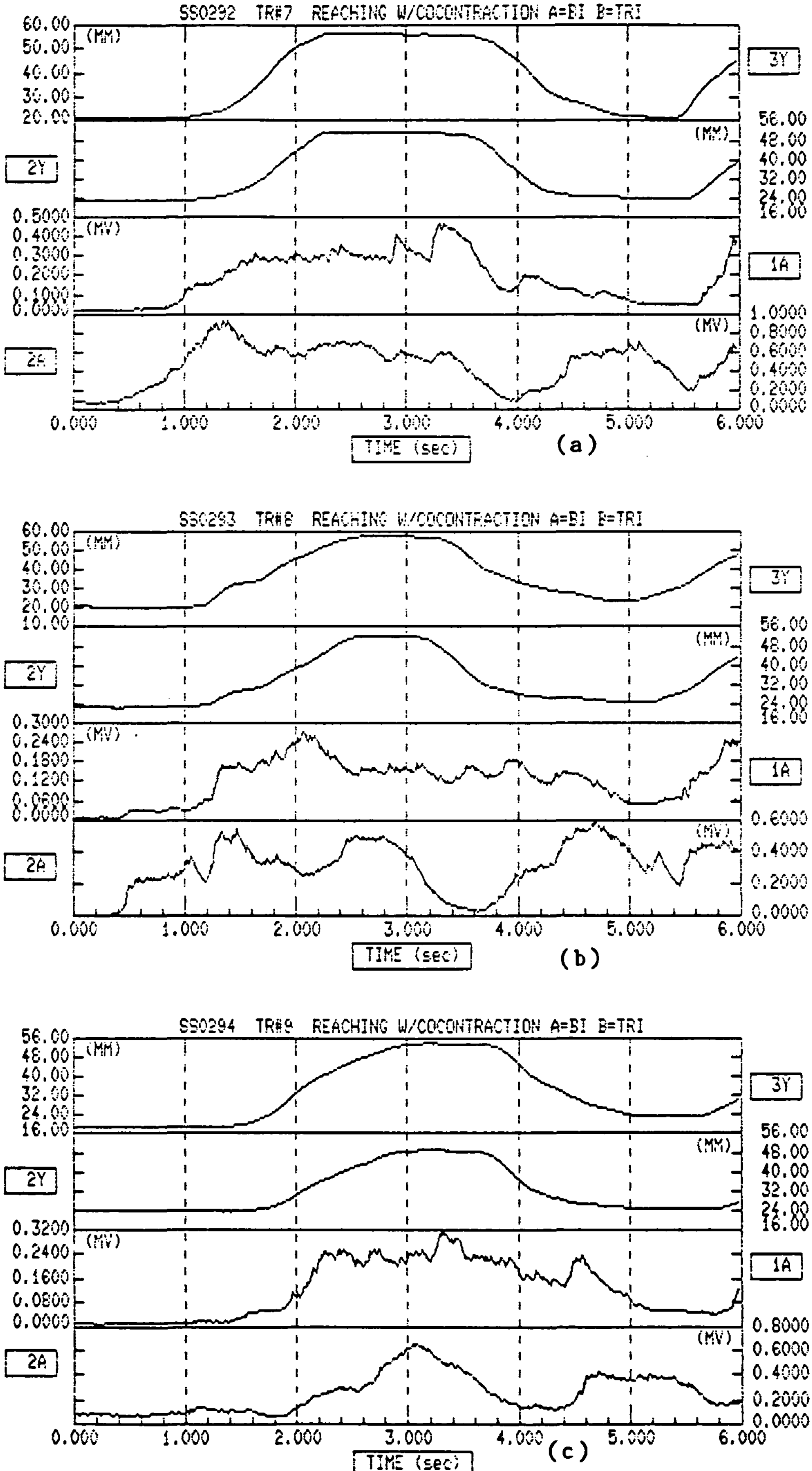


Figure D50. Elbow flexion then shoulder flexion reaching movement in the sagittal plane.

6.1.3 Reaching (Forearm Flexion then Shoulder Flexion); Sagittal Plane

Special conditions: With and without co-contraction (Phase I only)

EMG: anterior deltoid and latissimus dorsi

Description: Inital position; subject seated, right arm hanging relaxed at the side. Right side was facing the cameras. LEDs marked the wrist, elbow and shoulder. The subject was asked to perform a reaching motion initiated from a flexed forearm position, humerus aligned with the trunk. The midpoint of the movement was when the arm was extended at shoulder level. From this midpoint, the movement was characterized by simultaneous extension of the humerus and flexion of the forearm until the humerus was approximately in line with the trunk.

Figures: D51 a,b; D52 a,b,c;
Top strip chart (3Y) = displacement representing a change in vertical displacement of the wrist. Peaks (e.g. 60 mm) occur when the wrist is at shoulder level. Minimum values (e.g. 20 mm) occur when the humerus is in line with the body and the forearm is at a 90° angle with respect to the humerus. Second strip chart (2Y) = displacement data representing a change in the vertical position of the elbow. Maximum values (e.g. 55 mm) occur when the upper arm has been raised to shoulder level in the sagittal plane. Minimum values (20mm) occur when the longitudinal axis of the humerus is parallel to the longitudinal axis of the trunk. Third strip chart (1A) = EMG recording from the anterior deltoid. The anterior deltoid was monitored as a prime mover in shoulder flexion. Fourth strip chart (2A) = EMG recording from the latissimus dorsi. The latissimus dorsis was monitored to determine its role in control of the extension phase and its level of activation during shoulder flexion.

Observations:

The anterior deltoid (1A) exhibited a good phase relationship with the flexion/extension pattern of the shoulder. This was expected as the anterior deltoid was shown in single-segment tasks to correlate well with shoulder flexion. The latissimus dorsi, on the other hand, is a shoulder extensor under conditions of resistance. Again, when assisted by gravity, shoulder extension was controlled by the eccentric contraction of the agonist, or anterior deltoid. Under these no-resistance conditions, it was hard to envision the latissimus dorsi having a controlling influence on shoulder extension. The peak latissimus dorsi activity occured at the peak of shoulder flexion. This activity most likely related to movement artifact or passive stretch.

Under conditions of cocontraction tension levels increased, and once again there was increased variability. Note the changes in EMG patterns across trials D52a,b,c. We experimented with cocontraction trials to see if a reasonable control signal could be evoked from superifical muscles that were perhaps not prime movers, unless under conditions of resistance. While signal strength was increased under these circumstances, the variability in signal pattern also increased substantially. This variability eliminated cocontraction as a functional strategy in finding a reliable control signal for limb positioning.

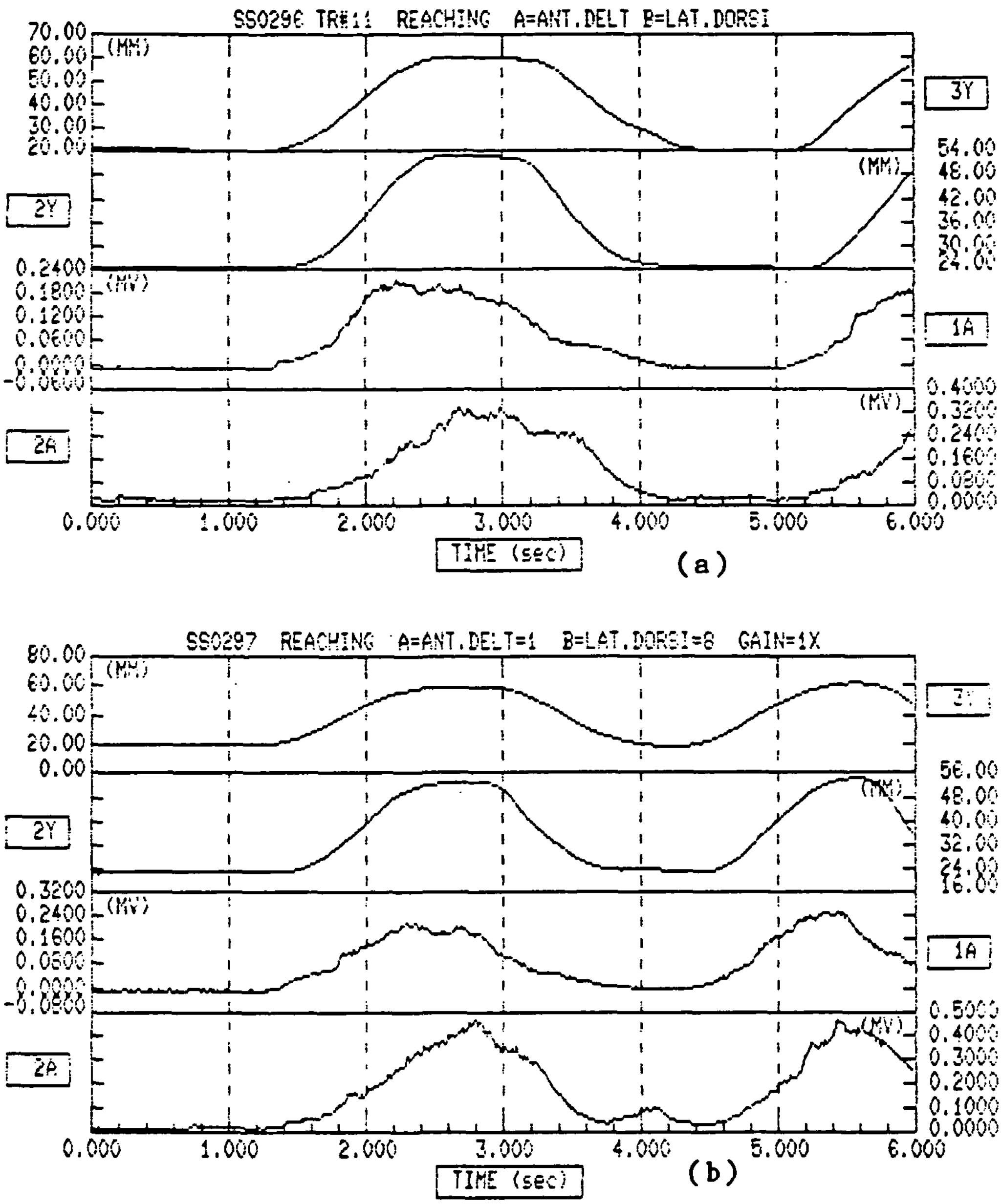


Figure D51. Elbow flexion then shoulder flexion reaching movement in the sagittal plane.

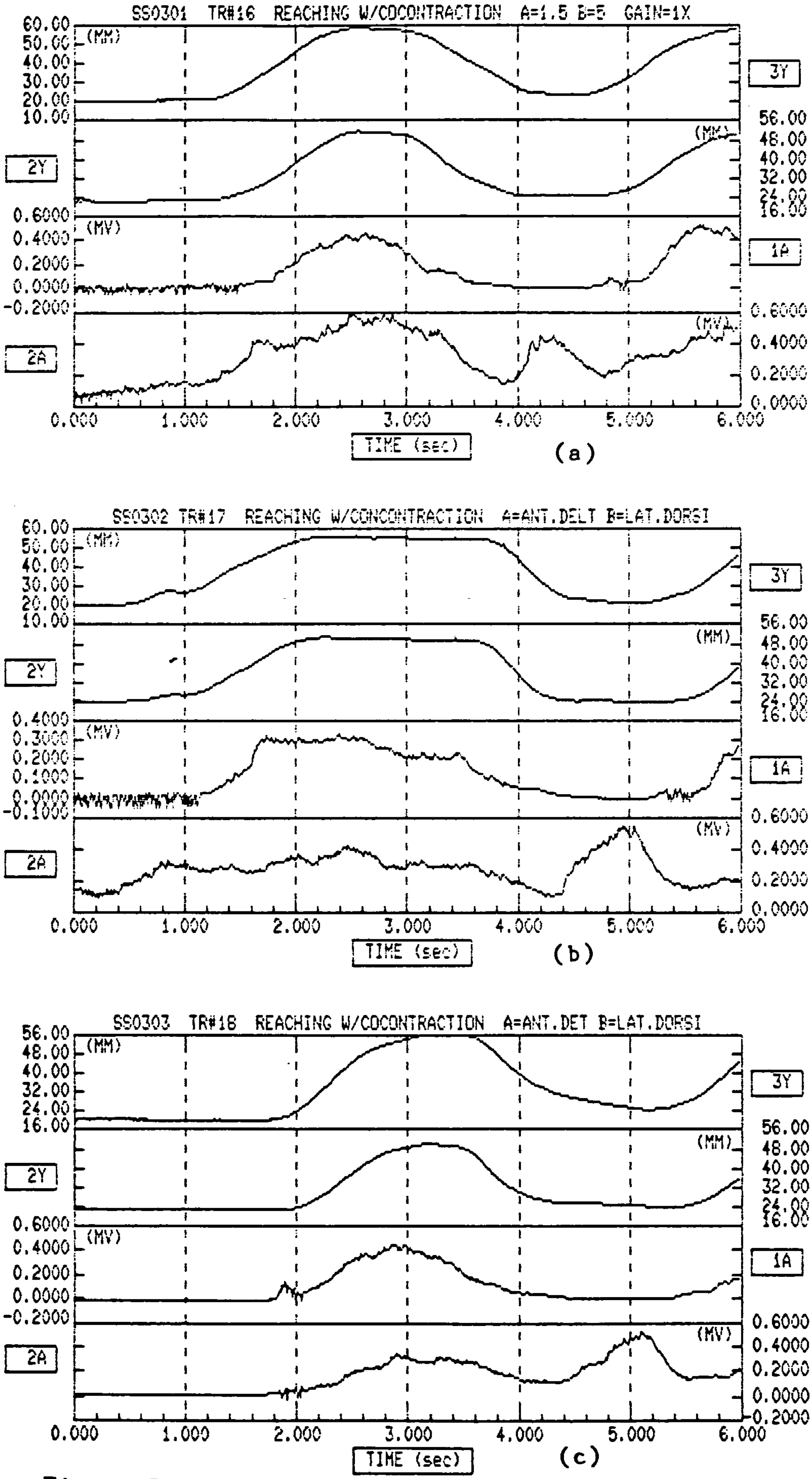


Figure D52. Elbow flexion then shoulder flexion reaching movement in the sagittal plane.

6.1.4 Normal Reaching Movement; Sagittal Plane

Special conditions: Slow and moderate speeds (Phase II only)

EMG: biceps brachii, triceps brachii, anterior deltoid and posterior deltoid.

Description: Initial position; subject in FSP, right arm hanging relaxed at the side. Subject was asked to perform a normal reaching motion; simultaneous forearm flexion, shoulder flexion, and forearm extension to reach the mid-point of the movement where the arm was fully extended and at an approximate 90° angle with the trunk, as viewed from the sagittal plane; the movement continued with simultaneous forearm flexion, shoulder extension and forearm extension to return to FSP.

Figures: D53 a,b; D54 a,b; D55 a,b,c,d,e; D56 a,b,c,d,e. EMG records from the biceps and anterior deltoid are displyed in the top graphs of D53a,b, D54a,b, D55b, and D56b. Displacement representing a change in angle is displayed in the bottom graphs of D53a and D54a, for the shoulder, and in D55a and D56a for the elbow (peaks indicate maximum flexion; valleys indicate maximum extension). EMG records from the biceps and triceps are displayed in the bottom graphs of D53b, and D54b, and in the top graphs of D55a,c and D56a,c. EMG records from the triceps and posterior deltoid are displayed in the bottom graphs of D55b and D56b. EMG records from the anterior deltoid and posterior deltoid are displayed in the bottom graphs of D55c and D56c. Raw EMG data is displayed in the top graphs of D55d, and D56d, for the biceps, and in D55e and D56e for the triceps. The corresponding processed EMG signal is displayed in the bottom graphs of each of the aforementioned figures.

Observations:

This normal reaching motion had some similarities to that conducted in section 6.1.1, however, there also were some differences. Bicep activity peaked during the first forearm flexion (i.e. prior to the midpoint of the movement) then gradually tapered off in the slow movement trials (Figures D55a, D56a), but displayed a double peak in the moderate speed movement trials (Figure D53a, D54a). This second peak was probably related to forearm flexion that took place after the midpoint of the movement, during shoulder extension (Figures D53a, D54a). Tricep activity again displayed a slight rise (Figures D53b, D54b, D55a, D56a), which may have been used to decrease the speed of shoulder flexion, or perhaps hyperextend the elbow joint (more evident in Figures D55a, D56a, as peak triceps activity occured at maximal elbow extension). As in section 6.1.1 (Phase II) the raw data for both the biceps and triceps did not correspond well with the processed signal (Figures D55d,e, D56d,e). These results clarify the importance of obtaining a clean signal.

Anterior deltoid activity correlated well with shoulder flexion as expected (Figures D53a, D54a). Once again it was evident that elevated bicep activity may have been related to shoulder flexion. Posterior deltoid activity displayed a very different pattern from that displayed in Phase II of section 6.2.1 (Figures D55b,c, D56b,c). This activity, which was very distinct and almost completely out of phase with the anterior deltoid activity, may reflect the effort to decrease the speed of shoulder flexion.

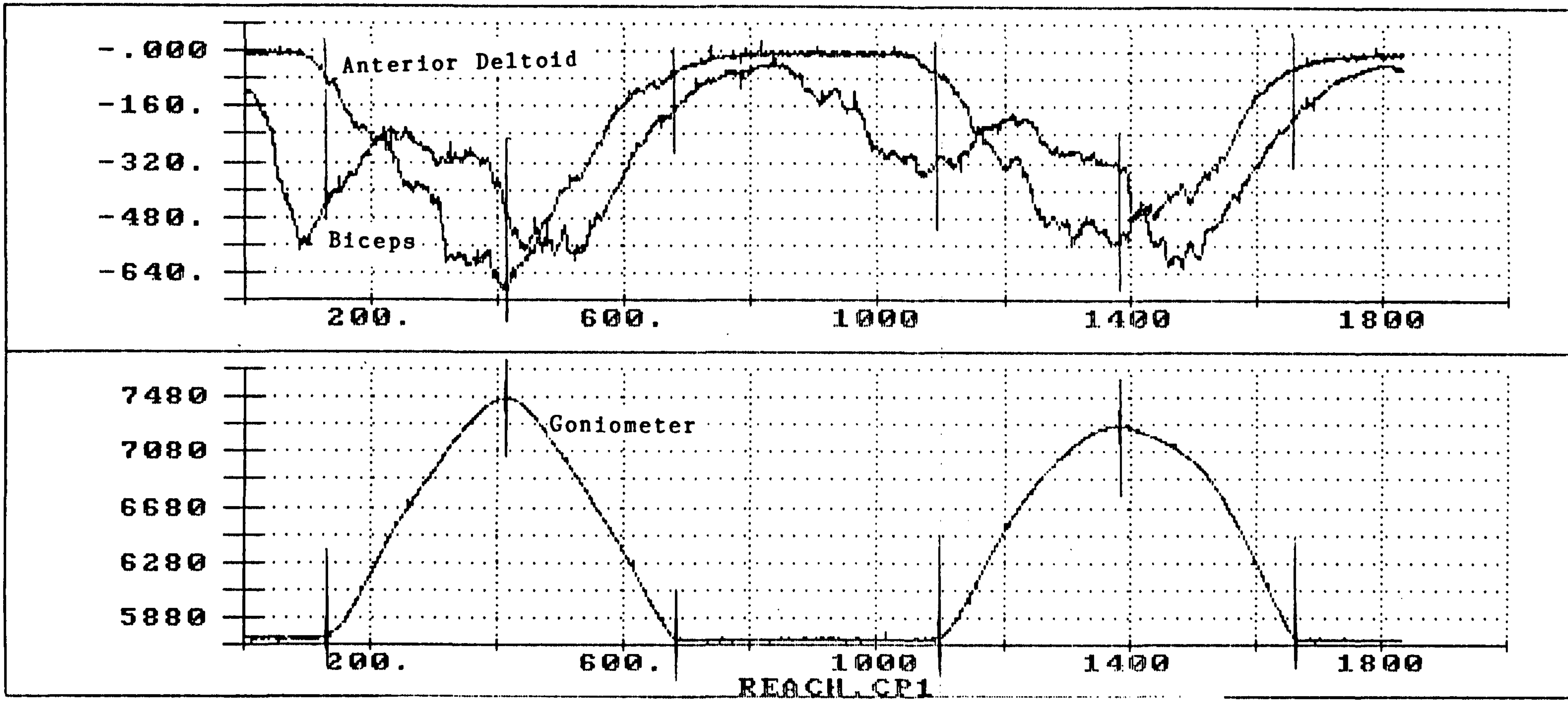


Figure D53a. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE

MOVEMENT SPEED: Medium SAMPLING RATE: 400 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Shoulder Flexion
Decreasing Signal Magnitude -- Shoulder Extension

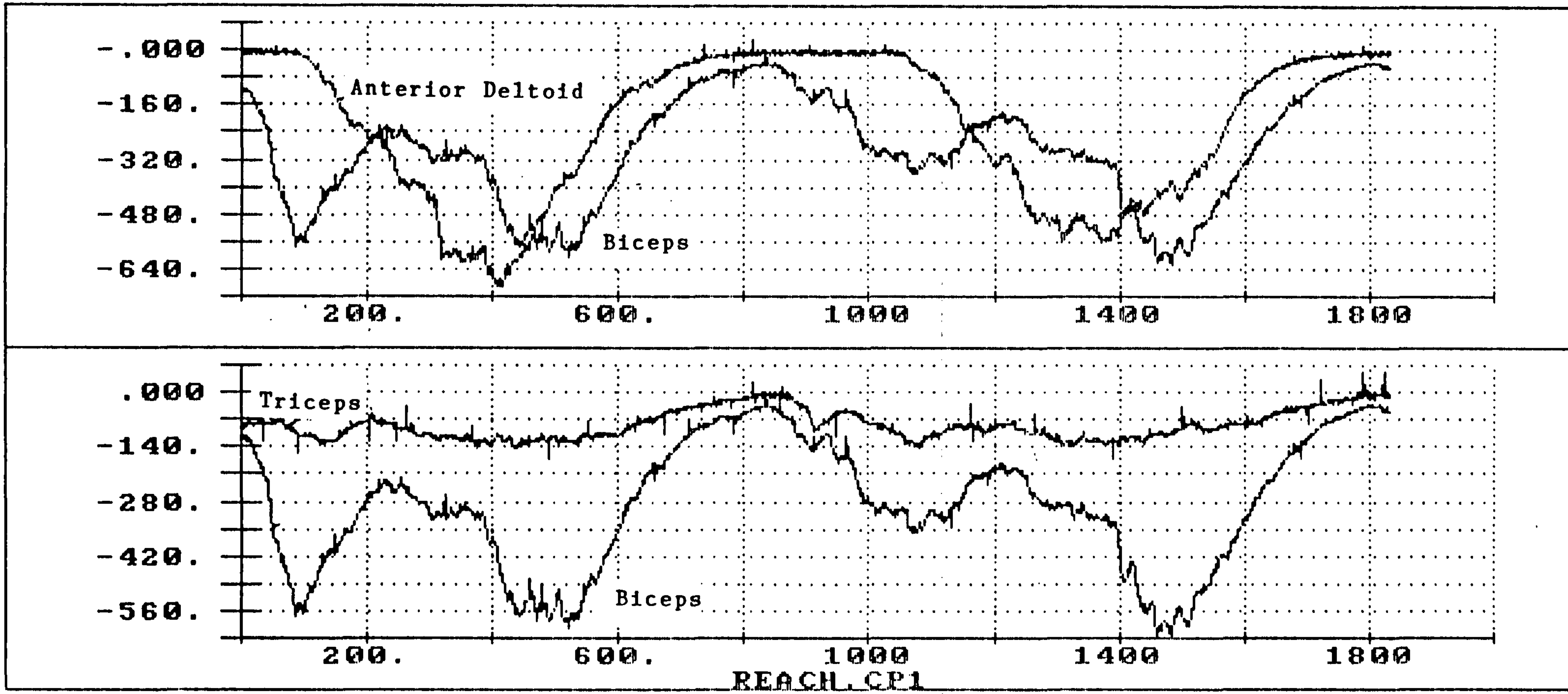


Figure D53b. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE

MOVEMENT SPEED: Medium SAMPLING RATE: 400 Samples/Sec/Channel

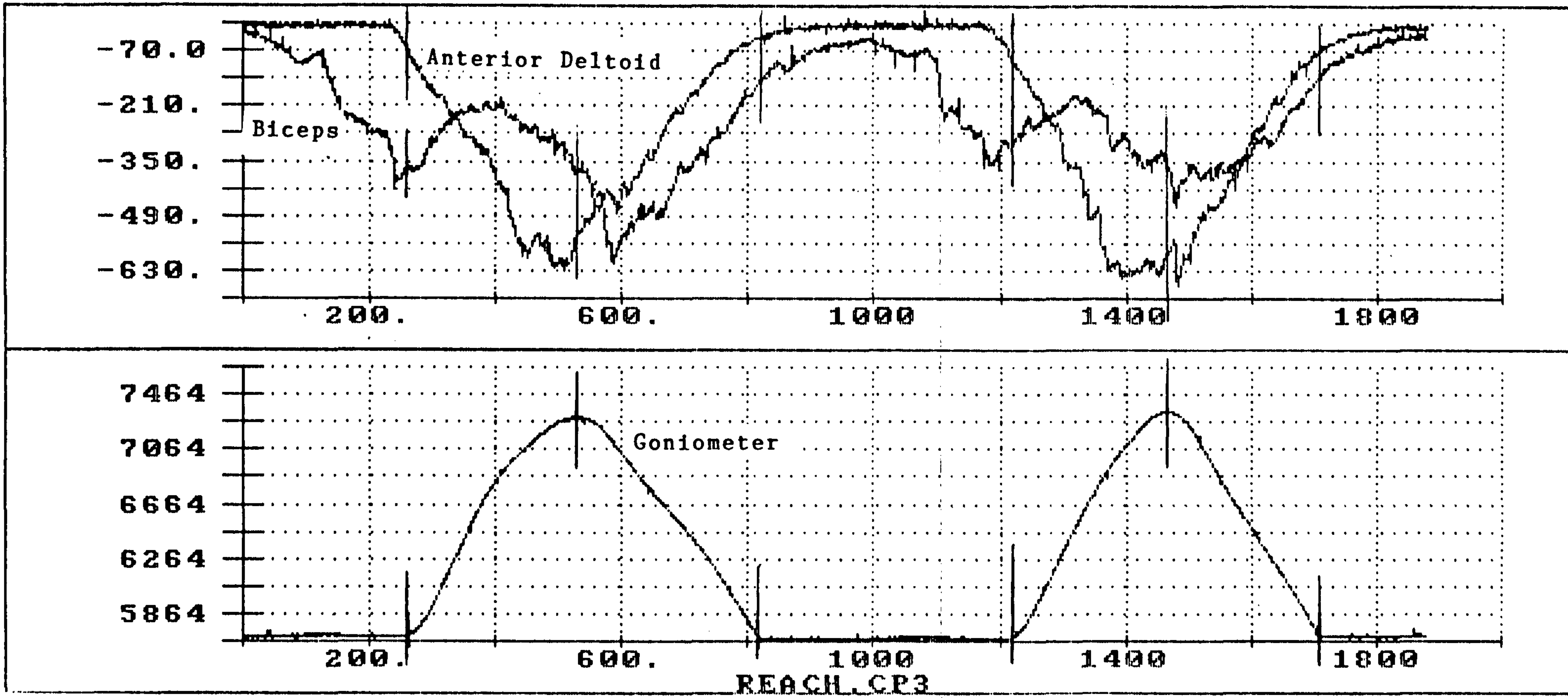


Figure D54a. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE

MOVEMENT SPEED: Medium SAMPLING RATE: 400 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Shoulder Flexion
Decreasing Signal Magnitude -- Shoulder Extension

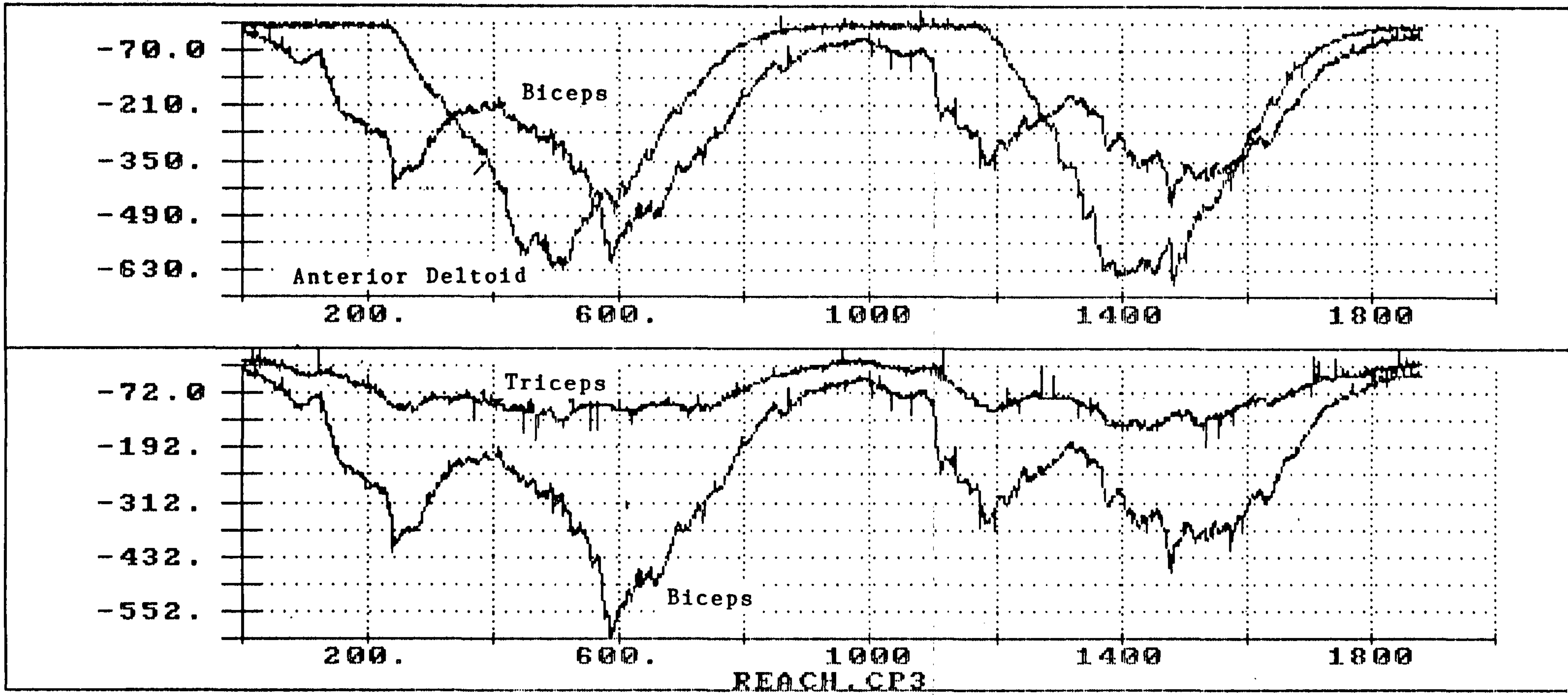


Figure D54b. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE

MOVEMENT SPEED: Medium SAMPLING RATE: 400 Samples/Sec/Channel

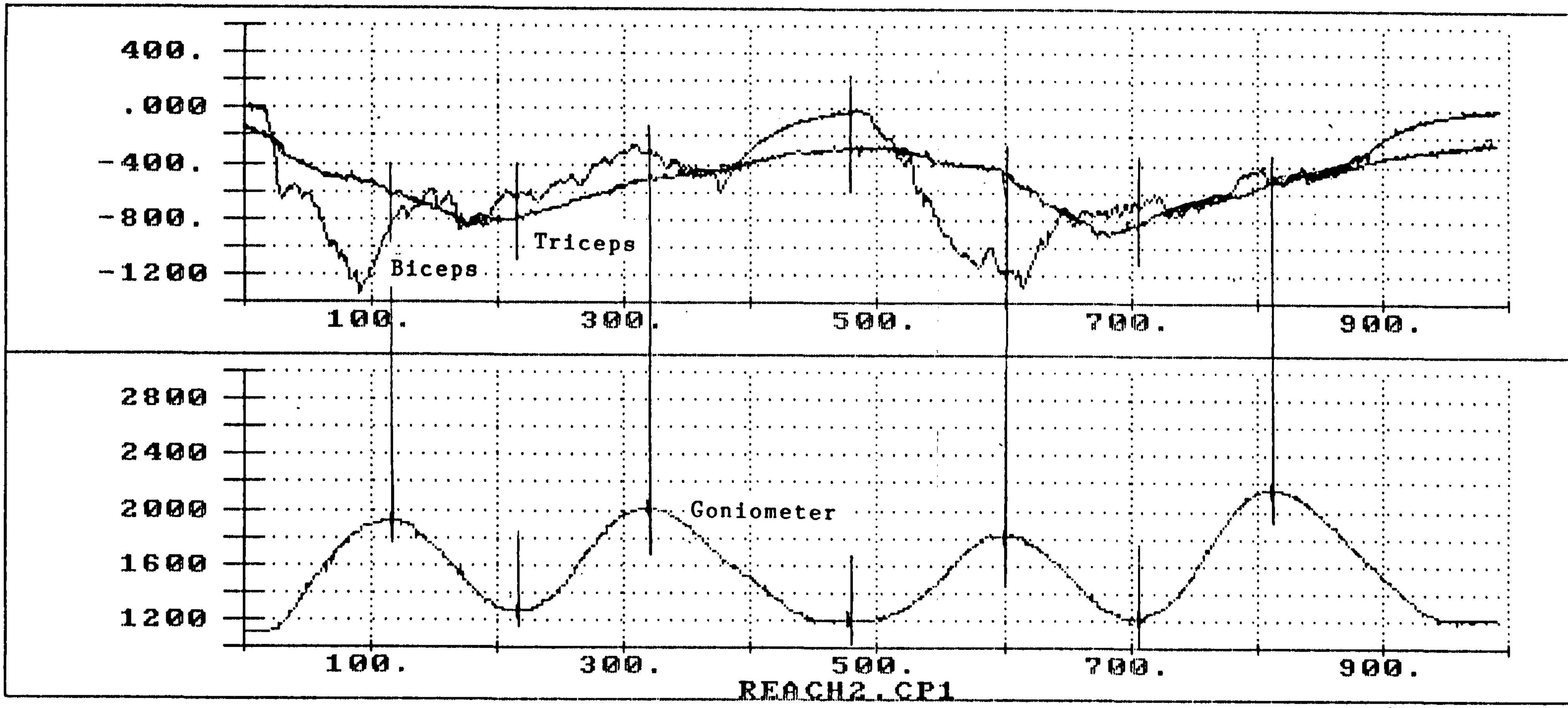


Figure D55a. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

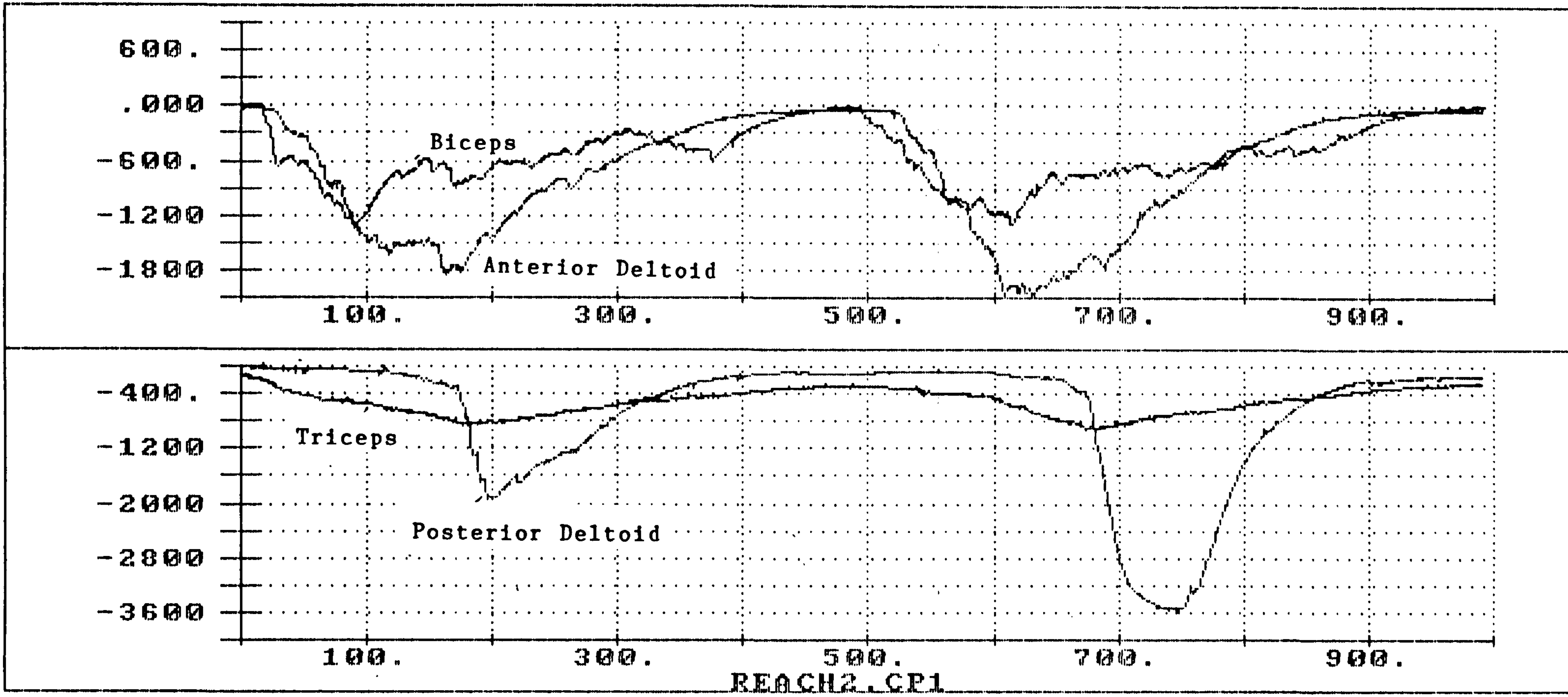
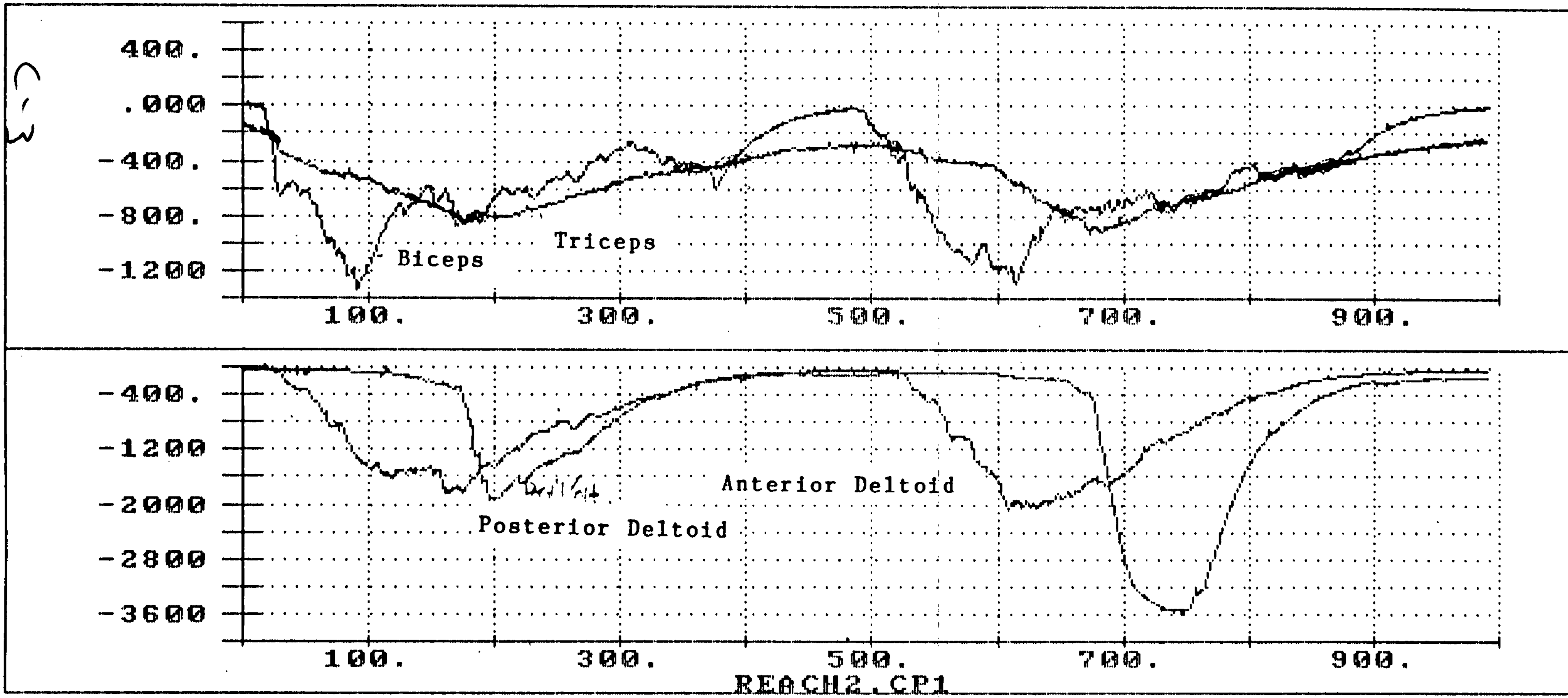


Figure D55b. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel



<u>Figure D55c.</u> SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

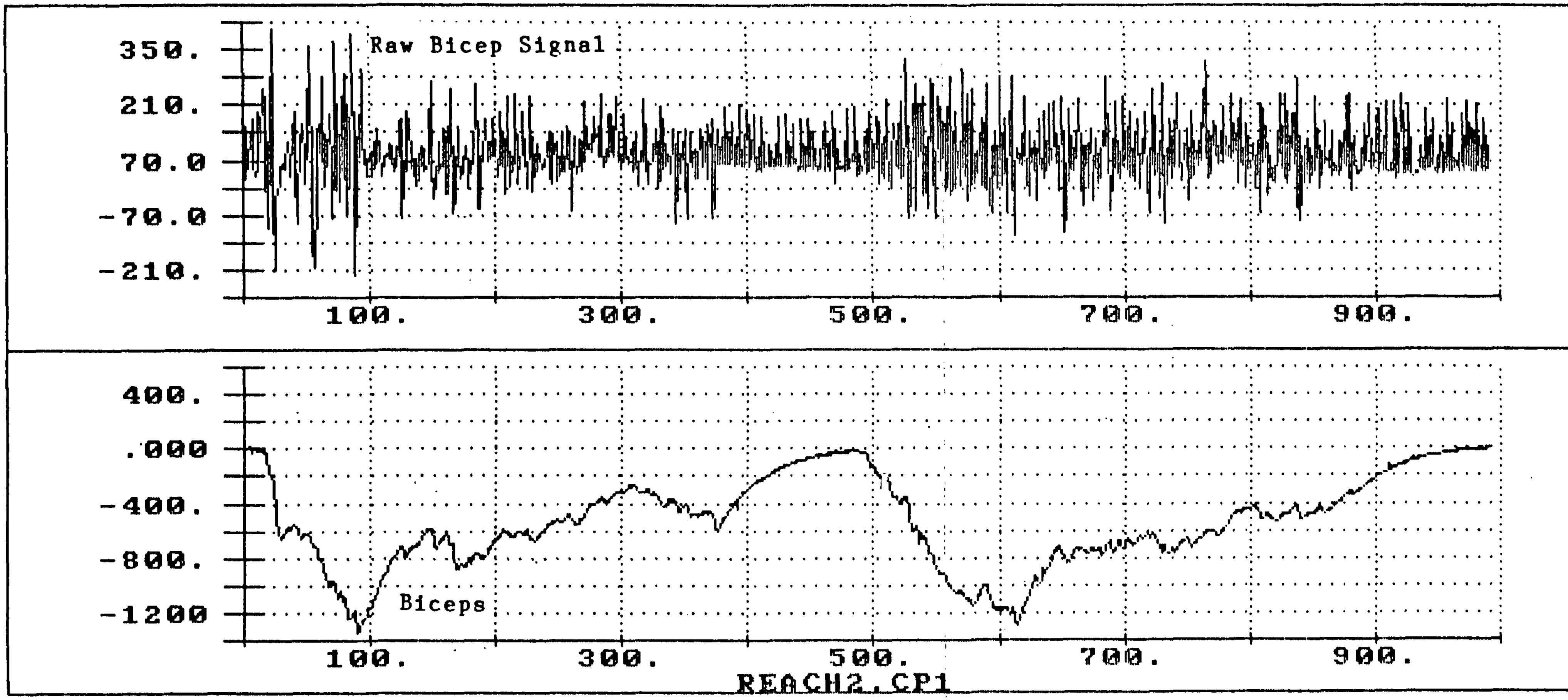


Figure D55d. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

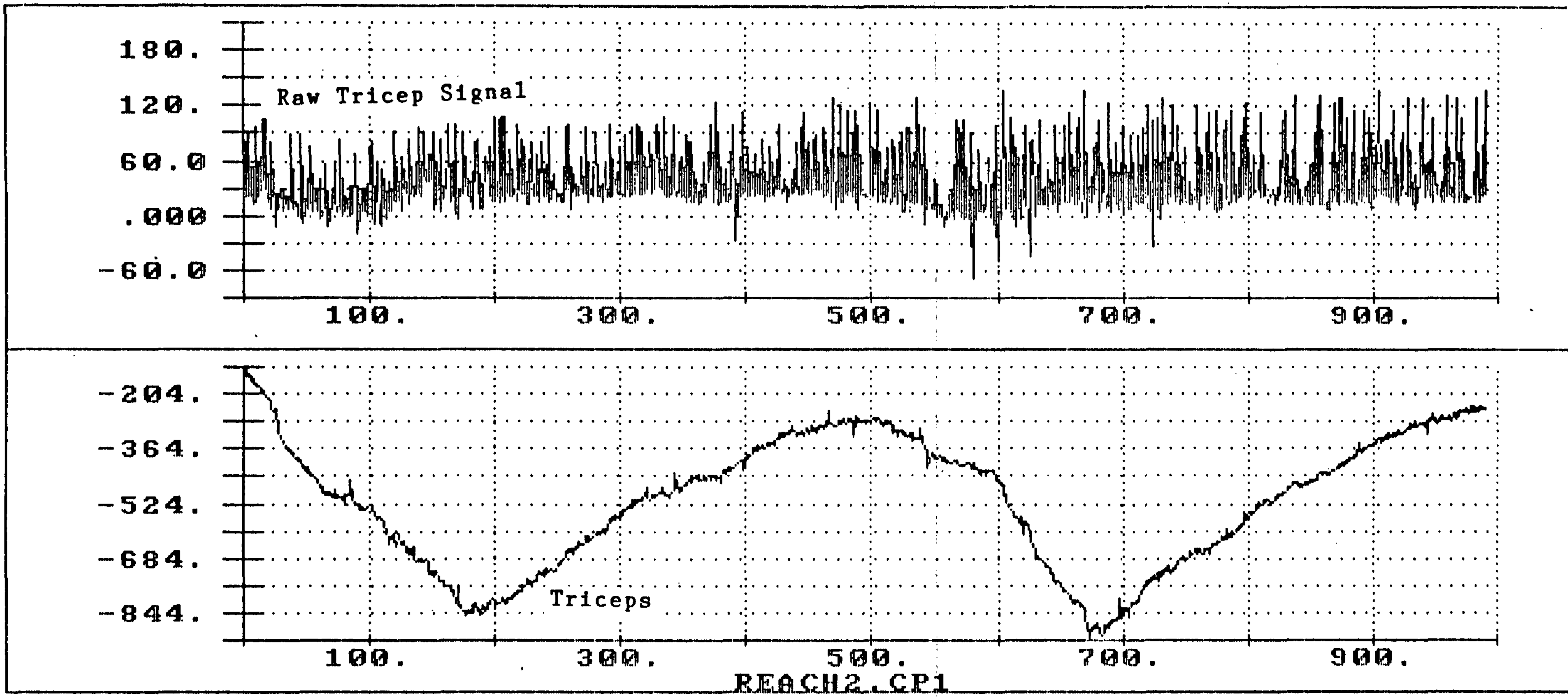


Figure D55e. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

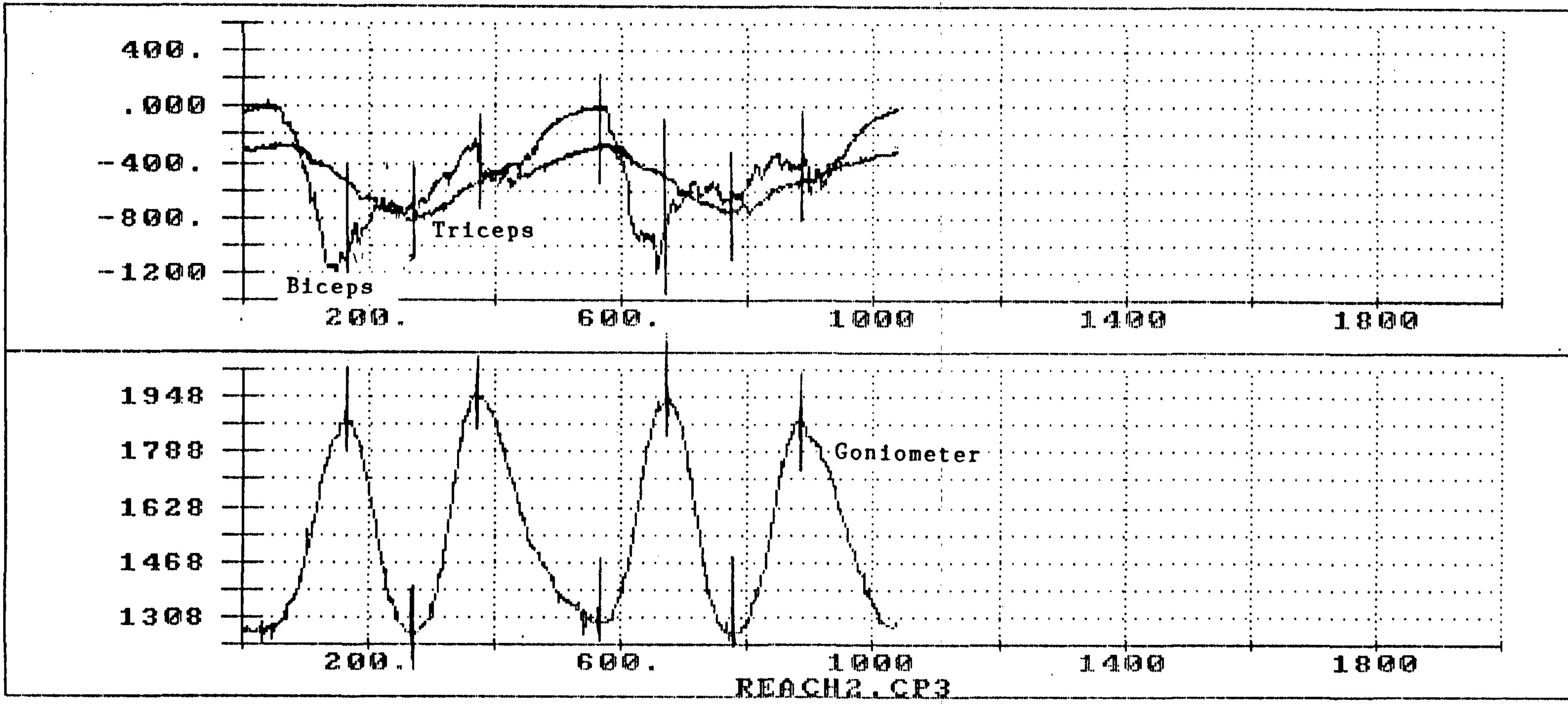


Figure D56a. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

Goniometer Key:
Increasing Signal Magnitude -- Elbow Flexion
Decreasing Signal Magnitude -- Elbow Extension

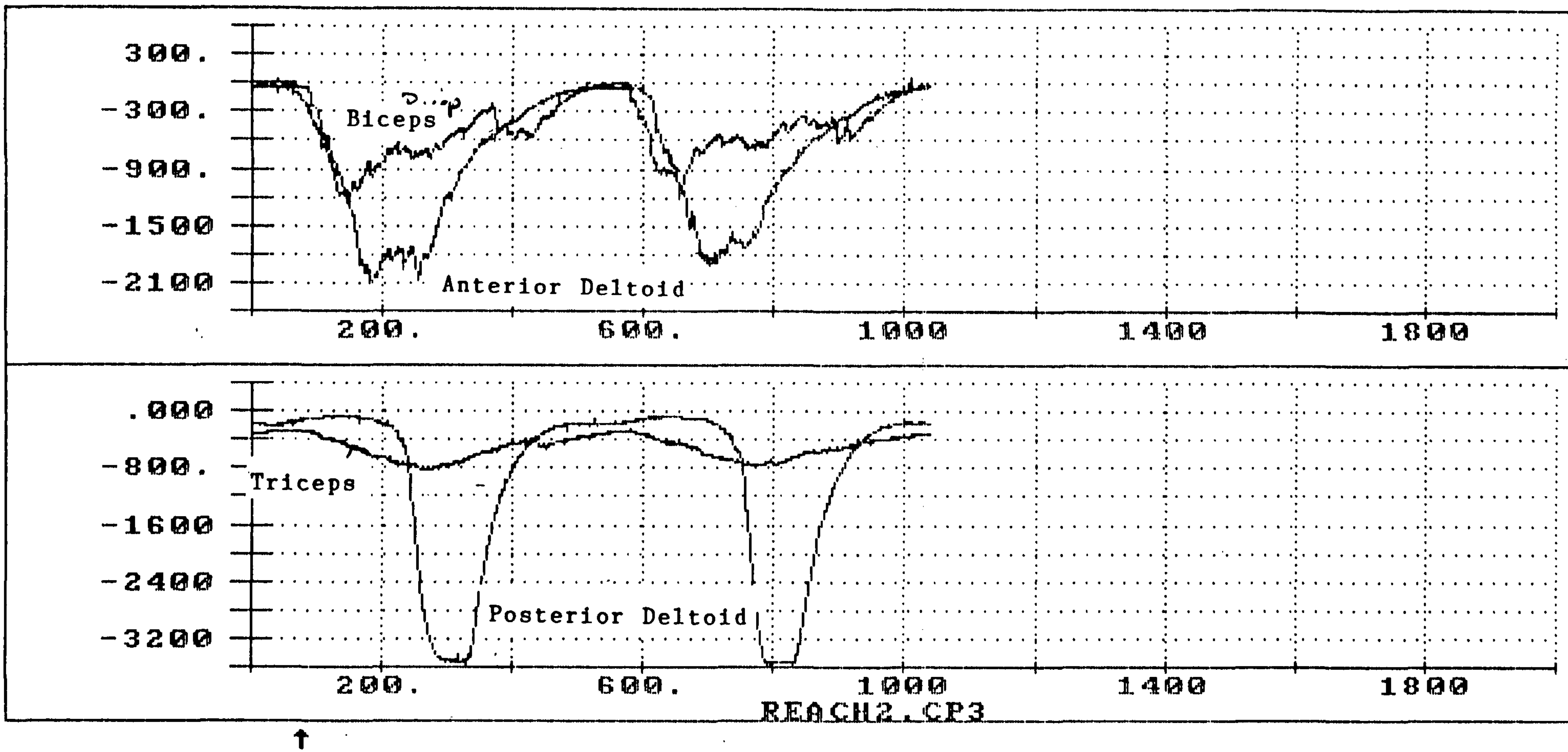


Figure D56b. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

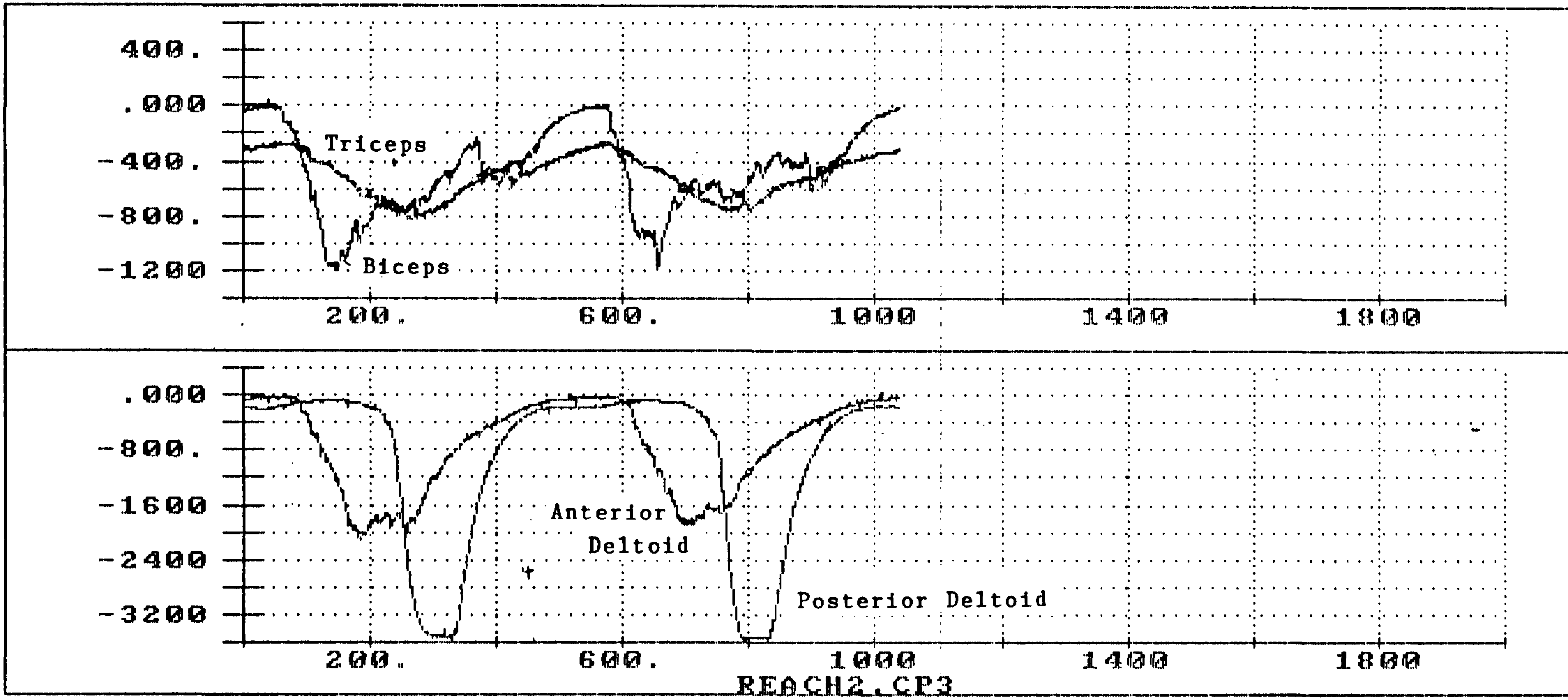


Figure D56c. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

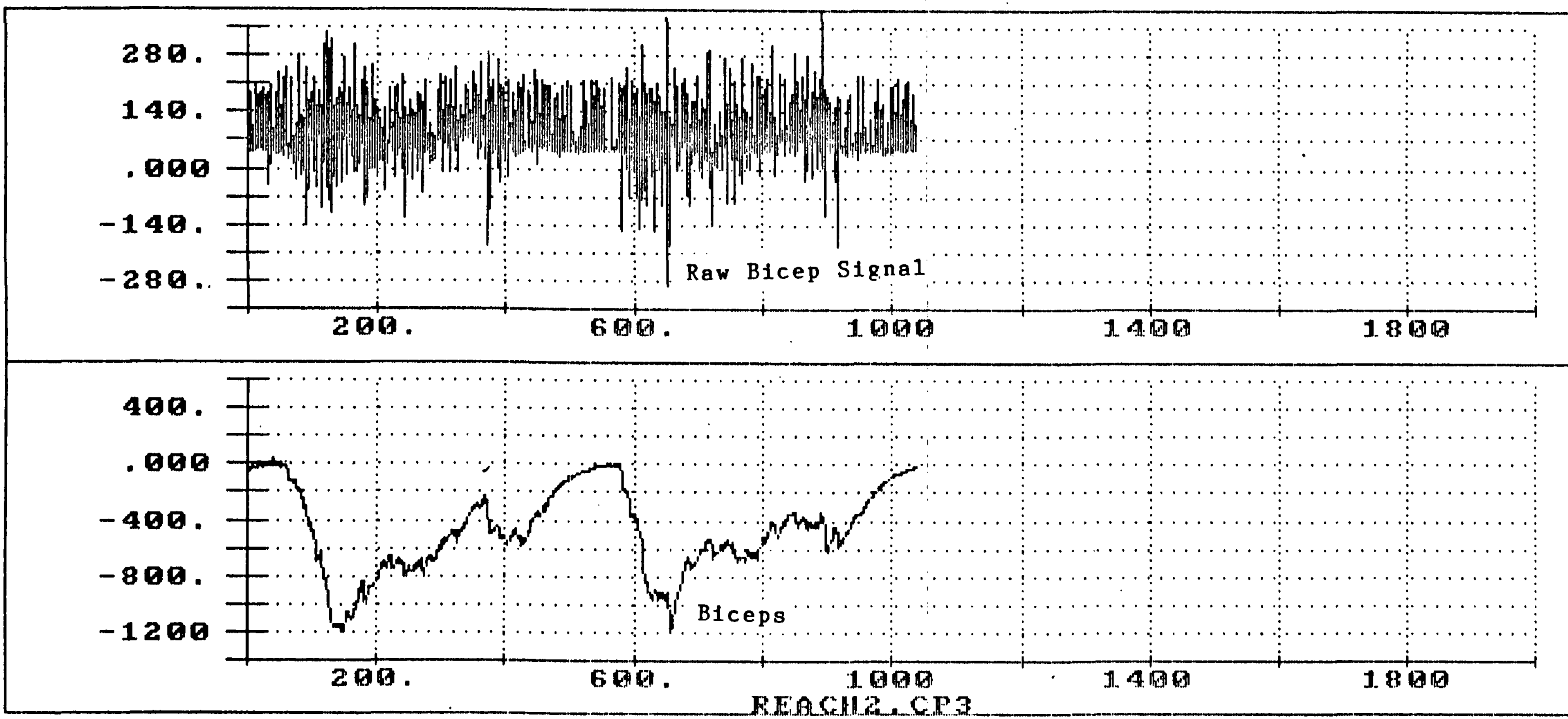


Figure D56d. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

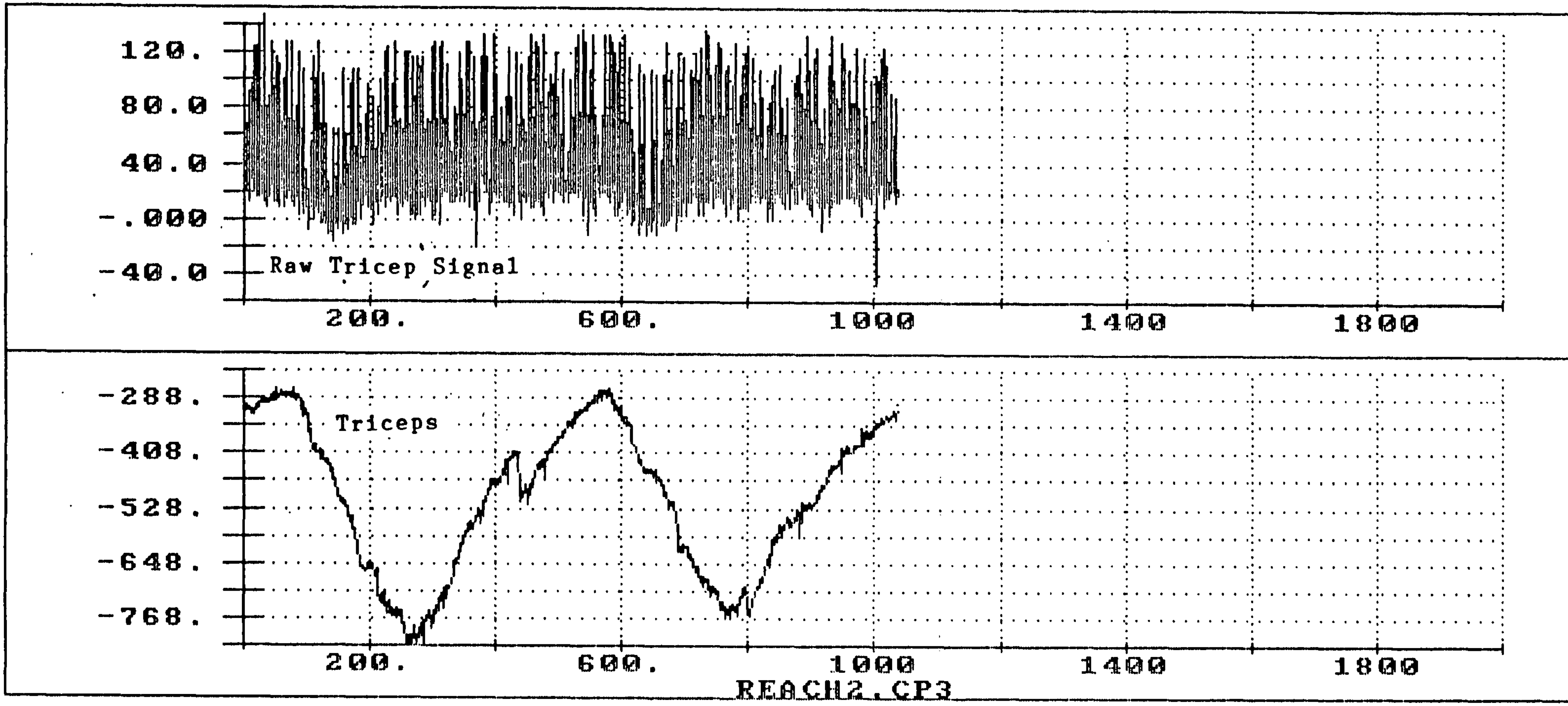


Figure D56e. SHOULDER & ELBOW - REACHING IN THE SAGITTAL PLANE

MOVEMENT SPEED: Slow SAMPLING RATE: 250 Samples/Sec/Channel

SECTION VI: SUMMARY

The specific goals of this project were to establish the "goodness" of the human myoelectric signal for use as a control signal, and to determine a mathematical relationship between the human myoelectric signal and the corresponding limb displacement for a variety of conditions in a one-degree-of-freedom movement. The investigation was seen as a two phase process. In the project reported here we completed the first of these phases.

The first phase examined previously established EMG/force relationships for isometric and constant velocity muscle contractions. Data collection was supposed to focus upon a simple one-degree-of-freedom movement (i.e. elbow flexion/extension). Collected data were to be processed and analyzed with emphasis on assessment of the quality of the EMG signal as a potential control signal. However, the first phase investigated numerous tasks ranging from a simple elbow flexion/extension task to a more complex reaching task. These data were qualitatively analyzed and assessed in reference to use as potential control signals.

Collectively the data from the elbow flexion/extension tasks, conducted in both the sagittal and transverse planes under a variety of conditions, showed the expected phase relationships. Agonist muscles (i.e. elbow flexors) showed a lot of activity during sagittal plane elbow flexion, and little activity during elbow extension as gravity acted to return the forearm to its original position. Antagonist muscles (i.e. elbow extensors) showed little if any activity during sagittal plane elbow flexion/extension. In the transverse plane elbow flexion/extension task, which lacked the influence of gravity, the flexors were active during elbow flexion and the extensors during elbow extension. However, there were large variations within the data of one subject and the problem of 'load sharing' among muscles seemed apparent. In addition, the importance of sampling rate and its effect upon the data became evident. Thus, the elbow flexion/extension data appeared to be adequate for a potential control signal in some but not all cases.

Shoulder movement data was collected across a variety of conditions for all 3 degrees-of-freedom at the gleno-humeral joint: (1) flexion/extension; (2) abduction and adduction; and (3) internal/external rotation. In isolated flexion/extension and abduction/adduction tasks in the sagittal and frontal planes respectively, the agonist and antagonist muscle activity demonstrated good phasic relationships and corresponded to the movements. Unfortunately neither of these tasks were performed in the transverse plane, so unlike a nongravitational environment, the effect of gravity was evident. However, at least under the conditions tested, these two degrees of freedom appeared to have potential for control signals. The internal and external rotation task data did not demonstrate a clear distinction between muscles defined as internal and external rotators. Thus myoelectric signals from this degree of freedom may not be attainable for the purposes of control.

Similarly data from the pronation/supination task did not show a clear distinction between the pronator and the supinators, except at the extremes of the range of motion. So EMG data from this movement would not be attainable for control.

Data from the forearm flexor and extensor groups demonstrated good phasic relationships with each of the corresponding movements: grasping and wrist flexion/extension. However, these movements were isolated, and the muscles are all within close proximity of each other. Thus if these movements were combined with each other or other hand and forearm movements, the distinction evident in isolated tasks may be lost. Thus precise control would be lost. However, use of these movements in isolation may provide 'trigger tasks' (i.e. a specific isolated movement used to trigger a different movement).

Thumb and 'pinky' movements were investigated as potential trigger movements. EMG data from both of these movements appeared to correspond well with the observed movement. Thus for movements which did not provide differentiation between agonist and antagonist EMG signals, there were potential trigger movements.

The most complex movement investigated was a two-degree-of-freedom reaching task performed in the sagittal plane. For each subject, the EMG data appeared to correspond well with the displacement data. However, the action of two-joint muscles became evident. For example the biceps was activated for both elbow and shoulder flexion. If a two-joint muscle signal were to be used for a control signal, there were need to be some means of determining which movement is elicited by activation of that muscle. Also, comparison of the reaching movement data across subjects showed few similarities. Perhaps the problems associated with control of a one-degree of-freedom robot from EMG signals need to be dealt with before control of a more complex movement is undertaken.

In summary the first phase of this project established that myoelectric signals from simpler movements, under some conditions, have potential for control signals. Myoelectric signals from movements conducted by agonists and antagonists which are far from the surface, or in close proximity have little potential for control signals (i.e. with surface electrodes). In addition, it would be easier to establish control signals from muscles which have only one function or those which span only one joint as opposed to muscles which have multiple functions and span multiple joints.

Future research is necessary to analyze these data quantitatively. The results of these analyses will lead to the second phase in exploration of the efficacy of using the human myoelectric signal as a control signal for a robot: determination of a relationship between the myoelectric signal and limb displacement.

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Appendix A

SELSPOT Data Collection - Cover Sheet

Investigator: ______________________________

Study: NASA - Elbow Flexion / Shoulder

Date: ______________________

Reference File: ________________________ Disk: ____

Calibration File: ________________________ Disk: ____

Subject Data:

Name: ______________________________ phone ___________

Age __________ Height _________ Weight _________

Segments Lengths: Forearm _________ Thigh _________

Upper Arm _________ Shank _________

Trunk _________ Foot _________

Other: ________________________

____

LED Setup

1. WRIST
2. ELBOW
3. SHOULDER
4. ____________________
5. ____________________
6. ____________________
7. ____________________
8. ____________________

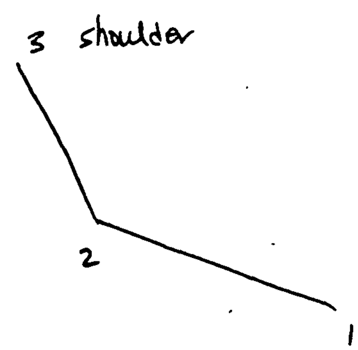
Analog:

EMG. BICEPS

ANTERIOR DELTOID

____

Body Diagram



SSS Form #3
4/87

Calibration Data

Calibration File: Newcal.518 Disk: 17
Creation Date: 5/18/89
Reference File: NewRef.515 Disk: 17
Creation Date: ____

Investigator: Jensen/Clarke Study: NASA

PROMS: 200 Hz Aim Analog? ____
AIM Alt: 1

C3.VI: Field of View

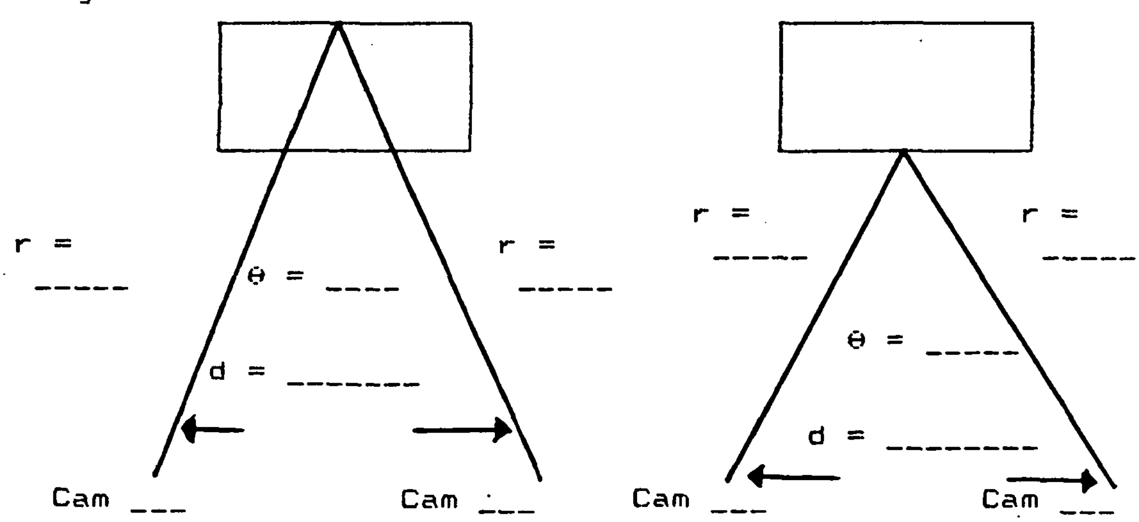
	X	Y
Cam1	____	____
Cam2	____	____

No. of Frames used in calibration:

	Cam1		Cam2	
No. of Frames	Cam1	____	Cam2	____
Average Distance:	Cam1	5.295	Cam2	7.591

Camera Set-up:				
radius	Cam1	____	Cam2	____
angle, θ	____			
tilt	Cam1	____	Cam2	____
height	Cam1	____	Cam2	____

Diagram:



File Titles:

Comments: - .95 scale factor

SSS: Form #1
3/87

Reference Creation

Reference File: New Ref. 518   Disk: 17

Creation Date: 5/18/87

Investigator: [illegible] / [illegible]

Study: NASA

Reference Description: ______

LED #	Coordinates (in mm) X	Y	Z	Detected Light Level Cam1	Cam2
1	0	518	0		
2	0	1052	0		
3	597	518	0		
4	597	1052	0		
5	0	518	588		
6	0	1052	588		
7	598	518	588		
8	598	1052	588		

Aperature

Cam1 ___

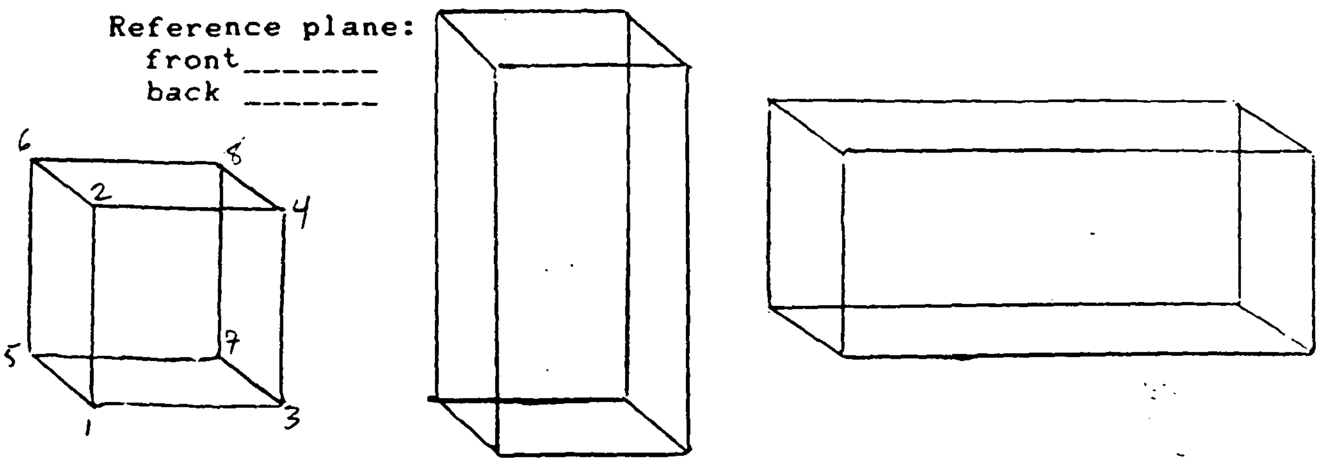
Cam2 ___

Analog:

Ch.	Units	Offset	Scale Factor	Description
1	mV		-.95	
2				
3				
4				
5				
6				
7				
8				

Reference Diagram: (mark and number LED locations)

Reference plane:
front ______
back ______



For hanging reference: Front track ______
Back track ______

SSS Form #1
4/87

SELSPOT Data Collection - Trials Records

Investigator: Newref /Newcd. 518 Date: 5/18/87
Study:

TRIAL	FILES		DISK		COMMENTS
	Note: Forearm in Neutral Position				
✓ 1	SS0093	.RAW	DISK	17	Gain A = Bicep = 10 B = Delt = 4
	SS0093	.POS	DISK	17	TR#1 Elbow Flexion A: Bicep B: Delt - Slow
		.POF	DISK		
✓ 2	SS0094	.RAW	DISK	17	Elbow Flexion " " TR#2
	SS0094	.POS	DISK	17	
		.POF	DISK		
✓ 3	SS0095	.RAW	DISK	17	TR#3 Elbow Flexion A: Bicep B: Delt
	SS0095	.POS	DISK	17	Slow
		.POF	DISK		
✓ 4	SS0096	.RAW	DISK	18	Gain A = 10 Gain B = 3
	SS0096	.POS	DISK	18	TR#4 Shoulder Flexion A: Bicep B: Delt Sl
		.POF	DISK		
✓ 5	SS0097	.RAW	DISK	18	TR#5 Shoulder Flex " " Slow
	SS0097	.POS	DISK	18	
		.POF	DISK		
✓ 6	SS0098	.RAW	DISK	18	TR#6 Shoulder Flexion Slow
	SS0098	.POS	DISK	18	
		.POF	DISK		
✓ 7	SS0099	.RAW	DISK	19	Gain A = 8 B = 5 TR#7 Elbow Flexion - Fast
	SS0099	.POS	DISK	19	
		.POF	DISK		
✓ 8	SS0100	.RAW	DISK	19	TR#8 Elbow Flexion - Fast
	SS0100	.POS	DISK	19	
		.POF	DISK		

SELSPOT Data Collection - Trials Records

Investigator: ______________________ Date: 5/14/87
Study: ______________________

TRIAL	FILES		DISK		COMMENTS
					Gain A=8 B=5
✓ 9	550101	.RAW	DISK	19	TR#9 Elbow Flexion A=Bicep
	550101	.POS	DISK	19	B=Delt Fast
		.POF	DISK		
					Gain A=10 B=2
✓ 10	550102	.RAW	DISK	20	TR#10 Shoulder Flexion
	550102	.POS	DISK	20	A=10 B=2 Fast
		.POF	DISK		
✓ 11	550103	.RAW	DISK	20	TR#11 Shoulder Flexion
	550103	.POS	DISK	20	A=Bicep B=Delt Fast
		.POF	DISK		Possibly lost wrist LED
✓ 12	550104	.RAW	DISK	20	TR#12 Shoulder Flexion Fast
	550104	.POS	DISK	20	
		.POF	DISK		
					Gain A=10 B=2
✓ 13	550105	.RAW	DISK	21	TR#13 Elbow Flex - Should Flex
	550105	.POS	DISK	21	
		.POF	DISK		
✓ 14	550106	.RAW	DISK	21	TR#14 Elbow Flex - Shoulder Flex
	550106	.POS	DISK	21	A=10 B=2
		.POF	DISK		
✓ 15	550107	.RAW	DISK	22	TR#15 Elbow Flex - Shoulder Flex
	550107	.POS	DISK	22	A=10 B=2
		.POF	DISK		
✓ 16	550108	.RAW	DISK	22	TR#16 Elbow Flex - Shoulder Flexs
	550108	.POS	DISK	22	Closed fist / Natural Motion
		.POF	DISK		

NASA DATA

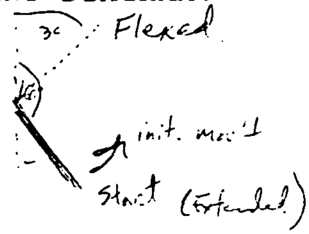
DATE: 11/13/87

SUBJECT: Rich Seibert

INVESTIGATOR(S): Truly & Clarke

MOVEMENT:
- a) Initial position: elbow flexion/extension
- b) Direction of 1st movement: Flexion
- c) Definition of 1 repetition: Flex to Ext

MOVEMENT DIAGRAM:



DATA FILE NAME: ELFE43.DAT

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
CH A	Tric		1	.854/1	-.876
CH B	Bicep		2	1.706/1	-.898
MYOLAB II					
CH A	Raw Bicep		4-5	1.706/1	
CH B					

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1: Goni	1	3	1.706/1	.927
JT2:				

SAMPLING RATE: 2000 samples/sec
400 per Channel

MOVEMENT SPEED: (FAST) MED SLOW

NUMBER OF REPETITIONS/SET: 8

NUMBER OF SETS: 3

INITIALIZED DATA FILE SIZE: 409600

COLLECTED DATA FILE SIZE: 3

ADDITIONAL COMMENTS:

Only trials which appear to give good raw data readings

Goni. slipped 1st Set

GOOD - NOISEY

NASA DATA

SUBJECT: Russell DATE: 10/30/87

INVESTIGATOR(S): Russell / Tumly / Clarke

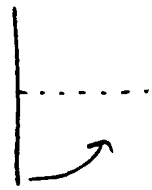
MOVEMENT: *Robot Movement - Elbow Flex & Ext

a) Initial position: Ext

b) Direction of 1st movement: Flex

c) Definition of 1 repetition: Flex - Ext

MOVEMENT DIAGRAM:



DATA FILE NAME: Quikflex.dat

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
CH A					
CH B	Bicep	4	2	1.708/1	.078
MYOLAB II					
CH A	Tricep	4	1=6	1.708/1	-1.462
CH B					

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:	ELBOW FLEX/EXTENSION	3	1.708/1	.761
JT2:				

[SAMPLING RATE: 2000] ÷ [NUMBER OF INPUT CHANNELS ACTIVATED 6] =>

SAMPLING RATE: 333 samples/sec (per channel) MOVEMENT SPEED: (FAST) MED SLOW

NUMBER OF REPETITIONS/SET: 6

NUMBER OF SETS: 2

INITIALIZED DATA FILE SIZE: 204800

COLLECTED DATA FILE SIZE: 39623

ADDITIONAL COMMENTS:

* HOLD in FLEXED position - accelerated movement to EXTENDED position and HOLD, etc.

SELSPOT Data Collection - Cover Sheet

Investigator: ______________________________
Study: NASA - HORIZONTAL FLEX/EXT

Date: ________________________

Reference File: ____________________________ Disk: ____
Calibration File: ___________________________ Disk: ____

Subject Data:

Name: ___________________________________ phone ____________
Age ___________ Height __________ Weight __________

Segments Lengths: Forearm __________ Thigh __________
Upper Arm __________ Shank __________
Trunk __________ Foot __________

Other: ____________________________
____

LED Setup

Body Diagram

1. ____________________________
2. ____________________________
3. ____________________________
4. ____________________________
5. ____________________________
6. ____________________________
7. ____________________________
8. ____________________________

Analog:
1 TRICEPS
2 BICEPS
____

SSS Form #3
4/87

Calibration Data

Calibration File: Horcal.629 Disk: Nasa 4
Creation Date: ______
Reference File: HorRef.629 Disk: NASA 4
Creation Date: ______

Investigator: ______ Study: ______

PROMS: ______ Analog? ______
AIM Alt: ______

C3.VI: Field of View

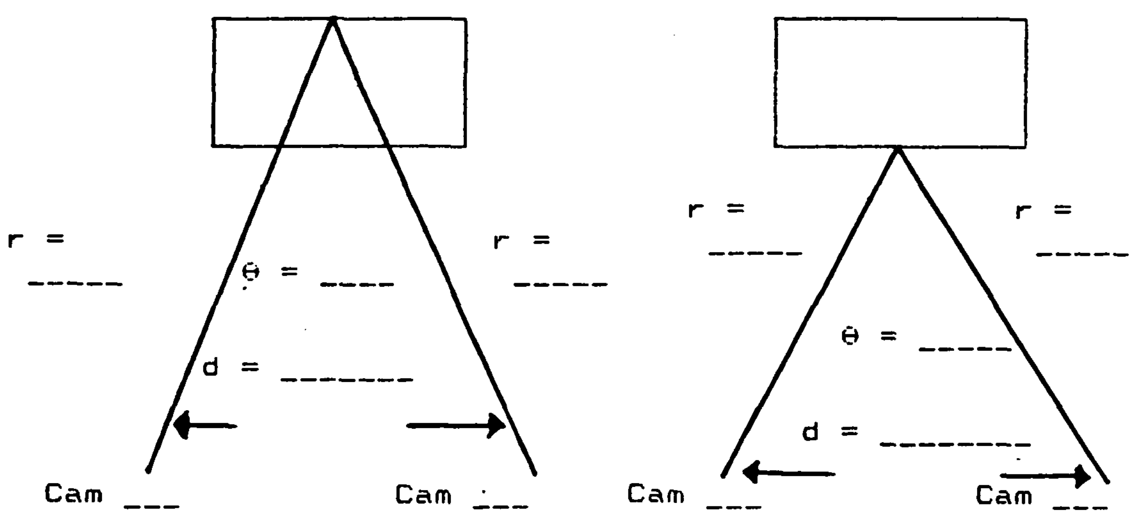
		X	Y
	Cam1	72	44
	Cam2	73	45

No. of Frames used in calibration:

	Cam1	100	Cam2	100
Average Distance:	Cam1	6.224	Cam2	3.143

Camera Set-up:	radius	Cam1	______	Cam2	______
	angle, θ		______		
	tilt	Cam1	______	Cam2	______
	height	Cam1	______	Cam2	______

Diagram:



File Titles:

Comments:

SSS: Form #1
3/87

Reference Creation

Reference File: Horef 1.629 Disk: NASA 4

Creation Date: ____________

Investigator: ____________

Study: ____________

Reference Description: ____________

LED #	Coordinates (in mm) X	Y	Z	Detected Light Level Cam1	Cam2
1	0	28	0		
2	0	178	0		
3	53.6	28	0		
4	53.6	178	0		
5	0	128	344		
6	53.6	128	344		
7					
8					

Aperature

Cam1 1

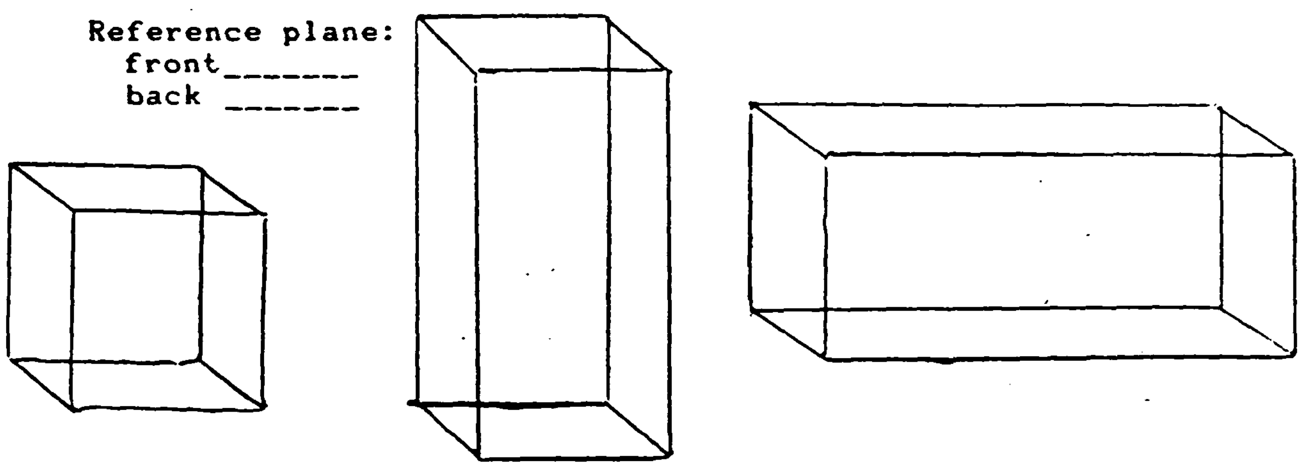
Cam2 1

Analog:

Ch.	Units	Offset	Scale Factor	Description
1	MV		-.95	
2				
3				
4				
5				
6				
7				
8				

Reference Diagram: (mark and number LED locations)

Reference plane:
front ______
back ______



For hanging reference: Front track ____________
Back track ____________

SSS Form #1
4/87

ORIGINAL PAGE IS
OF POOR QUALITY

SELSPOT Data Collection - Trials Records

Investigator: Truly / Clarke **Date:** 6/29/87
Study: [illegible]

TRIAL	FILES		DISK	COMMENTS	
1 (110°) ✓	SS0200	.RAW	DISK NASA4	Hor flex/ext	LC
	SS0200	.POS	DISK NASA4	GAIN A=3.5 B=4.25	
		.POF	DISK	10X A=Tri B=Bi	
2 PLOTTED	SS0201	.RAW	DISK NASA4	" flex/ext	LC
	SS0201 II	.POS	DISK		
		.POF	DISK		
3 PLOT	SS0202	.RAW	DISK NASA5	" flex/ext	
	SS0202 II	.POS	DISK		LC
		.POF	DISK		
4 plotted	SS0203	.RAW	DISK NASA5	" flex/ext	
	SS0203	.POS	DISK NASA5		LC
		.POF	DISK		
5 plotted	SS0204	.RAW	DISK NASA6	" CO-CONTRACTION	
	SS0204	.POS	DISK NASA4	(faster rate than	LC
		.POF	DISK	previous 4 trials)	
6 plotted	SS0205	.RAW	DISK NASA6	" flex/ext	
	SS0205	.POS	DISK NASA6		LC
		.POF	DISK		
7 Plotted	SS0206	.RAW	DISK NASA7	" CO-CONTRACTION	
	SS0206	.POS	DISK	(NOT MUCH ACTIVITY	LC
		.POF	DISK	ON MYOLAB)	
8 plotted	SS0207	.RAW	DISK NASA7	" CO-CONTRACTION	
	SS0207	.POS	DISK	(PEAKED-OUT ON BICEPS)	LC
		.POF	DISK		

Margin notes: 1 at 90° ... stopped ... flex/ext; 1 at 90° ... no stop; 1 at 90° stopped at 110° next flex/ext; 1 at 90° stop at 110° nine flex/ext; at 90° stop at 110° nine flex/ext; 1 at 90° stopped at 110° nine flex/ext; end at 110°; at 90° to 110° stop ... nine to flex+ext

ORIGINAL PAGE IS OF POOR QUALITY

SELSPOT Data Collection - Trials Records

Investigator: CLARKE / TRULY **Date:** 6/29/87
Study:

	TRIAL	FILES		DISK	COMMENTS	
[illegible] at 90°	9	SS0208	.RAW	DISK 13	" CO-CONTRACTION	
[illegible]	plotted	SS0208	.POS	DISK 13	(GOOD TRIAL)	LC deleted
110° - [illegible]			.POF	DISK		
[illegible]						
	10	SS0209	.RAW	DISK 13	" CO-CONTRACTION	
"	Plotted	SS0209	.POS	DISK 13	(GOOD TRIAL)	LC
			.POF	DISK		
			.RAW	DISK		
			.POS	DISK		
			.POF	DISK		
at 90°	11	SS0210	.RAW	DISK 14	HOR FLEX/EXT	
stop at 110°	plotted	SS0210	.POS	DISK 14	A = TRi GAIN = 3.0 10X	SS
[illegible]			.POF	DISK	B = Bi GAIN = 4.0	
[illegible]					(NOT GOOD - NO ACTIVITY ON MYOLAB)	
	12	SS0211	.RAW	DISK 14	"	[illegible]
"	plotted	SS0211	.POS	DISK	"	SS
			.POF	DISK	(NO ACTIVITY ON MYOLAB)	
	13	SS0212	.RAW	DISK 15	"	[illegible]
"	plotted	SS0212	.POS	DISK	A = TRi GAIN = 4.0 10X	SS
			.POF	DISK	B = Bi GAIN = 4.0	
					(NOT MUCH ACTIVITY ON MYOLAB)	
"	14	SS0213	.RAW	DISK 15	"	[illegible]
	plotted	SS0213	.POS	DISK		SS
			.POF	DISK	(GOOD TRIAL)	
	15	SS0214	.RAW	DISK 16	CO-CONTRACTION	
	plotted	SS0214	.POS	DISK	A - TRi 4.0	SS
			.POF	DISK	B - Bi 4.0	
					(GOOD TRIAL)	

SSS Form #4
4/87

SELSPOT Data Collection - Trials Records

Investigator: [illegible] Date: 6/20/87
Study: NASA [illegible]

TRIAL	FILES		DISK		COMMENTS	
at 90° + stop at 110° [illegible] to [illegible] 16 ✓	SS0215	.RAW	DISK	16	Hor flex/ext	
	SS0215	.POS	DISK		[illegible]	SS
	(Regraphed - off paper)	.POF	DISK		A=TRi, 40, B=Bi, 4.0 (GOOD TRIAL)	[illegible]
" 17 ✓	SS0216	.RAW	DISK	17	HOR flex/ext	
	SS0216	.POS	DISK		COCONTRACTION	SS
		.POF	DISK		" (GOOD TRIAL)	[illegible]
" 18 ✓	SS0217	.RAW	DISK	17	"	
	SS0217	.POS	DISK		COCONTRACTION	SS
		.POF	DISK		(GOOD TRIAL)	
" 19 ✓	SS0218	.RAW	DISK	18	"	
	SS0218	.POS	DISK		COCONTRACTION	SS
		.POF	DISK		(GOOD TRIAL)	[illegible]
" 20 ✓	SS0219	.RAW	DISK	18	"	
	SS0219	.POS	DISK		COCONTRACTION	SS
		.POF	DISK		(OK TRIAL)	[illegible]
		.RAW	DISK			
		.POS	DISK			
		.POF	DISK			
		.RAW	DISK			
		.POS	DISK			
		.POF	DISK			
		.RAW	DISK			
		.POS	DISK			
		.POF	DISK			

NASA DATA

SUBJECT: Pam Russell DATE: 10/9/84

INVESTIGATOR(S): P. Russell + L. Clarke

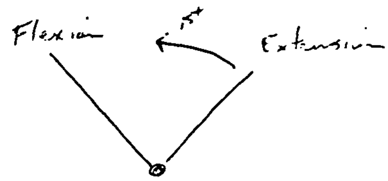
MOVEMENT: Elbow flexion/extension In Horizontal Plane

a) Initial position: Extended at (≈85°)

b) Direction of 1st movement: Flexion

c) Definition of 1 repetition: Flex to Extension

MOVEMENT DIAGRAM:



DATA FILE NAME: ~~ELBFEL.DAT~~ ElbFE1.DAT

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
CH A	Tricep	4	1	.854/1	-.640
CH B	Bicep	5.8	2	.854/1	.078
MYOLAB II					
CH A					
CH B					

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:	1	3=5	854/1	2.353
JT2:				

SAMPLING RATE: 200 samples/sec MOVEMENT SPEED: FAST (MED) SLOW

→ per channel - 200/5 = 40 samples/sec

NUMBER OF REPETITIONS/SET: 8

NUMBER OF SETS: 3

INITIALIZED DATA FILE SIZE: 102400

COLLECTED DATA FILE SIZE: 0001396 3

ADDITIONAL COMMENTS:

Note: Wrist Position is supinated - Rotation is at shoulder.

NASA DATA

DATE: 10-8-87

SUBJECT: Dave Penn

INVESTIGATOR(S): Terri Truly, Pam Russell

MOVEMENT: Elbow flexion/extension

MOVEMENT DIAGRAM:

a) Initial position: Started in extended position (Right arm)

b) Direction of 1st movement: flexed in (to left)

c) Definition of 1 repetition: flex/extend

DATA FILE NAME: ELBFE.DAT

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
(#182838) CH A	BICEP	6	1	.213/1	-.144
CH B	TRICEP	4-6	2	.213/1	.626
MYOLAB II					
CH A					
CH B					

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1: ELBOW	F/E	3/4 = 5	.854/1	2.353
JT2:				

SAMPLING RATE: 200 samples/sec MOVEMENT SPEED: FAST (MED) SLOW

→ per channel = 200/5 = 40 samples/sec

NUMBER OF REPETITIONS/SET: 10

NUMBER OF SETS: 3

INITIALIZED DATA FILE SIZE: ~~48~~ 102400

COLLECTED DATA FILE SIZE: 16893

ADDITIONAL COMMENTS:

No reading on tricep for 2nd and 3rd sets - BUT tricep reading was good when performed tricep extension

NASA DATA

SUBJECT: Pam Russell

DATE: 10/9/87

INVESTIGATOR(S): P. Russell L. Clarke

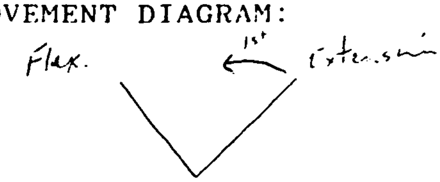
MOVEMENT: Horizontal Plane Elbow flexion/extension w/ cocontraction

a) Initial position: Extension

b) Direction of 1st movement: Flexion

c) Definition of 1 repetition: Flex to Ext

MOVEMENT DIAGRAM:



DATA FILE NAME: ElbFEC.DAT

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
CH A	Tricep	4	1	.854/1	-.642
CH B	Bicep	5.8	2	.854/1	.078
MYOLAB II					
CH A					
CH B					

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:	1	3=5	.454/1	2.353
JT2:				

SAMPLING RATE: 200 samples/sec MOVEMENT SPEED: FAST (MED) SLOW

↳ per channel = 200/5 = 40 samples/sec

NUMBER OF REPETITIONS/SET: 8

NUMBER OF SETS: 3

INITIALIZED DATA FILE SIZE: 102400

COLLECTED DATA FILE SIZE: ________

ADDITIONAL COMMENTS:

Flex/Ext w/ Cocontraction

SELSPOT Data Collection - Cover Sheet

Investigator: ______________________________
Study: NASA - Horizontal Flexion / Ext. Elbow

Date: ______________________

Reference File: ____________________________ Disk: ____
Calibration File: __________________________ Disk: ____

Subject Data:

Name: ________________________________ phone ____________
Age __________ Height __________ Weight __________

Segments Lengths: Forearm __________ Thigh __________
Upper Arm __________ Shank __________
Trunk __________ Foot __________

Other: ______________________________
____

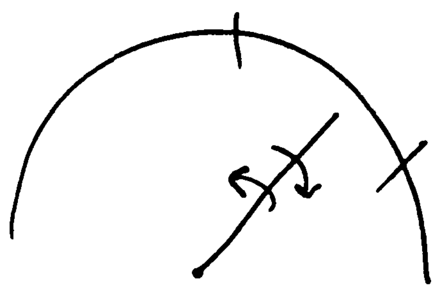
LED Setup

1. ________________________
2. ________________________
3. ________________________
4. ________________________
5. ________________________
6. ________________________
7. ________________________
8. ________________________

Analog:
Biceps
Triceps
____

Sample filtering

Body Diagram



SSS Form #3
4/87

SELSPOT Data Collection - Trials Records

Investigator: ______________________ Date: ________

Study: ______________________________________

TRIAL	FILES		DISK	COMMENTS
1	~~SS0151~~	.RAW	~~8~~	5/4/87 TR#1 W/ COCONTRACTION
		.POS		
		.POF		
2	~~SS0152~~	.RAW	~~8~~	5/4/87 TR#2 FAST SPEED W/ CO-CONTRACTION
		.POS		
		.POF		
1	SS0153	.RAW	8	TR#1: LC: MOD SPEED W/ CO-CONTRACTI-
	SS0153	.POS	8	
		.POF		
2	SS0154	.RAW	8	TR#2: LC: FAST SPEED W/ CO-CON
	SS0154	.POS		
		.POF		
3	SS0155	.RAW	8	TR#3: LC: FAST SPEED
	SS0155	.POS		
		.POF		
4	SS0156	.RAW	10	TR#4: LC: AMM 0-10: MOD SPEED W/ CO-CONTRACTION
		.POS		
		.POF		
5	SS0157	.RAW	10	TR#5: LC: AMM 0-10: MOD SPEED W/ CO-CONTRACTION
		.POS		
		.POF		
6	SS0158	.RAW	10	TR#6: LC: AMM 0-10: VERTICAL MOTION
		.POS		
		.POF		

(Left margin beside trial 4: K SWITCHED / O /)-10 VOLTS)

Appendix B

SELSPOT Data Collection - Cover Sheet

Investigator: ______________________________

Study: NASA - Elbow Flexion / Shoulder

Date: ______________________

Reference File: ____________________________ Disk: ____

Calibration File: ____________________________ Disk: ____

Subject Data:

Name: ______________________________ phone ____________

Age __________ Height __________ Weight __________

Segments Lengths: Forearm __________ Thigh __________

Upper Arm __________ Shank __________

Trunk __________ Foot __________

Other: ______________________________

____

LED Setup

1. WRIST
2. ELBOW
3. SHOULDER
4. ____________________
5. ____________________
6. ____________________
7. ____________________
8. ____________________

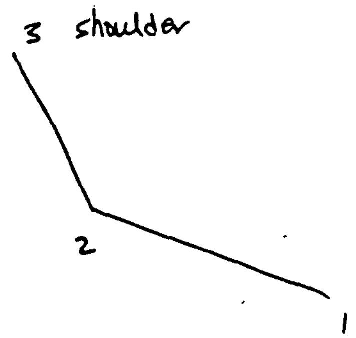
Analog:

EMG. BICEPS

ANTERIOR DELTOID

____

Body Diagram



SSS Form #3
4/87

Flexion

Calibration Data

Calibration File: Newcal.518 Disk: 17
Creation Date: 5/18/89
Reference File: NewRef.518 Disk: 17
Creation Date: ________________

Investigator: Jensen/Clarke Study: NASA

FROMS: 200 Hz Aim Analog? __________
AIM Alt: 1

C3.VI: Field of View

	X	Y
Cam1	______	______
Cam2	______	______

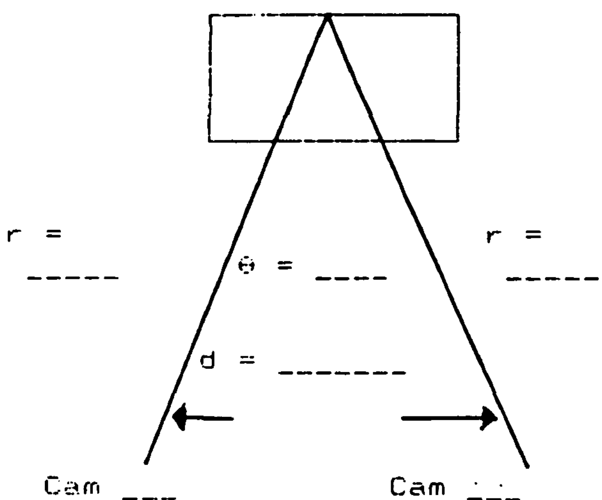
No. of Frames used in calibration: Cam1 ______ Cam2 ______

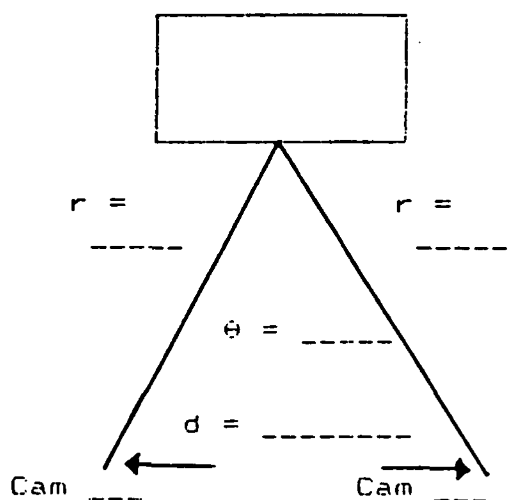
Average Distance: Cam1 5.295 Cam2 7.591

Camera Set-up:

	Cam1		Cam2	
radius	Cam1	______	Cam2	______
angle, θ		________________		
tilt	Cam1	______	Cam2	______
height	Cam1	______	Cam2	______

Diagram:





File Titles:

Comments: -.95 scale factor

SSS: Form #1
3/87

Reference Creation

Reference File: New Ref. 518 Disk: 17
Creation Date: 5/18/89

Investigator: [illegible]
Study: NASA

Reference Description:

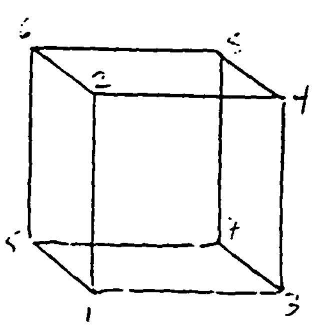
LED #	Coordinates (in mm) X	Y	Z	Detected Light Level Cam1	Cam2	Aperature
1	0	518	0			Cam1
2	0	1052	0			Cam2
3	597	518	0			
4	597	1052	0			
5	0	518	588			
6	0	1052	588			
7	598	518	588			
8	598	1052	588			

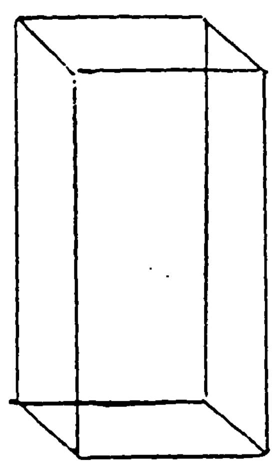
Analog:

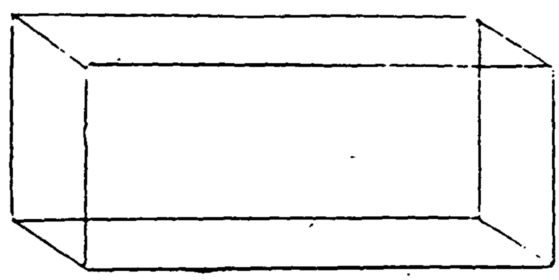
Ch.	Units	Offset	Scale Factor	Description
1	mV		-.95	
2				
3				
4				
5				
6				
7				
8				

Reference Diagram: (mark and number LED locations)

Reference plane:
front
back







For hanging reference: Front track
Back track

SSS Form #1
4/87

SELSPOT Data Collection - Trials Records

Investigator: Newref /Newref 518 Date: 5/18/87
Study:

TRIAL	FILES		DISK		COMMENTS
	Note: Forearm in Neutral Position				
✓1	SS0093	.RAW	DISK	17	Gain A = Bicep = 10, B = Delt = 4
	SS0093	.POS	DISK	17	TR#1 Elbow Flexion A: Bicep B: Delt - Slow
		.POF	DISK		
✓2	SS0094	.RAW	DISK	17	Elbow Flexion " " TR#2
	SS0094	.POS	DISK	17	
		.POF	DISK		
✓3	SS0095	.RAW	DISK	17	TR#3 Elbow Flexion A: Bicep B: Delt
	SS0095	.POS	DISK	17	Slow
		.POF	DISK		
✓	SS0096	.RAW	DISK	18	Gain A = 10 Gain B = 3
	SS0096	.POS	DISK	18	TR#4 Shoulder Flexion A: Bicep B: Delt Slow
		.POF	DISK		
✓	SS0097	.RAW	DISK	18	TR#5 Shoulder Flex " " Slow
	SS0097	.POS	DISK	18	
		.POF	DISK		
✓	SS0098	.RAW	DISK	18	TR#6 Shoulder Flexion Slow
	SS0098	.POS	DISK	18	
		.POF	DISK		
✓7	SS0099	.RAW	DISK	19	Gain A = 8 B = 5; TR#7 Elbow Flexion - Fast
	SS0099	.POS	DISK	19	
		.POF	DISK		
✓	SS0100	.RAW	DISK	19	TR#8 Elbow Flexion : Fast
	SS0100	.POS	DISK	19	
		.POF	DISK		

SSS Form #4
4/87

NASA DATA

DATE: 10/30/87

SUBJECT: Pam Russell

INVESTIGATOR(S): Russell / Hanly / Clarke

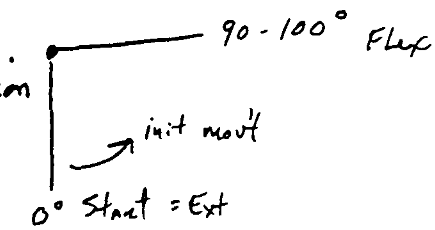
MOVEMENT: Shoulder Flex + Extension - Sagittal Plane

a) Initial position: Anatomical

b) Direction of 1st movement: Flexion

c) Definition of 1 repetition: Flexion/Extension

MOVEMENT DIAGRAM:



DATA FILE NAME: SDFXEXS.DAT

	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
MYOLAB I					
CH A	Ant. Delt	2	1	.854/1	-.759
CH B	Bicep	5	2	.854/1	.078
MYOLAB II					
CH A	Raw Ant. Delt		4=4	.854	.366
CH B					

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:	SHD FLEXION/EXTENSION	3	1.708/1	3.271
JT2:				

[SAMPLING RATE: 2000] ÷ [NUMBER OF INPUT CHANNELS ACTIVATED 5] =>

SAMPLING RATE: 400 samples/sec (per channel) MOVEMENT SPEED: FAST (MED) SLOW

NUMBER OF REPETITIONS/SET: 6

NUMBER OF SETS: 3

INITIALIZED DATA FILE SIZE: 204800

COLLECTED DATA FILE SIZE: 96366

ADDITIONAL COMMENTS:

SELSPOT Data Collection - Cover Sheet

Investigator: ______________________

Study: NASA Shoulder- Abduction/Adduction

Date: ______________________

Reference File: ______________________ Disk: ____

Calibration File: ______________________ Disk: ____

Subject Data:

Name: J. Jensen ______________________ phone ____________

Age __________ Height __________ Weight __________

Segments Lengths: Forearm __________ Thigh __________

Upper Arm __________ Shank __________

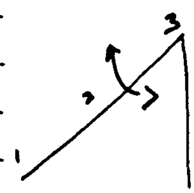
Trunk __________ Foot __________

Other: ______________________

LED Setup

1. WRIST
2. ELBOW
3. SHOULDER
4. ______
5. ______
6. ______
7. ______
8. ______

Body Diagram



Anterior view

Analog:

MIDDLE DELTOID - PROX END OF HUMERUS

POSTERIOR DELTOID

- later trials - anterior deltoid

SSS Form #3
4/87

Reference Creation

Reference File: NS 518.Ref Disk: 13
Creation Date: 5-18-87

Investigator: NASA / Jensen / Clarke
Study: NASA

Reference Description: Cube / Black Drape

LED #	Coordinates (in mm) X	Y	Z	Detected Light Level Cam1	Cam2
1	0	518	0	8	9
2	0	1052	0	8	9
3	597	518	0	7	9
4	597	1052	0	8	10
5	0	518	588	8	9
6	0	1052	588	10	10
7	598	518	588	7	9
8	598	1052	588	9	10

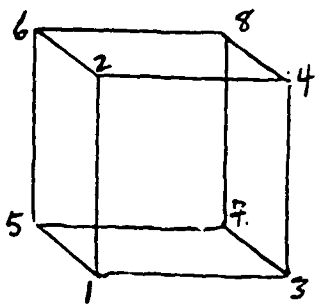
Aperature
Cam1 1
Cam2 1

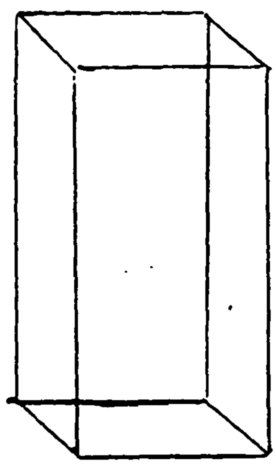
Analog:

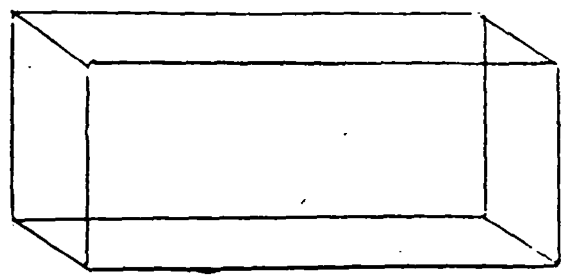
Ch.	Units	Offset	Scale Factor	Description
1	MV		.95	
2				
3				
4				
5	" "		" "	
6				
7				
8				

Reference Diagram: (mark and number LED locations)

Reference plane:
front ______
back ______







For hanging reference: Front track ______
Back track ______

SSS Form #1
4/87

Calibration Data

Calibration File: NSCAL.518 Disk: 13
Creation Date: 5-18-87
Reference File: NS518.Ref Disk: 13
Creation Date: 5-19-87

Investigator: [illegible] Study: [illegible]

PROMS: 200 Hz AIM Analog?
AIM Alt: J

C3.VI: Field of View

	X	Y
Cam1	50	40
Cam2	49	40

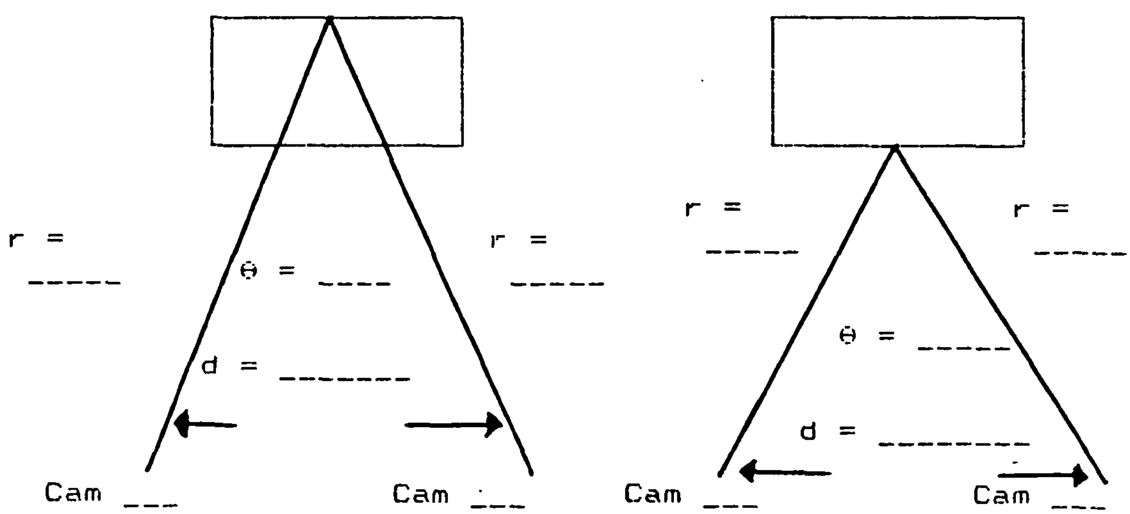
No. of Frames used in calibration:

	Cam1		Cam2	
No. of Frames	Cam1	100	Cam2	100
Average Distance:	Cam1	5.235	Cam2	7.3 7.279

Camera Set-up:

radius	Cam1		Cam2	
angle, θ				
tilt	Cam1	none	Cam2	none
height	Cam1	93.6 cm	Cam2	93.6 cm

Diagram:



File Titles:

Comments:

SSS: Form #1
3/87

SELSPOT Data Collection - Trials Records

Investigator: ______________ Date: 5-14-87
Study: NASA

TRIAL	FILES		DISK		COMMENTS
1	SS00461	.RAW	DISK	13	Gain A - 3 (~~Anterior~~ MIDDLE) Gain B - 3 (Posterior Delt)
	SS0081	.POS	DISK		Trial 1 Shoulder Abd, Add - Slow
		.POF	DISK		
2	SS0042	.RAW	DISK	13	Gain A - 3 Gain B - 3 Title unchanged
	SS0082	.POS	DISK		
		.POF	DISK		
3	SS0083	.RAW	DISK	13	Gain A - 3 B - 3
	SS0083	.POS	DISK		Trial 3 Shoulder Ab, Add - Slow
		.POF	DISK		
4	SS0084	.RAW	DISK	14	Gain A - 2 B 2
	SS0084	.POS	DISK		Trial 4 Shoulder Abd, Add Fast
		.POF	DISK		
5	SS0085	.RAW	DISK	14	Gain A - 2 B 2
	SS0085	.POS	DISK		Trial 5 Shoulder Abd, Add Fast
		.POF	DISK		
6	SS0086	.RAW	DISK	14	Gain A - 2 B 2
	SS0086	.POS	DISK		Trial 6 Shoulder Abd, Add Fast
		.POF	DISK		
7	SS0087	.RAW	DISK	15	Gain A 2 B 2 (1A = ~~Anterior~~ Middle Delt) 2A = Trap
	SS0087	.POS	DISK		Trial 7 Shoulder Ab, Ad w/Trap Slow
		.POF	DISK		
8	SS0088	.RAW	DISK	15	Gain A 2 B 2
	SS0088	.POS	DISK		Trial 8 Shoulder Ab, Ad w/Trap Slow
		.POF	DISK		w/Cocontraction

SSS Form #4
4/87

SELSPOT Data Collection - Trials Records

Investigator: ______ Date: ______
Study: ______

TRIAL	FILES		DISK		COMMENTS
- 9	550089	.RAW	DISK	15	Gain A 2 B 2
	550089	.POS	DISK		Trial 9 Shoulder Ab, Ad w/Trap Slow
		.POF	DISK		w/Cocontraction
- 10	550090	.RAW	DISK	16	Gain A 2 B 2
	550090	.POS	DISK		Trial 10 Shoulder Ab, Ad w/Trap Fast
		.POF	DISK		
- 11	550091	.RAW	DISK	16	A 2 B 2
	550091	.POS	DISK		Trial 11 Shoulder Ab, Ad w/Trap
		.POF	DISK		Fast w/Cocontraction
12	550092	.RAW	DISK	16	A 2 B 2
	550092	.POS	DISK		Trial 11 Shoulder Ab, Ad w/Trap
		.POF	DISK		Fast w/Cocontraction
		.RAW	DISK		
		.POS	DISK		
		.POF	DISK		
		.RAW	DISK		
		.POS	DISK		
		.POF	DISK		
		.RAW	DISK		
		.POS	DISK		
		.POF	DISK		
		.RAW	DISK		
		.POS	DISK		
		.POF	DISK		

SSS Form #4
4/87

NASA DATA

DATE: 10-16-87

SUBJECT: Todd Mitchell

INVESTIGATOR(S): D. Russell + L. Clarkett

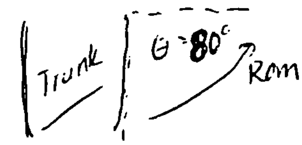
MOVEMENT: SHOULDER ABD/ADD

a) Initial position: Anatomical - seated subject.

b) Direction of 1st movement: ABDuction of arm

c) Definition of 1 repetition: ABD to ADD Ran -

MOVEMENT DIAGRAM:



DATA FILE NAME: SDABAD. DAT

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
CH A	MID DELT	5	1	.854	-.759
CH B	PECT	~~1.5~~ 4.5	2	.854	-.009
MYOLAB II					
CH A					
CH B					

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:	SHD ABD/ADD	3/4 = 5	.854	2.353
JT2:				

SAMPLING RATE: 200 samples/sec MOVEMENT SPEED: FAST (MED) SLOW

↳ per channel = 40 samples/sec

NUMBER OF REPETITIONS/SET: 8

NUMBER OF SETS: 3

INITIALIZED DATA FILE SIZE: 102400

COLLECTED DATA FILE SIZE: 24533

ADDITIONAL COMMENTS:

Movement rather slow

NASA DATA

DATE: 10-16-87

SUBJECT: Todd Mitchell

INVESTIGATOR(S): P. Russell + L. Clarke

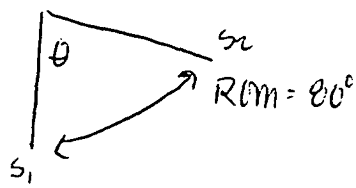
MOVEMENT: Shoulder ABDUCTION/ADDUCTION w/ CO-CONTRACTION

a) Initial position: ABDuction i Anatomical Position

b) Direction of 1st movement: ABDuction

c) Definition of 1 repetition: ABD/ADD

MOVEMENT DIAGRAM:



DATA FILE NAME: SDABADC.DAT (Includes raw data signal)

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
CH A	ANT. DELT.	5	4 (4)	1.708	-.002
CH B	PECT. MAJOR	5	~~1~~ (3)	1.708	+.002
MYOLAB II					
~~CH A~~	ANT. DELT. ~~PECT MAJOR~~ X (raw data signal) X	5	2 - (6)	1.708	.002
CH B					

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:	SHD ABD/ADD	3(-5)	.854	2.449
JT2:				

SAMPLING RATE: 200 samples/sec MOVEMENT SPEED: FAST MED SLOW

↳ per channel = 33.33 samples/sec

NUMBER OF REPETITIONS/SET: 8

NUMBER OF SETS: 3

INITIALIZED DATA FILE SIZE: 102400

COLLECTED DATA FILE SIZE: 28670

ADDITIONAL COMMENTS:

Rawdata signal for pec major

Movement in the frontal plane

SELSPOT Data Collection - Cover Sheet

Investigator: ______________________________

Study: NASA - Int/Ext rotation

Date: ______________________

Reference File: ______________________ Disk: ____

Calibration File: ______________________ Disk: ____

Subject Data:

Name: ______________________ phone ____________

Age __________ Height __________ Weight __________

Segments Lengths: Forearm __________ Thigh __________

Upper Arm __________ Shank __________

Trunk __________ Foot __________

Other: ______________________

____

LED Setup

1. ______________________
2. ______________________
3. ______________________
4. ______________________
5. ______________________
6. ______________________
7. ______________________
8. ______________________

Analog:

Infraspinatus } trying to sort out
Teres Major

____

Body Diagram

using horizontal arm. Elbow coincident with axis. Internal/external rotation of the humerus. Monitored by displacement of the movable arm

SSS Form #3
4/87

Calibration Data

Calibration File: Movcal.702 Disk: 13
Creation Date: 7/2/87
Reference File: Azef1.629 Disk: NAS 4
Creation Date: "

Investigator: Clarke Study: NASA

PROMS: ______ Analog? ______
AIM Alt: ______

C3.VI: Field of View

	X	Y
Cam1	72	44
Cam2	73	46

No. of Frames used in calibration:

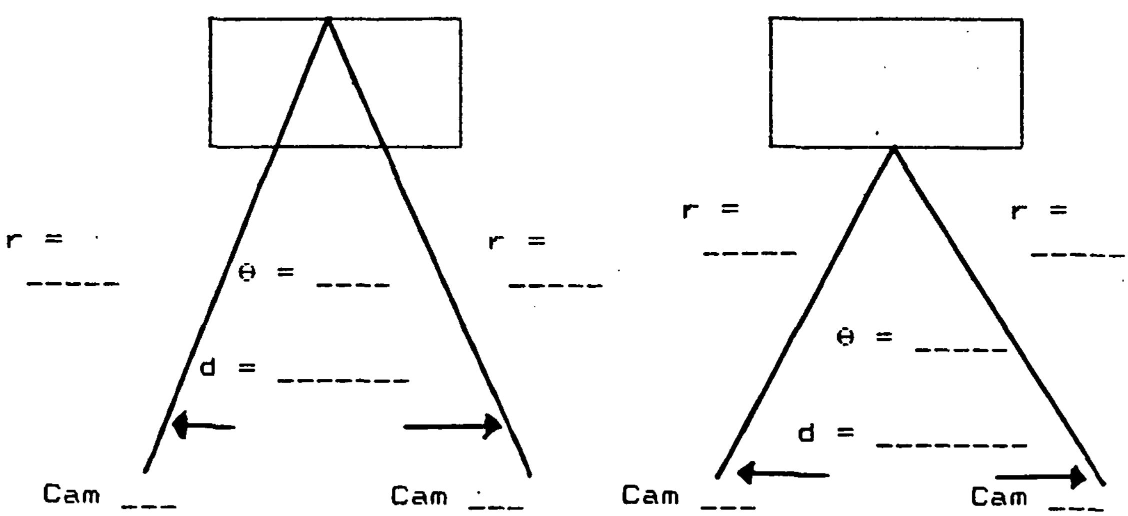
Cam1	100	Cam2	100

Average Distance: Cam1 6.987 Cam2 3.418

Camera Set-up:

radius	Cam1	______	Cam2	______
angle, θ		______		
tilt	Cam1	______	Cam2	______
height	Cam1	______	Cam2	______

Diagram:



File Titles:

Comments:

SSS: Form #1
3/87

Reference Creation

Reference File: Hbref1.629 Disk: Nam 4
Creation Date: 6/20/87
Investigator: Charles Kornly
Study: NASA

Reference Description:

LED #	Coordinates (in mm) X	Y	Z	Detected Light Level Cam1	Cam2
1	0	24	0		
2	0	178	0		
3	53.5	25	0		
4	53.5	178	0		
5	0	178	744		
6	53.5	178	7		
7					
8					

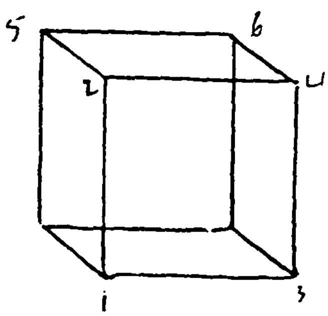
Aperature
Cam1 ___
Cam2 ___

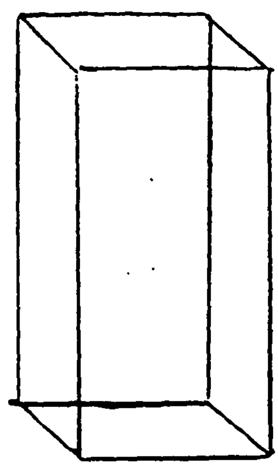
Analog:

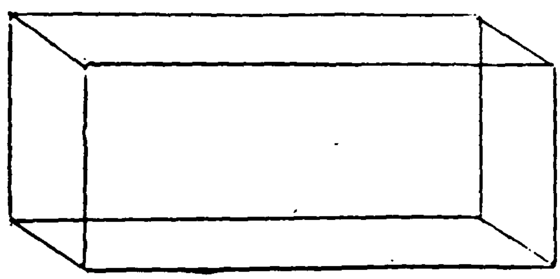
Ch.	Units	Offset	Scale Factor	Description
1				
2				
3				
4				
5				
6				
7				
8				

Reference Diagram: (mark and number LED locations)

Reference plane:
front _______
back _______







For hanging reference: Front track ____________
Back track ____________

SSS Form #1
4/87

Stop at 90° Mark
110° Mark (towards cameras)
Then continues swing

SELSPOT Data Collection - Trials Records

Investigator: Clarke Date: 7/02/87
Study: UAF Internal/External Rotation

Subject: Mitch Frid

Notes	TRIAL	FILES		DISK	COMMENTS
Stop at 90° 110° End at 110°	1	SS0220	.RAW	DISK 13	TR#1 Internal/Ext Rotation
	✓	SS0220	.POS	DISK	Teres Major, Infraspinatus
			.POF	DISK	Gain = 1X A = Teres Maj B = Infrasp. Trunk at 45° A = 4 B = 4.5
Stop at 90° 110° End at 90°	2	SS0221	.RAW	DISK 13	TR#2 Int/Ext Rotation
	✓	SS0221	.POS	DISK	A = 4 B = 4.5 Gain = 1X
			.POF	DISK	Trunk at 45°
End at 90°	3	SS0222	.RAW	DISK 14	TR#3 Int/Ext Rotation
	✓	SS0222	.POS	DISK	A = 4 B = 4.5
			.POF	DISK	Trunk at 45°
End at 90°	4	SS0223	.RAW	DISK 14	TR#4 Int/Ext Rotation
	✓	SS0223	.POS	DISK	
			.POF	DISK	Trunk at 0°
stopped at 30°	5	SS0224	.RAW	DISK 15	TR#5 Int/Ext Rotation
	✓	SS0224	.POS	DISK	
			.POF	DISK	Trunk at 0°
stopped 90° 110° 90° End on 30°	6	SS0225	.RAW	DISK 15	TR#6 Int/Ext Rotation
	✓	SS0225	.POS	DISK	Cocontraction
			.POF	DISK	A = 4.0 B = 4.5 Trunk at 0°
stop 90° 110° End 30	7 ✓	SS0226	.RAW	DISK 17	TR#7 Int/Ext Rotation
		SS0226	.POS	DISK	Cocontraction
			.POF	DISK	Trunk at 0°
stop 90° 110° 30°	8	SS0227	.RAW	DISK 17	TR#8 Int/Ext Rotation
	✓	SS0227	.POS	DISK	Cocontraction
			.POF	DISK	Trunk at 0°

ALL FILES DELETED 7/7/87 - J. Jensen

Note: Sampling time: 6 seconds
Starting Position (Away from camera, such that movement begins towards cameras.)

SSS Form #4
4/87

SELSPOT Data Collection - Trials Records

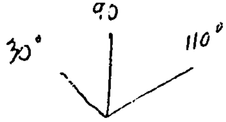
Investigator: Clarke Date: 7/8/87
Study: NASA Int/Ext Rotation

TRIAL	FILES Subject: Mitch Fred		DISK		COMMENTS
90° 110° end 90°-30° 9 ✓	SS0228	.RAW	DISK	18	TR#9 Int/Ext Rotation
	SS0228	.POS	DISK		Cocontraction
		.POF	DISK		Trunk at 45°
90° 110° end 90°-30° 10 ✓	SS0229	.RAW	DISK	18	TR#10 Int/Ext Rotation
	SS0229	.POS	DISK		Cocontraction
		.POF	DISK		Trunk at 45°
stop 90° 110° 11 ✓	SS0230	.RAW	DISK	19	TR#11
	SS0230	.POS	DISK		A = Anterior Delt, B = Pectoralis Major
		.POF	DISK		45° A = 6.5 B = 11 Gain = 1X EMG?
12 ✓	SS0231	.RAW	DISK	19	TR#12 Int/Ext Rotation
	SS0231	.POS	DISK		45°
		.POF	DISK		EMG?
stop 90° 110° End 90-30 13 ✓	SS0232	.RAW	DISK	22	TR#13 Int/Ext Rotation
	SS0232	.POS	DISK		45°
		.POF	DISK		Gain 10X A = 6.5 B = 4.0
slower speed 90° 110° 14 ✓	SS0233	.RAW	DISK	22	TR#14 Int/Ext Rotation
	SS0233	.POS	DISK		45
		.POF	DISK		A = Ant Delt B = Pect
stop 90° 110° 15 ✓	SS0234	.RAW	DISK	Nasa 4	TR#15 Int/Ext Rotation
	SS0234	.POS	DISK		0° Cocontraction
		.POF	DISK		A = 9.0 B = 5.0 Gain = 1X
stop 90° No real stop at 110° 16 ✓	SS0235	.RAW	DISK	Nasa 4	TR#16 Int/Ext Rotation
	SS0235	.POS	DISK		Cocontraction
		.POF	DISK		0° A = 9.0 B = 5.0 Gain = 1X
					weak on Cocontraction

J. Jasper 7/7/87

All Files Deleted

SSS Form #4
4/87



SELSPOT Data Collection - Trials Records

Investigator: Clarke **Date:** 7/2/87
Study: NASA Int/Ext. Rotation

	TRIAL	FILES Subject Mitch Fr.d		DISK		COMMENTS	
Stop 90° 110° End 30°	17 ✓	SS0236	.RAW	DISK	Nasa 5	TR# 17 Int/Ext Rotation	No Light
		SS0236	.POS	DISK		Ant. Delt, Pect. Major	
			.POF	DISK		Cocontraction 45°	
Stop at 90° ? 110° end close to 90°	18 ✓	SS0237	.RAW	DISK	Nasa 5	TR# 18	
		SS0237	.POS	DISK		Cocontraction	
			.POF	DISK		45° A=8.0 B=5.0 Gain=10X	
Stop at 90° 110° End near 90°	19 ✓	SS0238	.RAW	DISK	Nasa 6	TR# 19 Int/Ext Rotation	
		SS0238	.POS	DISK		" A=6.5 B=4.0 Gain=10X	
			.POF	DISK		0°	
Stop 90° 110	20 ✓	SS0239	.RAW	DISK	Nasa 6	TR# 20 Int/Ext Rotation	
		SS0239	.POS	DISK		" "	
			.POF	DISK		0° A=6.5 B=4.0 Gain 10X	
			.RAW	DISK			
			.POS	DISK			
			.POF	DISK			
			.RAW	DISK			
			.POS	DISK			
			.POF	DISK			
			.RAW	DISK			
			.POS	DISK			
			.POF	DISK			
			.RAW	DISK			
			.POS	DISK			
			.POF	DISK			

All files deleted 7/7/87 J. Jensen

SSS Form #4
4/87

ORIGINAL PAGE IS
OF POOR QUALITY

NASA DATA

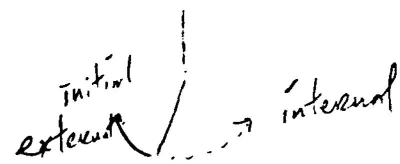
SUBJECT: Rich Seibert DATE: 11/20/87

INVESTIGATOR(S): L. Clarke & T. Truly

MOVEMENT: Internal/External Rotation at Shoulder

a) Initial position: NEUTRAL
b) Direction of 1st movement: EXTERNAL ROTATION
c) Definition of 1 repetition: INTERNAL ROTATION

MOVEMENT DIAGRAM:



DATA FILE NAME: SHDINEX.DAT

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
CH A					
CH B	Infra	2	1 = 2	1.706/1	-1.356
MYOLAB II					
CH A	Teres Mj	4	2 = 6	.854/1	-.675
CH B					

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:				
JT2:				

[SAMPLING RATE: 2000] ÷ [NUMBER OF INPUT CHANNELS ACTIVATED 6] =>

SAMPLING RATE: 333 samples/sec MOVEMENT SPEED: FAST MED (SLOW)
(per channel)

NUMBER OF REPETITIONS/SET: 8

NUMBER OF SETS: 2 Second

INITIALIZED DATA FILE SIZE: 204800

COLLECTED DATA FILE SIZE: 204800

ADDITIONAL COMMENTS:

Graph starts w/ EX ROT.

NASA DATA

DATE: 11/20/87

SUBJECT: Rich Seibert

INVESTIGATOR(S): Clarke / Truly /

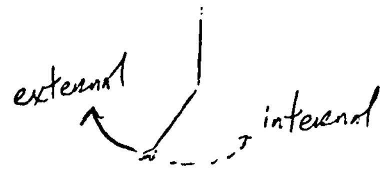
MOVEMENT: Shoulder internal/external rotation

a) Initial position: Neutral

b) Direction of 1st movement: external

c) Definition of 1 repetition: int

MOVEMENT DIAGRAM:



DATA FILE NAME: SHDINEX 2. DAT

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
CH A					
CH B	Infra	2	1 = 2	.854/1	-.632
MYOLAB II					
CH A	Teres Mij	4	3 = 6	.854/1	-.400
CH B					

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:	Raw Infraspinatus	2 = 5	.213	.024
JT2:				

[SAMPLING RATE: 2000] ÷ [NUMBER OF INPUT CHANNELS ACTIVATED 6] =>

SAMPLING RATE: 333 samples/sec (per channel) MOVEMENT SPEED: FAST MED (SLOW)

NUMBER OF REPETITIONS/SET: 8

NUMBER OF SETS: 2 2nd set = 6 reps.

INITIALIZED DATA FILE SIZE: 204800

COLLECTED DATA FILE SIZE: 204800

ADDITIONAL COMMENTS:

NASA DATA

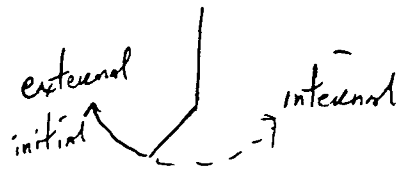
SUBJECT: Rich Seibert DATE: 11/20/87

INVESTIGATOR(S): Clarke / Truly

MOVEMENT: Shd internal/ext. rotation - Cocontraction

a) Initial position:
b) Direction of 1st movement:
c) Definition of 1 repetition:

MOVEMENT DIAGRAM:



DATA FILE NAME: SHDINEX3.DAT

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
CH A					
CH B	Infra	1	1 = 2	1.708/1	-.895
MYOLAB II					
CH A	Teres Mj	4	2 = 6	1.708/1	-.947
CH B					

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:				
JT2:				

[SAMPLING RATE: 400] ÷ [NUMBER OF INPUT CHANNELS ACTIVATED 6] =>

SAMPLING RATE: 66.6 samples/sec (per channel) MOVEMENT SPEED: FAST MED (SLOW)

NUMBER OF REPETITIONS/SET: 8

NUMBER OF SETS: 1

INITIALIZED DATA FILE SIZE: 204800

COLLECTED DATA FILE SIZE: 003

ADDITIONAL COMMENTS: Movement done with cocontraction

NASA DATA

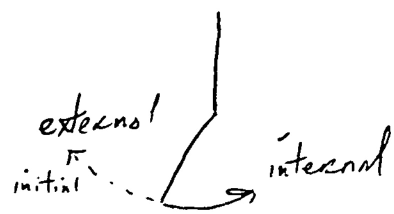
SUBJECT: Rich Seibert DATE: 11/20/87

INVESTIGATOR(S): Truly / Clarke

MOVEMENT: Shoulder Internal/Ext Rotation - Cocontraction

a) Initial position: Neutral
b) Direction of 1st movement: external
c) Definition of 1 repetition: Ext to int to ext

MOVEMENT DIAGRAM:



DATA FILE NAME: SHDINEX4.DAT

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
CH A					
CH B	Infra	1	1=2	1.708/1	-.895
MYOLAB II					
CH A	Tere	4	2=6	1.708/1	-.947
CH B					

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:				
JT2:				

[SAMPLING RATE: 2000] ÷ [NUMBER OF INPUT CHANNELS ACTIVATED 6] =>

SAMPLING RATE: 333 samples/sec (per channel) MOVEMENT SPEED: FAST MED (SLOW)

NUMBER OF REPETITIONS/SET: 6

NUMBER OF SETS: 2

Set 3 only has 1 rep

INITIALIZED DATA FILE SIZE: 204800

COLLECTED DATA FILE SIZE: 204800

ADDITIONAL COMMENTS:

Movement of Cocontraction

SELSPOT Data Collection - Trials Records

Investigator: Clarke Date: 7/22/87
Study: Internal/External Rotation

TRIAL	FILES Subject: Mitch Fried		DISK	COMMENTS
1	SS0220	.RAW	DISK 13	TR#1 Internal/Ext Rotation
✓	SS0220	.POS	DISK	Teres Major, Infraspinatus
		.POF	DISK	Gain = 1X A = Teres Maj B = Infrasp. Trunk at 45° A = 4 B = 4.5
2	SS0221	.RAW	DISK 13	TR#2 Int/Ext Rotation
✓	SS0221	.POS	DISK	A = 4 B = 4.5 Gain = 1X
		.POF	DISK	Trunk at 45°
3	SS0222	.RAW	DISK 14	TR#3 Int/Ext Rotation
✓	SS0222	.POS	DISK	A = 4 B = 4.5
		.POF	DISK	Trunk at 45°
4	SS0223	.RAW	DISK 14	TR#4 Int/Ext Rotation
✓	SS0223	.POS	DISK	
		.POF	DISK	Trunk at 0°
5	SS0224	.RAW	DISK 15	TR#5 Int/Ext Rotation
✓	SS0224	.POS	DISK	
		.POF	DISK	Trunk at 0°
6	SS0225	.RAW	DISK 15	TR#6 Int/Ext Rotation
✓	SS0225	.POS	DISK	Cocontraction
		.POF	DISK	A = 4.0 B = 4.5 Trunk at
7	SS0226	.RAW	DISK 17	TR#7 Int/Ext Rotation
✓	SS0226	.POS	DISK	Cocontraction
		.POF	DISK	Trunk at 0°
	SS0227	.RAW	DISK 17	TR#8 Int/Ext Rotation
✓	SS0227	.POS	DISK	"cocontraction
		.POF	DISK	Trunk at 0°

ALL FILES DELETED 7/7/87 - J. Jensen

Note: Sampling time: 6 seconds

SSS Form #4
4/87

Appendix C

SELSPOT Data Collection - Cover Sheet

Investigator: ______________________________
Study: NASA Supination / Pronation

Date: ______________________

Reference File: ______________________ Disk: ____
Calibration File: ______________________ Disk: ____

Subject Data:

Name: ______________________ phone ____________
Age __________ Height __________ Weight __________

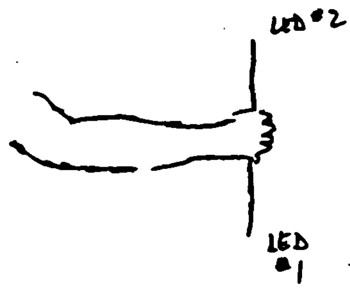
Segments Lengths: Forearm __________ Thigh __________
Upper Arm __________ Shank __________
Trunk __________ Foot __________

Other: ______________________
____

LED Setup

1. Bottom of Ruler
2. Top of Ruler
3. ______________________
4. ______________________
5. ______________________
6. ______________________
7. ______________________
8. ______________________

Body Diagram



Analog:

Pronation/Supination

EMG - Supinator / Flexors Grip
EMG - Pronator / Extensors
____

SSS Form #3
4/87

SELSPOT Data Collection - Trials Records

Investigator: Jensen / Clarke Date: 5/19/87
Study: NASA

TRIAL	FILES		DISK		COMMENTS
	All start from Supinated position				
	LED 1 = Bottom 2 = Top				A = Supinator B = Pronator
al 1.519 ✓ 1	SS0109	.RAW	DISK	23	Gain A = 7 B = 7
	SS0109	.POS	DISK	23	TR#1 (4 sec) Supination/Pronation
		.POF	DISK		
✓ 2	SS0110	.RAW	DISK	23	TR#2 Sup/Pro 3 sec A=7 B=7
	SS0110	.POS	DISK	23	
		.POF	DISK		
3	SS0111	.RAW	DISK	23	TR#3 Sup/Pronation
		.POS	DISK		
		.POF	DISK		
					A = Sup B = Bicep Gain A = 8 B = 10
✓ 4	SS0112	.RAW	DISK	24	TR#4 Supination / Bicep
	SS0112	.POS	DISK		(3 sec) Cocontraction
		.POF	DISK		Note: Holding Forearm
✓ 5	SS0113	.RAW	DISK	24	TR#5 Sup/Bicep w/out
	SS0113	.POS	DISK		(4 sec) Cocontraction
		.POF	DISK		
6	SS0114	.RAW	DISK	24	TR#6 Supination/Bicep
		.POS	DISK		(4 sec)
		.POF	DISK		
					A = 4 B = 5
...t at Open Hand 7	SS0115	.RAW	DISK	4	Flexors Extensors
	SS0115	.POS	DISK		TR#7 Grasping A = Flex B = Ext 4 sec
		.POF	DISK		(Unsupported Forearm)
8	SS0116	.RAW	DISK	4	TR#8 Grasping A = Flex B = Ext
	SS0116	.POS	DISK		Supported Forearm
		.POF	DISK		

#7 & 8 Questioned placement of flexor EMG

SSS Form #4
4/87

SELSPOT Data Collection - Trials Records

Investigator: ______________________ Date: 5/19/87
Study: ______________________

TRIAL	FILES		DISK		COMMENTS
✓ 9	SS0117	.RAW	DISK	5	A=6 B=3 TR#9 Grasping - Cocontraction/Unsupported
	SS0117	.POS	DISK		All fingers straight/moved together
		.POF	DISK		
10	SS0118	.RAW	DISK	5	TR#10 Grasping - Cocontraction/Supported
	SS0118	.POS	DISK		A=6 B=3
		.POF	DISK		A: Flex B: Ext
		.RAW	DISK		
		.POS	DISK		
		.POF	DISK		
		.RAW	DISK		
		.POS	DISK		
		.POF	DISK		
		.RAW	DISK		
		.POS	DISK		
		.POF	DISK		
		.RAW	DISK		
		.POS	DISK		
		.POF	DISK		
		.RAW	DISK		
		.POS	DISK		
		.POF	DISK		
		.RAW	DISK		
		.POS	DISK		
		.POF	DISK		

SSS Form #4
4/87

Calibration Data

Calibration File: Cal1.519 Disk: 23

Creation Date: 5/19/87

Reference File: Newref.518 Disk: 23

Creation Date: 5/18/87

Investigator: ____________________ Study: ______________

PROMS: ______________________ Analog? ____________________

AIM Alt: __________

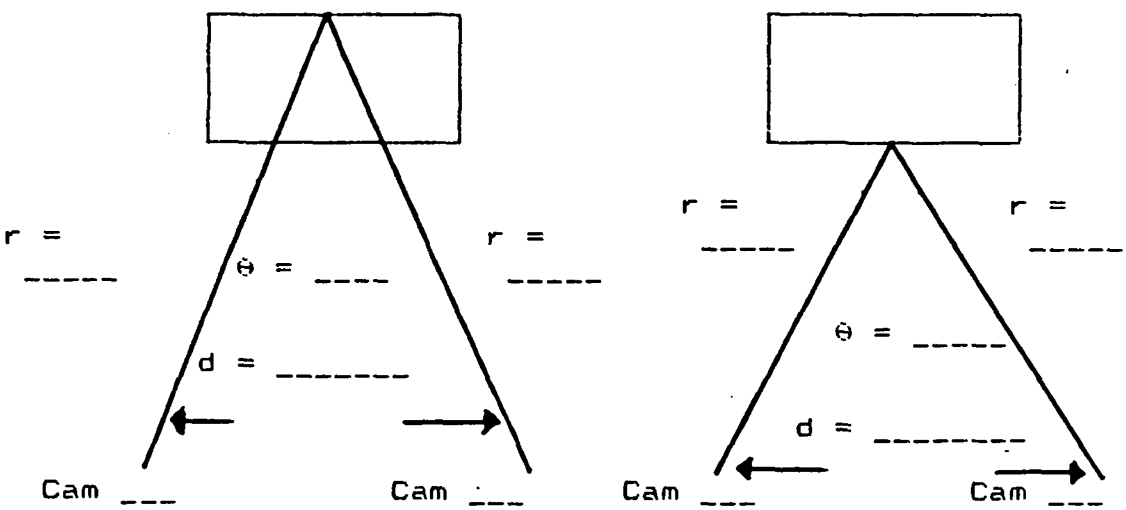
C3.VI: Field of View

	X	Y
Cam1	83	71
Cam2	84	71

No. of Frames used in calibration:

No. of Frames used in calibration:		Cam1	100	Cam2	100
Average Distance:		Cam1	4.454	Cam2	7.566
Camera Set-up:	radius	Cam1	1.53 cm	Cam2	1.53 cm
	angle, θ				
	✓tilt	Cam1	7°	Cam2	8°
	height	Cam1	93.6 cm	Cam2	93.6 cm

Diagram:



File Titles:

Comments: Close range and -.95 scale factor

SSS: Form #1
3/87

Reference Creation

Reference File: Naref.518 Disk: [illegible]
Creation Date: ____

Investigator: ____
Study: ____

Reference Description: ____

LED #	Coordinates (in mm) X	Y	Z	Detected Light Level Cam1	Cam2
1					
2					
3					
4					
5					
6					
7					
8					

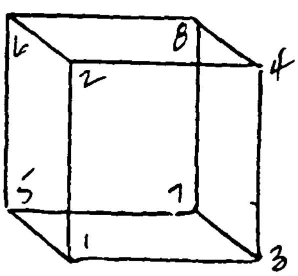
Aperature
Cam1 ___
Cam2 ___

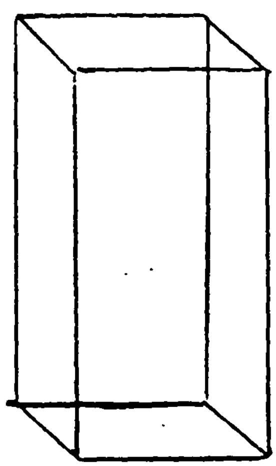
Analog:

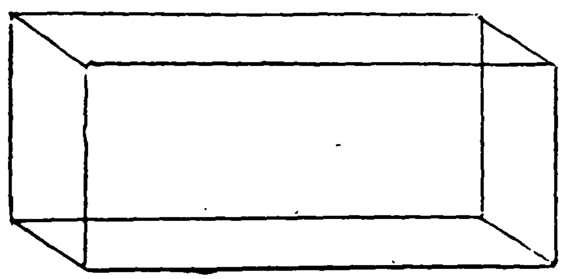
Ch.	Units	Offset	Scale Factor	Description
1	mV		-.95	EMG
2	mV		-.95	EMG
3				
4				
5				
6				
7				
8				

Reference Diagram: (mark and number LED locations)

Reference plane:
front ✓
back ____







For hanging reference: Front track ____
Back track ____

SSS Form #1
4/87

NASA DATA

SUBJECT: Peter Russell DATE: 11-10-87

INVESTIGATOR(S): Russell

MOVEMENT: WRIST EXTENSION fast w/out a hold

a) Initial position: Neutral
b) Direction of 1st movement: Extension
c) Definition of 1 repetition: Extension - Neutral

MOVEMENT DIAGRAM:

DATA FILE NAME: WRSTFE2.DAT

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
CH A	~~EXTENSORS~~ FLEXORS (filtered data)	6	1 (2)	.854	-.427
CH ~~B~~ A	~~EXTENSORS~~ FLEXORS (raw data)	6	2 (5)	.854	.078
MYOLAB II					
CH A					
CH B					

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:	WRIST EXTENSION	3 = 3	1.708	1.650
JT2:				

SAMPLING RATE: 2000 samples/sec MOVEMENT SPEED: (FAST) MED SLOW

2000/5 = 400 samples/sec/channel

NUMBER OF REPETITIONS/SET: 6

NUMBER OF SETS: 3

INITIALIZED DATA FILE SIZE: 204800

COLLECTED DATA FILE SIZE: 35421

ADDITIONAL COMMENTS:

NASA DATA

SUBJECT: P. Russell

DATE: 11-10-87

INVESTIGATOR(S): Russell

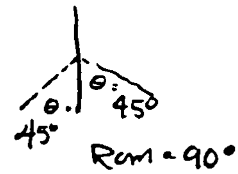
MOVEMENT: Wrist flexion/extension - accelerated w/hold

a) Initial position: Neutral

b) Direction of 1st movement: Extend

c) Definition of 1 repetition: Ext/Flex/to neutral.

MOVEMENT DIAGRAM:



DATA FILE NAME: WRSTFE.DAT

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
CH A	EXTENSORS	6-7	1	1.708	-.720
CH B	FLEXORS	5-6	2	1.708	-.683
MYOLAB II					
CH A					
CH B					

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:	WRIST/FLX/EXT	3	1.708	1.376
JT2:				

[SAMPLING RATE: 900] ÷ [NUMBER OF INPUT CHANNELS ACTIVATED 3] =>

SAMPLING RATE: 300 samples/sec (per channel) MOVEMENT SPEED: (FAST) MED SLOW

NUMBER OF REPETITIONS/SET: 6 (space of blank data after 1st set)

NUMBER OF SETS: 3

INITIALIZED DATA FILE SIZE: 204800

COLLECTED DATA FILE SIZE: 68213

ADDITIONAL COMMENTS:

NASA DATA

SUBJECT: P. Russell

DATE: 10/24/87

INVESTIGATOR(S): P. Russell : T. Truly

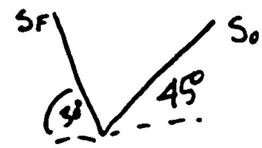
MOVEMENT: WRIST FLEXION/EXTENSION HORIZ. PLANE

a) Initial position: extended

b) Direction of 1st movement: flex

c) Definition of 1 repetition: FLX/EXT

MOVEMENT DIAGRAM:



DATA FILE NAME: WFXEXH.DT2

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
CH A	flexors	8	1	.427/1	-.222
CH B	extensors	4.5	2	.854/1	-.078
MYOLAB II					
CH A					
CH B					

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:	flexion - extension	3=5	1.708/1	2.353
JT2:				

SAMPLING RATE: 400 samples/sec MOVEMENT SPEED: (FAST) MED SLOW

Sampling rate /channel = 80 samples/sec

NUMBER OF REPETITIONS/SET: 8

NUMBER OF SETS: 3

INITIALIZED DATA FILE SIZE: 10240

COLLECTED DATA FILE SIZE: 7653

ADDITIONAL COMMENTS:

Horizontal Plane - fast

NASA DATA

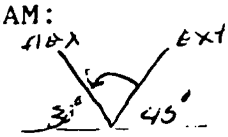
SUBJECT: P Russell

DATE: 10/23/87

INVESTIGATOR(S): P Russell & T. Tmly

MOVEMENT: WRIST FLEXION/ EXTENSION - HORIZ. PLANE

MOVEMENT DIAGRAM:



a) Initial position: extended
b) Direction of 1st movement: flexion
c) Definition of 1 repetition: flexion/extension

DATA FILE NAME: WFXEXH.DAT

MYOLAB I	MUSCLE GRP		GAIN	SCRN CH	FSV	BL
CH A	flexors ~~extensors~~	A	8	1	.213/1	-.113
CH B	extensors	B	4.5	2	.854/1	.048
MYOLAB II						
CH A						
CH B						

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:	flexion-extension	3=5	1.708/1	2.353
JT2:				

SAMPLING RATE: 200 samples/sec MOVEMENT SPEED: FAST (MED) SLOW

Sampling rate /channel = 40 samples/sec

NUMBER OF REPETITIONS/SET: 8

NUMBER OF SETS: 3

INITIALIZED DATA FILE SIZE: 102400

COLLECTED DATA FILE SIZE: 8063

ADDITIONAL COMMENTS:

Horizontal plane

Set 2 - A data did not look good - reset gain on channel A

Appendix D

SELSPOT Data Collection - Cover Sheet

Investigator: ______________________________

Study: NASA Supination / Pronation

Date: ______________________

Reference File: __________________________ Disk: ____

Calibration File: ________________________ Disk: ____

Subject Data:

Name: ______________________________ phone ____________

Age __________ Height __________ Weight __________

Segments Lengths: Forearm __________ Thigh __________

Upper Arm __________ Shank __________

Trunk __________ Foot __________

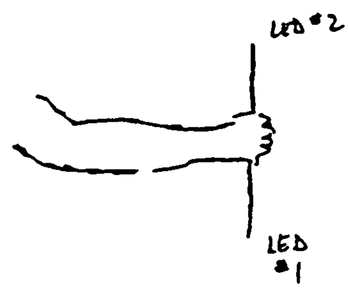
Other: ________________________

____

LED Setup

1. Bottom of Ruler
2. Top of Ruler
3. ______________________
4. ______________________
5. ______________________
6. ______________________
7. ______________________
8. ______________________

Body Diagram



Analog:

Pronation/Supination EMG - Supinator / Flexors Grip

EMG - Pronator / Extensors

____

SSS Form #3
4/87

SELSPOT Data Collection - Trials Records

Investigator: Jensen / Charles   Date: 5/19/87
Study: NASA

TRIAL   FILES All start from Supinated position   COMMENTS

LED1 = Bottom 2 = Top   A = Supinator B = Pronator

TRIAL	FILES		DISK	COMMENTS
1	SS0109	.RAW	DISK 23	Gain A = 7 B = 7
	SS0109	.POS	DISK 23	TR#1 (4 sec) Supination / Pronation
		.POF	DISK	
2	SS0110	.RAW	DISK 23	TR#2 Sup/Pro 3 sec A=9 B=9
	SS0110	.POS	DISK 23	
		.POF	DISK	
3	SS0111	.RAW	DISK 23	TR#3 Sup/Pronation
		.POS	DISK	
		.POF	DISK	
4	SS0112	.RAW	DISK 24	A = Sup B = Bicep Gain A = 8 B = 10 TR#4 Supination / Bicep
	SS0112	.POS	DISK	(3 sec) Cocontraction
		.POF	DISK	Note: Holding Forearm
5	SS0113	.RAW	DISK 24	TR#5 Sup/Bicep w/out
	SS0113	.POS	DISK	(4 sec) Cocontraction
		.POF	DISK	
6	SS0114	.RAW	DISK 24	TR#6 Supination/Bicep
		.POS	DISK	(4 sec)
		.POF	DISK	
7	SS0115	.RAW	DISK 4	A = 6 B = 5 Flexores Extensores
	SS0115	.POS	DISK	TR#7 Grasping A=Flex B=Ext
		.POF	DISK	(Unsupported Forearm)
8	SS0116	.RAW	DISK 4	TR#8 Grasping A=Flex B=Ext
	SS0116	.POS	DISK	supported forearm
		.POF	DISK	

#224 [illegible]

SSS Form #4
4/87

SELSPOT Data Collection - Trials Records

Investigator: ________________________ Date: 5/19/47
Study: ____

TRIAL	FILES		DISK		COMMENTS
9	SS0117	.RAW	DISK	5	A=6 B=3 TR#9 Grasping - Cocontraction/Unsupported
	SS0117	.POS	DISK		All fingers straight/moved together
		.POF	DISK		
10	SS0118	.RAW	DISK	5	TR#10 Grasping - Cocontraction/Supported
	SS0118	.POS	DISK		A=6 B=3
		.POF	DISK		A:Flex B:Ext
		.RAW	DISK		
		.POS	DISK		
		.POF	DISK		
		.RAW	DISK		
		.POS	DISK		
		.POF	DISK		
		.RAW	DISK		
		.POS	DISK		
		.POF	DISK		
		.RAW	DISK		
		.POS	DISK		
		.POF	DISK		
		.RAW	DISK		
		.POS	DISK		
		.POF	DISK		
		.RAW	DISK		
		.POS	DISK		
		.POF	DISK		

SSS Form #4
4/87

Appendix E

NASA DATA

SUBJECT: P. Russell

DATE: 10/15/87

INVESTIGATOR(S): Pam Russell, Luis Tiraly

MOVEMENT: Thumb ADD/ABD w/ cocontraction

a) Initial position: ABDUCTED

b) Direction of 1st movement: ADDUCTED

c) Definition of 1 repetition: AB/AD

MOVEMENT DIAGRAM: Palm supinated Horizontal plane fingers together thumb fully extended thumb abducted

DATA FILE NAME: TADABC.DAT

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
CH A	ABDUCTOR POLLICUS	5	1	.854/2	-.427
CH B					

MYOLAB II

CH A

CH B

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:				
JT2:				

SAMPLING RATE: 200 samples/sec MOVEMENT SPEED: FAST (MED) SLOW COCONTRACTION

↳ perchannel = 200 samples/sec

NUMBER OF REPETITIONS/SET: 8

NUMBER OF SETS: 3

INITIALIZED DATA FILE SIZE: 10240

COLLECTED DATA FILE SIZE: 8704

ADDITIONAL COMMENTS:

apply resistance to thumb

NASA DATA

DATE: 10/15/87

SUBJECT: P. Russell

INVESTIGATOR(S): P. Russell T. T. Andry

MOVEMENT: Thumb ADD/ABD
a) Initial position: abducted
b) Direction of 1st movement: adduction
c) Definition of 1 repetition: ab/ad

MOVEMENT DIAGRAM: palm supinated horizontal plane fingers ~~together~~ thumb fully extended thumb ~~abd~~ abducted (to index finger sagittal plane)

DATA FILE NAME: TADAB.DAT

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
CH A	ABDUCTOR POLLICUS	5	1	3.417/1	-.334
CH B					

MYOLAB II

CH A

CH B

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:				
JT2:				

SAMPLING RATE: 200 samples/sec MOVEMENT SPEED: FAST MED SLOW
→ perchannel = 200 samples/sec

NUMBER OF REPETITIONS/SET: 8

NUMBER OF SETS: 3

INITIALIZED DATA FILE SIZE: 102400

COLLECTED DATA FILE SIZE: 7362

ADDITIONAL COMMENTS:
only adducting to index finger
(if flex thumb - get a small signal.)

NASA DATA

SUBJECT: P. Russell   DATE: 10/15/87

INVESTIGATOR(S): P. Russell & T. T[illegible]

MOVEMENT: "Pinky" ABD/ADD
 a) Initial position: ~~[illegible]~~ ADDUCTION
 b) Direction of 1st movement: ABDUCTION
 c) Definition of 1 repetition: AB/AD

MOVEMENT DIAGRAM:
HAND HORZ
PALM DOWN
3-FINGERS HELD TOGETHER

DATA FILE NAME: PABAD DAT

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
CH A			~~[illegible]~~		
CH B	ABDUCTOR DIGITI MINIMI		~~[illegible]~~ 2	.854/1	.427
MYOLAB II					
CH A					
CH B					

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:				
JT2:				

SAMPLING RATE: 200 samples/sec   MOVEMENT SPEED: FAST (MED) SLOW
↳ perchannel 200/2 = 100 samples/sec

NUMBER OF REPETITIONS/SET: 8

NUMBER OF SETS: 3

INITIALIZED DATA FILE SIZE: 102400

COLLECTED DATA FILE SIZE: 6200

ADDITIONAL COMMENTS:

Appendix F

SELSPOT Data Collection - Cover Sheet

Investigator: ______________________

Study: NASA Shoulder - Abduction / Adduction

Date: ______________________

Reference File: ______________________ Disk: ____

Calibration File: ______________________ Disk: ____

Subject Data:

Name: J. Jensen phone ____________

Age __________ Height __________ Weight __________

Segments Lengths: Forearm __________ Thigh __________

Upper Arm __________ Shank __________

Trunk __________ Foot __________

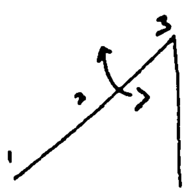
Other: ______________________

____

LED Setup

1. WRIST
2. ELBOW
3. SHOULDER
4. ________
5. ________
6. ________
7. ________
8. ________

Body Diagram



Anterior View

Analog:

MIDDLE DELTOID - PROX END OF HUMERUS

POSTERIOR DELTOID

- later trials - anterior deltoid

SSS Form #3
4/87

Reference Creation

Reference File: NS 518.Ref Disk: 13
Creation Date: 5-18-87

Investigator: NASA / Jensen / Clarke
Study: NASA

Reference Description: Cube / Black Drape

LED #	Coordinates (in mm) X	Y	Z	Detected Light Level Cam1	Cam2
1	0	518	0	8	9
2	0	1052	0	8	9
3	597	518	0	7	9
4	597	1052	0	8	10
5	0	518	588	8	9
6	0	1052	588	10	10
7	598	518	588	7	9
8	598	1052	588	9	10

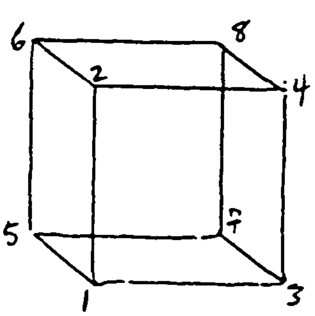
Aperature
Cam1 1
Cam2 1

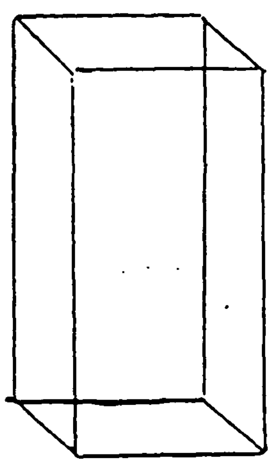
Analog:

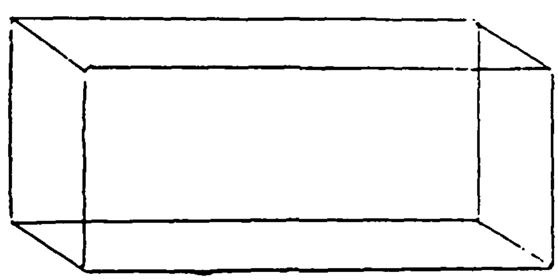
Ch.	Units	Offset	Scale Factor	Description
1	MV		.95	
2				
3				
4				
5	"	"	" "	
6				
7				
8				

Reference Diagram: (mark and number LED locations)

Reference plane:
front _______
back _______







For hanging reference: Front track ________________
Back track ________________

SSS Form #1
4/87

Shoulder heights

Calibration Data

Calibration File: NSCAL.518 Disk: 13
Creation Date: 5-18-87
Reference File: NS518.Ref Disk: 13
Creation Date: 5-19-87

Investigator: Jensen/Clarke Study: NASA

FROMS: 200 Hz AIM Analog?
AIM Alt: J

C3.VI: Field of View

	X	Y
Cam1	50	40
Cam2	49	40

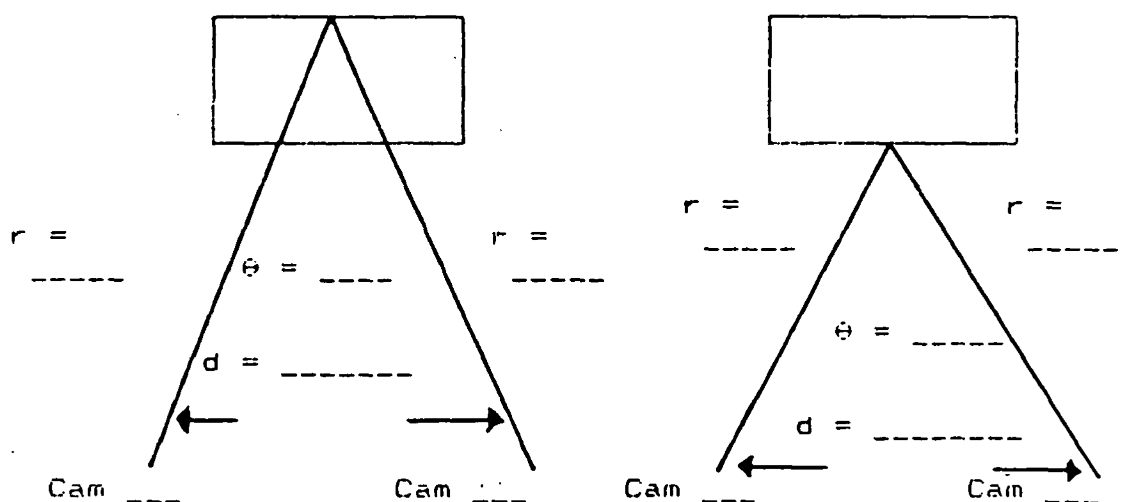
No. of Frames used in calibration:

	Cam1		Cam2	
No. of Frames	Cam1	100	Cam2	100
Average Distance:	Cam1	5.235	Cam2	7.3 7.279

Camera Set-up:

radius	Cam1		Cam2	
angle, θ				
tilt	Cam1	none	Cam2	none
height	Cam1	93.6cm	Cam2	93.6cm

Diagram:



File Titles:

Comments:

SSS: Form #1
3/87

SELSPOT Data Collection - Trials Records

Investigator: ____________ Date: 5/14/97
Study: ____________

TRIAL	FILES		DISK		COMMENTS
					Gain ~~A=8~~ B=5
9	550101	.RAW	DISK	19	TR# 9 Elbow Flexion A: Bicep
✓	550101	.POS	DISK	19	B: Delt Fast
		.POF	DISK		
					Gain A=10 B=2
✓10	550102	.RAW	DISK	20	TR# 10 Shoulder Flexion
	550102	.POS	DISK	20	A=10 B=2 Fast
		.POF	DISK		
✓11	550103	.RAW	DISK	20	TR# 11 Shoulder Flexion
	550103	.POS	DISK	20	A=Bicep B=Delt Fast
		.POF	DISK		Possibly [illegible]
✓12	550104	.RAW	DISK	20	TR# 12 Shoulder Flexion Fast
	550104	.POS	DISK	20	
		.POF	DISK		
					Gain A=10 B=2
✓13	550105	.RAW	DISK	21	TR# 13 Elbow Flex - Should Flex
	550105	.POS	DISK	21	
		.POF	DISK		
✓14	550106	.RAW	DISK	21	TR# 14 Elbow Flex - Shoulder Flex
	550106	.POS	DISK	21	A=10 B=2
		.POF	DISK		
✓15	550107	.RAW	DISK	22	TR# 15 Elbow Flex - Shoulder Flex
	550107	.POS	DISK	22	A=10 B=2
		.POF	DISK		
✓	550108	.RAW	DISK	[illegible]	TR# 16 Elbow Flex - Shoulder Flex
	550108	.POS	DISK	22	[illegible]
		.POF	DISK		

NASA DATA

DATE: 10/30/87

SUBJECT: Pam Russell

INVESTIGATOR(S): Russell / Mealy / Clarke

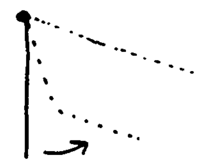
MOVEMENT: Reach

a) Initial position: Ext.

b) Direction of 1st movement: Flex - Should + Elbow

*c) Definition of 1 repetition: Flex - Ext - Flex - Ext

MOVEMENT DIAGRAM:



DATA FILE NAME: Reach . DAT

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
CH A	Ant Delt		1 = 1	.854/1	-.690
CH B	Bicep		2 = 2	.427/1	.019
MYOLAB II					
CH A	Tricep		3 = 6	.213/1	-.175
CH B					

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:	SHOULDER FLX/EXT	4 = 3	1.708	4.707
JT2:				

[SAMPLING RATE: 2000] ÷ [NUMBER OF INPUT CHANNELS ACTIVATED 5] =>

SAMPLING RATE: 400 samples/sec (per channel) MOVEMENT SPEED: FAST (MED) SLOW

NUMBER OF REPETITIONS/SET: 6 — 2 full Sets

NUMBER OF SETS: 3 — 3rd Set = 5 rep's

INITIALIZED DATA FILE SIZE: 204800

COLLECTED DATA FILE SIZE: 204806

ADDITIONAL COMMENTS:

* {Shoulder Flex,
{Elbow - Flex,
Elbow Ext
{Elbow Flex
{Shoulder Flex

SELSPOT Data Collection - Cover Sheet

Investigator: Clarke
Study: NASA - Reaching

Date: 7/10/87

Reference File: Newref.710 Disk: NASA 23
Calibration File: Newcal.710 Disk: NASA 23

Subject Data:

Name: Steve Siders phone ____________
Age 25 Height ________ Weight ________

Segments Lengths: Forearm ________ Thigh ________
Upper Arm ________ Shank ________
Trunk ________ Foot ________

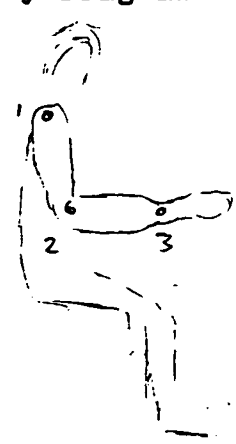
Other: ____________________

LED Setup

1. Shoulder
2. Elbow
3. Wrist
4. ____________
5. ____________
6. ____________
7. ____________
8. ____________

Analog:
Bicep / tricep
Ant. Delt / Lat. Dorsi

Body Diagram



SSS Form #3
4/87

Calibration Data

Calibration File: NewCAL.710 Disk: NASA 23
Creation Date: 7/10/87
Reference File: NewRef.710 Disk: NASA 23
Creation Date: 7/10/87

Investigator: Clarke Study: NASA - Reaching

PROMS: 200 Hz Analog? ____
AIM Alt: ____

C3.VI: Field of View

	X	Y
Cam1	56%	59%
Cam2	56%	59%

No. of Frames used in calibration:

Cam1	100	Cam2	100

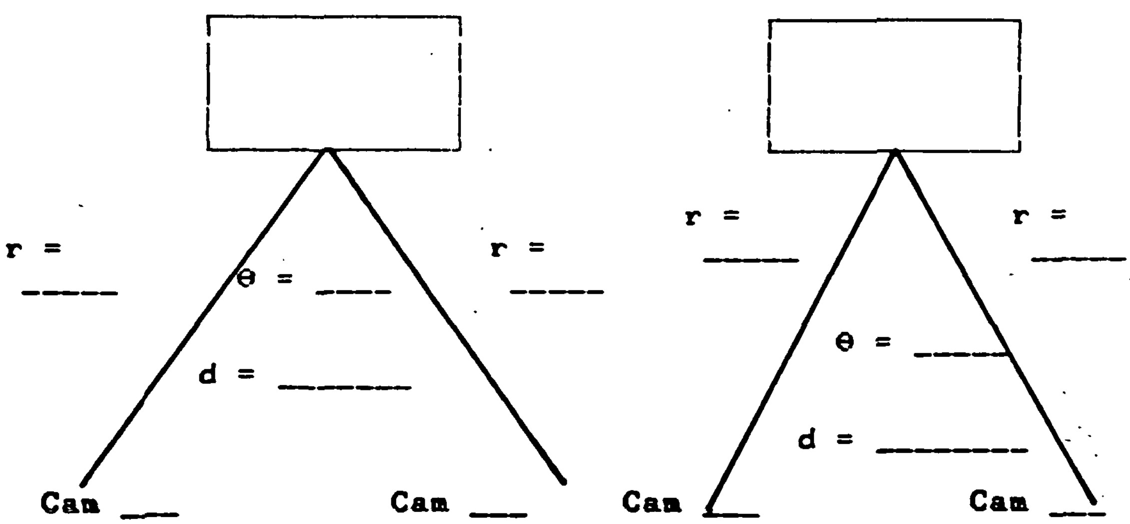
Average Distance:

Cam1	.351	Cam2	.536

Camera Set-up:

radius	Cam1	____	Cam2	____
angle, θ		____		
tilt	Cam1	____	Cam2	____
height	Cam1	____	Cam2	____

Diagram:



Comments:

Reference Creation

Reference File: NewRef Disk: NASA 23
Creation Date: ______

Investigator: Clarke
Study: NASA - Reaching

Reference Description: ______

LED #	Coordinates (in mm) X	Y	Z	Detected Light Level Cam1	Cam2
1	0	0	0		
2	0	58.6	0		
3	55.0	0	0		
4	55.0	58.6	0		
5	0	0	58.4		
6	0	58.6	58.4		
7	55.0	0	58.4		
8	55.0	58.6	58.4		

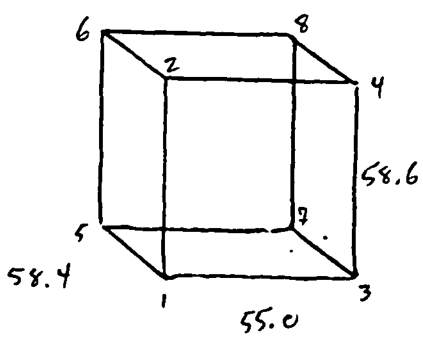
Aperature
Cam1 1
Cam2 1

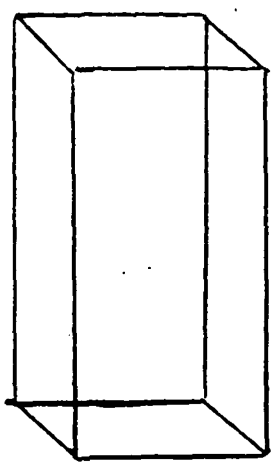
Analog:

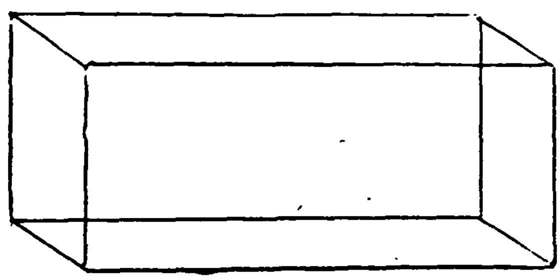
Ch.	Units	Offset	Scale Factor	Description
1				
2				
3				
4				
5				
6				
7				
8				

Reference Diagram: (mark and number LED locations)

Reference plane:
front ______
back ______



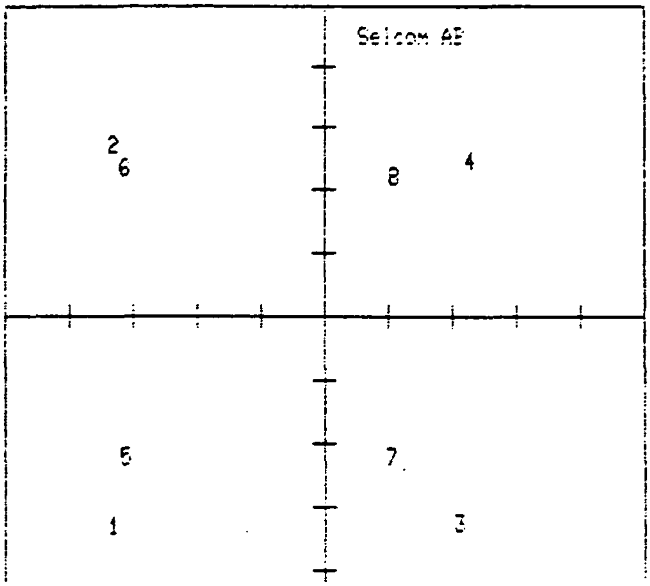




For hanging reference: Front track ______
Back track ______

SSS Form #1
4/87

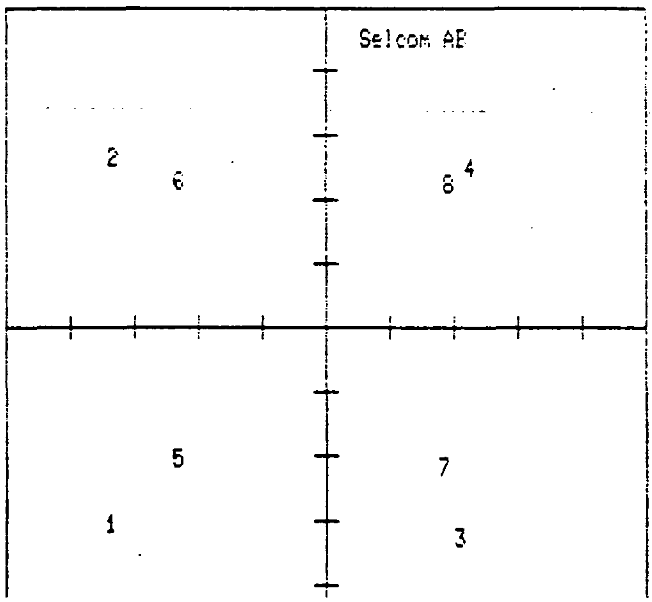
Camera view display



Camera # 1

Point	1	DLL	7
Point	2	DLL	9
Point	3	DLL	7
Point	4	DLL	10
Point	5	DLL	9
Point	6	DLL	10
Point	7	DLL	8
Point	8	DLL	10

Camera view display



Camera # 2

Point	1	DLL	8
Point	2	DLL	9
Point	3	DLL	9
Point	4	DLL	11
Point	5	DLL	10
Point	6	DLL	11
Point	7	DLL	9
Point	8	DLL	11

Newref. 710 Disk: Nasa 10
Newcal. 710 Disk NASA 23

X Y
.6% 59%
56 59

Misc
1 .351
2 .536

SELSPOT Data Collection - Trials Records

Investigator: Trub / Clarke **Date:** 2/10/87
Study: NASA - Reaching

TRIAL	FILES 6 sec.		DISK		COMMENTS
1	550286.	.RAW	DISK	NASA 5	TR#1 Reaching - Closed Fist
✓	550286	.POS	DISK		A = Bicep = 8 Gain = 1X
		.POF	DISK		B = Tricep = 7 off scale on B?
2	550287	.RAW	DISK	NASA 5	TR#2 Reaching
	550287	.POS	DISK		A = 8
		.POF	DISK		B = 7 Good!
3	550288	.RAW	DISK	NASA 5	TR#3 Reaching
	550288	.POS	DISK		A = Bi = 8 Good
		.POF	DISK		B = Tri = 7
4	550289	.RAW	DISK	NASA 5	TR#4 Reaching Didn't stop at
	550289	.POS	DISK		full extended
		.POF	DISK		position
5	550290	.RAW	DISK	NASA 6	TR#5 Reaching " "
	550290	.POS	DISK		
		.POF	DISK		
6	550291	.RAW	DISK	NASA 6	TR 6 Reaching Cocontraction
		.POS	DISK		A = 2 = Bi
		.POF	DISK		B = 4 = Tri
7	550292	.RAW	DISK	Nasa 6	TR 7 Reaching w/ Cocont
		.POS	DISK		A = Bi
		.POF	DISK		B = Tri
8	550293	.RAW	DISK	NASA 6	TR8 Reaching w/ Cocont
		.POS	DISK		A = Bi
		.POF	DISK		B = Tri

Cocontraction not as hard

ORIGINAL PAGE IS OF POOR QUALITY

~~ORIGINAL PAGE COLOR PHOTOGRAPH~~

SSS Form #4
4/87

SELSPOT Data Collection - Trials Records

Investigator: ______________________ Date: ________

Study: ______________________________________

TRIAL	FILES				COMMENTS	
9	550294	.RAW	DISK	NASA 7	Reach w/ Cocontraction	
		.POS	DISK		A = Bi	
		.POF	DISK		B = Tri	
10	550295	.RAW	DISK	NASA 7	TR # 10 Reaching w/ Cocontr.	
		.POS	DISK		A = Bi = 2	
		.POF	DISK		B = Tri = 4	
11	550296	.RAW	DISK	NASA 7	Reaching	
		.POS	DISK		A = Ant. Delt = 1	Gain = 1X
		.POF	DISK		B = Lat. Dorsi = 8	
12	550297	.RAW	DISK	NASA 7	Reaching	Smoother Reach ↓
		.POS	DISK		A = Ant. Delt	
		.POF	DISK		B = Lat Dorsi	
13	550298	.RAW	DISK	NASA 8	TR # 13 Reaching	
		.POS	DISK		A = 1	
		.POF	DISK		B = 8	
14	550299	.RAW	DISK	NASA 8	TR # 14 Reaching	
		.POS	DISK		A = 1	
		.POF	DISK		B = 8	
15	550300	.RAW	DISK	NASA 8	TR # 15 Reaching	
		.POS	DISK			
		.POF	DISK			
16	550301	.RAW	DISK	NASA 8	Reaching - Cocontraction	
		.POS	DISK		A = Ant. Delt = 1.5	Gain = 1X
		.POF	DISK		B = Lat Dorsi = 5.0	

SELSPOT Data Collection - Trials Records

Investigator: ______________________ Date: ________
Study: ____

TRIAL	FILES		DISK	COMMENTS
17	550302	.RAW	DISK NASA 9	TR# 17 Reaching w/ Concentration
		.POS	DISK	A = 1.5
		.POF	DISK	B = 5.0
18	550303	.RAW	DISK NASA 9	TR 18 Reaching w/ Concentration
		.POS	DISK	A: Ant. Delt
		.POF	DISK	B = Lat. Dorsi
19	550304	.RAW	DISK NASA 9	TR 19 Reaching w/ Concentration
		.POS	DISK	A = Ant. Delt
		.POF	DISK	B = Lat. Dorsi Smoothness Reach
20	550305	.RAW	DISK NASA 9	TR 20 Reaching w/ Concentration
	550305	.POS	DISK NASA 23	A = Ant. Delt
		.POF	DISK	B = Lat. Dorsi
		.RAW	DISK	
		.POS	DISK	
		.POF	DISK	
		.RAW	DISK	
		.POS	DISK	
		.POF	DISK	
		.RAW	DISK	
		.POS	DISK	
		.POF	DISK	
		.RAW	DISK	
		.POS	DISK	
		.POF	DISK	

NASA DATA

SUBJECT: Rich Seibert

DATE: 11/13/87

INVESTIGATOR(S) L Clarke c T Tuohy

NORMAL REACHING PATTERN

MOVEMENT: REACHING

MOVEMENT DIAGRAM:

a) Initial position: EXTENDED
b) Direction of 1st movement: ELBOW FLEXION/SHOULDER FLEXION WITH
c) Definition of 1 repetition: ELBOW EXTENSION/SHOULDER EXTENSION WITH ELBOW FLEXION

DATA FILE NAME: REACH2.DAT

MYOLAB I	MUSCLE GRP	GAIN	SCRN CH	FSV	BL
CH A	Tricep	10x 11.5	1	.854	-.876
CH B	Bicep	10x 2	2	1.708	-.898
MYOLAB II					
CH A	Anterior Delt	1x 9	6	1.708	-.004
CH B	Posterior Delt	6	7	.854/1	-.470

GONIOMETER	DOF MEASURED	SCRN CH	FSV	BL
JT1:	1	3	.854	.770
JT2:	RAW TRICEP	4	.427	.285
	RAW BICEP	5	.854	-.312

SAMPLING RATE: ~~250~~ 2000 p/c samples/sec MOVEMENT SPEED: FAST MED (SLOW)

NUMBER OF REPETITIONS/SET: 6

NUMBER OF SETS: 2

3RD set [illegible] full

INITIALIZED DATA FILE SIZE: 100 K

COLLECTED DATA FILE SIZE:

ADDITIONAL COMMENTS: ~~[illegible]~~

Set 1 - RAW DATA NO GOOD POSTERIOR DELT OFF SCALE
Set 2 " " " " " " "

A1.DAT NO GOOD

BICEP RAW DATA - OK