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# ANALYSIS OF THE COMPETITIVE WHEELCHAIR STROKE

by

DANIEL PATRICK BYRNES

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
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Date October 22, 1982

# DEDICATION

In memory of my mother:

Marjorie Elaine Byrnes

## ABSTRACT

The major purpose of this study was to examine the wheelchair stroking patterns of elite, physically disabled athletes in a competitive racing event. As a result of this investigation, a basic description of this means of locomotion was presented. Temporal, spatial and electromyographical information was gathered by synchronizing the 16 mm movie film with a two-channel electromyograph system.

Ten experienced, male athletes with permanent lower extremity disabilities were utilized as subjects. Each subject propelled his own competitive wheelchair at a speed judged to be equivalent to that used in a 1500 meter race, while situated on a wheelchair ergometer. During the performance of the activity, the subject's lateral (right) aspect was filmed simultaneously with the electromyogram as projected on the oscilloscope screen. This resulted in a single, permanent record of the movement and the EMG activity for later analysis. The record contained three trials for each of the electrode placements resulting in thirty trials per muscle.

Initially, the film record was visually analyzed for phasic division of the stroking cycle. The total cycle along with two primary phases were identified; the drive phase and the recovery phase. Also, specific events to establish boundaries for the above phases were identified, namely

hand-contact and hand-release.

The film was also nominally analyzed for the occurance of joint excursions put forward in a Kinesiological model prior to the study. Excursions at the shoulder, elbow and wrist were assessed temporarily and spatially. The excursions noted as necessary for wheelchair propulsion were found to occur. These excursions were shoulder elevation and depression, shoulder flexion and extension, elbow flexion and extension, wrist flexion/ulnar deviation and extension/radial deviation. Excursions were generally found to be shorter in duration (sec) during the drive phase as compared to excursions during the recovery phase.

The film record was examined for electrical activity of ten muscles identified as necessary for wheelchair propulsion. Electrical activity was classified as active or non-active and for consistency of occurance, based on criteria established by the investigator. EMG activity was then integrated with the other parameters and analyzed.

Electromyographical information indicated that the greatest amount of electrical activity occurred during the drive phase. The recovery period involved less active and more inconsistent electrical activity. The electromyograms indicated that the most active and most consistent muscles during the drive phase were the pectoralis major, triceps brachii and the flexor/extensor muscles of the wrist. The most active and consistent muscle of the recovery phase was the posterior deltoid.

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# I. INTRODUCTION

The understanding of movement patterns involved in a particular skill and how these movements can be made more efficient is of importance to both the athlete and the coach. For this reason, a large variety of sporting skills have been analyzed by both traditional and experimental kinesiological procedures. Kinesiological, experimental analyses have offered the use of electromyography (EMG) (see Joseph, 1960; Basmajian, 1967; Broer and Houtz, 1967, for extensive summaries). It is generally accepted that EMG analyses permit a more objective method of verifying the conclusions reached by traditional methods of analyses (i.e. direct observation and/or palpation). Despite this wide interest in understanding human movement, and the greater use of EMG in movement analyses, the skills of physically disabled individuals have stimulated minimal attention (Guttman and Mehra, 1973; Maes et al., 1975; Steadward, 1978).

With the recent improvements made by wheelchair athletes in both level of skill and performance, efficient wheelchair propulsion has become even more decisive in maximizing performance. Indeed, as more athletic opportunities unfold and larger numbers of competitors participate, those athletes and coaches who do not develop an understanding of wheelchair propulsion may never realize their full athletic or coaching potential.

However, wheelchair athletes and coaches have had very little information on which to base training programs. Those exercise programs that have been put forward (Richardson and Shaver, 1982; Curtis, 1981) lack specificity of purpose and, as a result, provide very little in the way of meaningful training programs. This may be due in part to the inability of the author to accurately and definitively assess the requirements of the particular movement. As a result, detailed and accurate information is needed from which meaningful training programs can be designed.

Medically, a greater understanding of the mechanics and physiology of propelling a wheelchair can aid in prevention, recognition, diagnosis and proper treatment of athletic injuries associated with this activity. It has become evident that medical problems have increased as a result of long-term wheelchair use (Curtis, 1982). Athletic events such as road racing and track have been associated most frequently with wheelchair athletic injuries (Curtis, 1982). Curtis further notes that over seventy percent of the wheelchair athletes may have acquired some injury requiring medical attention since their inital participation. Thus, those individuals involved in the sports medicine field must increase their awareness and knowledge of wheelchair athletes and wheelchair sports activities.

The small volume of information describing the technique of wheelchair propulsion has largely concerned the effects of wheelchair design. Hildebrandt et al. (1980) examined active propulsion of various wheelchair models. Similarily, Shuman (1979) and Rudwick (1979) discussed the efficiency of wheelchair propulsion based on considerations in wheelchair component selection and frame design. On a kinesiological level, Spooner (1981) reported on the pushing technique of wheelchair racers by outlining hand, arm and trunk positions required for stroking.

As far as this author can ascertain, only one descriptive study has been conducted on the techniques involved in pushing a wheelchair. Steadward (1978) investigated the classification system for wheelchair competitors by kinesiologically and electromyographically analyzing subjects performing the wheelchair sprint. As a result of the Steadward (1978), initial insight into efficient wheelchair propulsion was provided.

It is evident from this discussion that there is a lack of objective information concerning the kinesiolgical analysis of the competitive wheelchair stroke. Indeed, there exists so little published information, that initial investigations must provide fundamental descriptive knowledge of this particular sports skill before sufficient information is available to initiate experimental research.

It was the purpose of this study to investigate the stroking pattern used by elite, physically disabled athletes in propelling a wheelchair in competitive racing events. A basic description of this means of locomotion is provided with emphasis on the following:

1. The division of the stroking cycle into component phases which were of functional significance.

2. The identification of the joint excursions and their significance in the competitive wheelchair stroke.

3. The temporal relationship of the component phases and their significance in the competitive wheelchair stroke.

4. The electromyographical description of the muscular patterns characteristic of the competitive wheelchair stroke and the interrelationship of this pattern with the phasic, temporal and joint excursion sequences.

A. Delimitations

1. Propelling a competitive wheelchair was restricted to the stroking techniques used by the subject at competitve 1500 meter speeds.

2. Description was restricted to the performance of ten physically disabled male subjects, propelling personalized competitive wheelchairs on a wheelchair ergometer.

3. Electromyographic description was restricted to examination of ten muscle groups of the right, upper extremity and trunk; the muscles being examined two at a time and the EMG displayed on a two channel oscilloscope.

B. Limitations

1. The assumption that the subjects chosen (i.e. elite international athletes) would perform and duplicate the most efficient stroke was assumed.

2. The artificiality of the research setting under which the required movement was performed may have resulted in a stroking pattern different from that which might occur in a normal enviornment.

3. The accuracy of determining the muscular pattern of activity was dependent upon the examiner's ability to locate particular muscles and record and assess accurately the electromyograms from these muscles.

4. The accuracy of determining the temporal sequence of the activity was dependent upon the ability of the examiner to distinquish accurately the various stages of hand-rim contact.

C. Definition of Terms

*Wheelchair athlete:* refers to any individual with a permanent, physical disability which prohibits that person from participating in able-bodied sport and who chooses to utilize a wheelchair for participation in sporting activities.

*Competitive wheelchair:* refers to that piece of equipment used by wheelchair athletes as a means of locomotion in athletic events. It ususally consists of modifications to the standard wheelchair in accordance with the rules of the International Stoke Mandeville Games Federation (I.S.M.G.F.)

*Competitive wheelchair stroke:* refers to the technique used by wheelchair athletes to propel his/her wheelchair in racing events.

*Wheeling:* refers to progression in a wheelchair.

*Pushrim:* refers to that part of the wheelchair upon which the individual applies the force necessary for propulsion. It is usually a circular metal tube attached to the wheels.

*Wheelchair ergometer:* refers to an instrument used for tests or studies of physical work capacity specific to wheelchair propulsion. It consists of a level set of rollers and a mechanical brake, and is designed to accomodate an individual's personal wheelchair.

*Paraplegia:* refers to permanent paralysis of the lower legs and trunk, resulting in impaired function and sensation.

*Post-polio:* refers to an acute vius infection of the spinal cord often followed by residual paralysis of muscles (function only).

*Camber:* refers to the angle of the wheels in relation to the surface off the vertical plane. This modification maximizes control and handling of the wheelchair. In competitive wheelchairs the camber is negative or, the distance between the wheels is wider at the bottom than at the top.

## II. REVIEW OF LITERATURE

### A. Introduction

In order to better understand and study wheelchair propulsion, knowledge of electromyography and kinesiological principles are required. Thus, the following review will include the physiological principles of electromyography, EMG measurement systems and a kinesiological consideration of wheelchair propulsion. As well, a brief summary discussion of descriptive research and its justification in this study is included.

### B. Descriptive Research

Descriptive research is concerned with determining the nature and degree of existing conditions (Lehmann and Mehrens, 1979). Although the descriptive approach may not permit cause and effect statements, descriptive research does provide investigators with valuable information concerning the nature of phenomena and it also offers the information necessary to formulate hypotheses which can be tested via experiments. Indeed, employing approaches such as case studies, surveys, cross-sectional and longitudinal studies may be essential before more stringent research methods can be utilized (Weber and Lamb, 1970).

The body of knowledge concerning wheelchair sports as a whole, remains quite small and inadequate. Knowledge concerning the understanding of the unique sports skills of the wheelchair athlete is lacking. As a result, initial research must be basic in nature so as to provide an overview of the area. Thus, a descriptive study of the parameters characteristic of the competitive wheelchair stroke is the most logical approach for understanding these phenomena.

## C. Electromyography

Electromyography is based on the physiological principles of contracting muscle. These principles have been well reviewed by many authors (Sharkey, 1975; Åstrand and Rodahl, 1977; deVries, 1977; Guyton, 1977; Fox, 1979; Vander et al., 1980). Therefore, no attempt will be made to duplicate the large body of knowledge in this area. However, a brief summary on those basic principles and limiting physiological factors is of value.

### Basis of EMG

The basic functional structure of muscular contraction is the motor unit. The motor unit consists of a single motorneuron and those skeletal muscle fibers innervated by it (Lidell and Sherington, 1925). The number of muscle fibers per motor unit differs in various muscles. As few as five fibers per motor unit exist in the rectus occuli muscle (Torre, 1953). In contrast, limb muscles such as the gastrocnemius, may possess as many as 1900 fibers per motor unit (Feinstein et al., 1954).

The electrical activity of muscular contraction is based on electrophysiological evidence that the sarcolemma acts as semipermeable membrane (Vander et al., 1980). A molecular arrangement of sodium ions on the outside and potassium ions on the inside of the membrane results in an electrical differential known as the membrane potential. An electrical impulse transmitted via the myoneural junction to the muscle fiber causes the permeability of the membrane to change. As a result, sodium and potassium ions are exchanged and a wave of excitation passes along the muscle fiber. The electrical activity accompanying the exchange of ions is known as the action potential (AP). It is this bioelectrical activity which is monitored and recorded in electromyography.

It is generally accepted that action potentials are absent in relaxed muscle (Piper, 1907; Adrian and Bronk, 1929; Smith, 1934; Clemmenson, 1951). During muscular contraction, each action potential reflects the firing of a single motor unit (Adrian and Bronk, 1929). As the contraction strengthens, the frequency of the discharge of the individual motor unit increases and new motor units are recruited. As a result, these action potentials are distinquishable from earlier potentials in frequency and amplitude. During moderate and strong contractions individual acton potentials become indistinguishable and the electromyogram appears as an interference pattern.

**EMG Limiting Factors**

A number of physiological factors may contribute to the modification of the electromyogram. Consideration of these influences and their relevance is necessary to properly evaluate the EMG record.

Factors such as muscular fatique and temperature (Gydrkov and Kosarov, 1973, 1974), fiber size (Hakansson, 1962), biological aging (Sacco et al., 1962) as well as many neuromuscular disorders have all been shown to effect motor unit potentials. However, these influences appear to be more relevant in highly complex, phasic activities involving quantifed EMG studies. General investigations involving healthy subjects performing less complicated activities appear not to be directly affected by these factors. Of more importance in most EMG studies is the consideration of technical factors such as appropriate electrode selection and the utilization of proper amplifying, filtering and recording systems (O'Connell and Gardner, 1963).

**D. EMG Measurement Systems**

**Electrodes**

The electrodes used in electromyography are basically of two main types: surface (or skin) electrodes and inserted (wire or needle) electrodes (Basmajian, 1967). The advantages and disadvantages of either type have been well reviewed (O'Connell and Gardner, 1963; Grossman and Weiner, 1966; Basmajian, 1967; Hall, 1970; Lahoda et al., 1974). It is generally accepted that electrode selection is based primarily on the specific nature of the information needed (i.e. detailed vs. general knowledge).

Since many kinesiological studies are chiefly concerned with the duration and amount of activity in muscle as a whole, surface electrodes have been frequently used (O'Connell and Gardner, 1963). They are convient, readily obtainable, easily applied and provide minimal discomfort to the subject. Though surface electrodes provide only general information, this information is quite useful and satisfactory where simultaneous, gross-type movements are being studied (Brazier et al., 1946; Hall, 1970). For example, quite successful studies of the lower limb during bipedal locomotion have been conducted utilizing information secured through surface electrodes (Basmajian, 1967).

Despite the proven usefulness of surface electrodes, an understanding of their limitations is needed to better evaluate the information they provide on the electromyogram. It is generally accepted that their application be limited to superficial muscles (O'Connell an Gardner, 1963; Basmajian, 1967; Hall, 1970). These authors further state that surface electrodes are not capable of making distinctions based on depth and the possibility also exists that electrical activity may be picked up from more than one muscle. In addition, large muscles or groups of muscles are appropriate objects of study. Finally, electrical signals may be diminished and/or distorted due to tissue impedence or skin movement under the electrode. As a result, care in the proper selection of EMG apparatuses and the location of electrodes is a necessary precaution.

The actual technique of surface electrode application has been well reviewed by O'Connell and Gardner (1963). Proper disc diameter, inter-electrode distance, skin preparation and the proper anchoring of electrodes, as well as electrode placement verification may individually or in combination alter the electrical activity detected.

## EMG Amplifying Systems

The selection of EMG instrumentation requires that it contain a number of features to adequately record motor unit potentials. It is generally acknowledged that the apparatus possess high gain amplification, frequency response preference and filtering capabilities (Norris, 1963; O'Connell and Gardner, 1963; Basmajian, 1967; Hall, 1970; Lahode et al., 1974). A variety of commercial electromyographs are available that meet these requirements. However, these instruments are generally designed for clinical studies and may be inappropriate for kinesiological research. The major problem in kinesiological studies is the taking of multiple measurements from a moving subject. This condition presents additional requirements not typically available with clinical EMG instruments.

## EMG Telemetry Systems

A critical element of an EMG instrument used for kinesiological investigations is its telemetric capabilities (Sprigings, et al., 1977). Measuring physiological phenomena during a physical activity requires that interference of normal movement patterns be kept to a minimum. As a result, the information sought must be measured, transmitted, received and recorded at a distance. Various telemetric procedures have been utilized to meet this demand.

Kramer (1979), in his analysis of backwards walking, reviewed various EMG telemetry systems. He assessed the advantages and disadvantages of three of the most common techniques: radiotelemetry systems; portable recording systems and; trailing wire systems. Thus, only a brief summary of these systems will be referenced below.

Radiotelemetry involves the use of radiant, electrical energy to transmit information over a distance. A transmittor (attached to the subject) and a separate receiver are used to monitor EMG activity. Apparently, difficulty of equipment arrangement and antenna positioning, compromises in signal fidelity, frequency of baseline drift, and physical impedence problems posed by transmittor size raise questions regarding the efficiency of this method (Sprigings, et al., 1977; Kramer, 1979).

Portable recording systems involve small, lightweight tape recorders that monitor EMG activity by taping FM signals for later translation and display. The primary concern with this system appears to be its compatability with synchronized cinematography (Kramer, 1979). The major sychronizing technique with this system is the utilization of a light source on the subject or in the background to mark both the recording tape and film with regard to the beginning and ending of the activity. Thus, questions of physical influence of the equipment and dependancy upon camera visualization of the light source appear to limit the usefulness of this system.

The trailing wire method, which employs various lengths of cable connecting the subject to the apparatus, has been the most frequently used. The major limitation has been the relatively short lengths of electrode cable available to the moving subject. As a result, the range of movement is significantly restricted. To solve this problem, Sprigings et al. (1977) designed a system that utilized lightweight, flexible cable (up to 30 meters in length) and offered continuous, independent and discrete outputs that resulted in high fidelity transmissions. The system has been successfully used by several investigators in various analyses of human activities (Sprigings, 1975; Steadward, 1978; Kramer, 1979). Appendix A offers more technical information on this system.

EMG Synchronization Systems

Unless EMG recordings are objectively correlated with the course of the movement being performed, they are of little value (O'Connell, 1968). Without correlation it is virtually impossible to determine at which point during the movement each muscle begins or ends its activity. Thus, to maximize EMG information, a cinematographic record is typically synchronized with the electromyogram in kinesiological studies.

Various cine-EMG synchronization techniques have been utilized. These range from single flash photographs (Joseph, 1968) to the more common method of employing high-speed cameras. The latter technique utilizes 16 mm cameras and some form of electronic device to mark the EMG record with regard to the onset and conclusion of the movement (Hermann, 1962; Sutherland, 1966; O'Connell, 1968; Leggett and Waterland, 1973; Marhold, 1973; Vorro and Hobart, 1973). In the above studies, the marking of the EMG record was performed by either the investigator or the subject. As a result, various time lags existed between the actual occurance of electrical activity and the corresponding filmed movement. In addition, such methods often resulted in large quantities of seperate data records. In an effort to eliminate these differences, several investigators superimposed the EMG record directly onto the film by means of mirrors, prisms or split lenses (Sutherland, 1966; Flint, 1968; Steadward, 1978; Kramer, 1979).

The method utilizing a split-field lens filter appears to be the most efficient and economical system to date. By attaching the special lens to the existing lens, simultaneous focusing on the the EMG display and the subject is possible. This provides a single, synchronized record of EMG activity and the required movement.

E. **Wheelchair Propulsion**

As indicated earlier, there has been a dearth of information regarding propelling a wheelchair. One approach to this problem is the identification and understanding of similar forms of human locomotion. The many mobile parts, the simultaneous actions of many joints, the constantly changing magnitude and direction of forces in each segment and the various mechanical factors involved in propelling a wheelchair, give it a complexity that is similar to human bipedal locomotion. Thus, a review of the various parameters used to conceptualize bipedal locomotion and their relevance to wheelchair propulsion is beneficial.

In discussing locomotion, definitive terms arise to provide a better understanding of the activity. For example, in human locomotion descriptive terms are used to describe various styles (i.e. ataxic gait) and to define various components (i.e. swing phase). Descriptive terms regarding wheelchair propulsion, though minimal, have recently been put forward.

Steadward (1978, 1979) examinated the wheelchair sprint and divided wheelchair propusion into two separate phases: the push or drive phase; and the recovery phase. Steadward defined the driving phase as that period during which the hands are in contact with the tires or push-rims of the wheelchair. The recovery phase consisted of that period during which the hands are not in contact with the wheels or push-rims.

Spooner (1981), in describing the technical characteristics of wheelchair racing, also divided the stroking cycle into two basic components. Spooner termed the phase of force application as the "push phase" and the period absent of these forces as the "dead phase" or recuperation phase.

Descriptions relating to the temporal and spatial characteristics of the above phases have not been reported to date. Similarily, detailed division of the phasic components has yet to be investigated. Furthermore, terminology describing various stroking styles (i.e. stroke cadence and length) has yet to be reported in the literature.

## Kinesiological Requirements

As with most locomotion, propelling one's self in a wheelchair appears to be a reflex action. The reflexes control not only the movement of the upper extremities but also the stabilization of the trunk and head. Thus, smooth, coordinated movement requires properly functioning reflexes, normal flexibility of the joints and optimum stability of the body as a whole during the various phases of the activity (Wells and Luttgens, 1976).

Normal wheelchair propulsion is accomplished by the simultaneous, repetitive action of the two upper extremities. It is an example of translatory motion of the body as a whole brought about by means of the angular motion of some of its parts which act on a vehicle, namely the wheelchair. The upper extremities undergo two phases, the driving phase and the recovery phase.

**Mechanical Considerations**

Propelling a wheelchair can best be classified as movement that requires giving impetus to an external object. Various mechanical principles regarding this categorization and their application to wheeling have been identified by the investigator and others (Steadward, 1979; Spooner, 1981). and are listed below:

1. As in all motion, the initial mechanical problem is to overcome inertia of the body and the wheelchair as a whole. Since wheelchair propulsion is produced by the repetitive angular motion of the upper extremities, any interruption in the continued motion of the upper extremities must be minimized so that overcoming inertia is not necessitated with every stroke.

2. The forces produced by the upper exremities are

downwardly diagonal and therefore consist of two components, horizontal and vertical. Both components serve to produce forward motion during the driving phase.

3. The speed of moving in a wheelchair is directly related to the magnitude and the velocity of the pushing force, its frequency and to the direction of its action. This force is provided primarily by the muscles of the shoulder, elbow and wrist joints.

4. The economy and efficiency of wheeling is related to the timing of the upper extremities. In competitive wheeling, the most efficient movement appears to be that which permits circular-type motion of the upper extremities.

5. Since motion is imparted to the trunk by the forward thrust of the arms, the trunk has a tendancy to move backward. A brief restraining action of the trunk muscles along with proper wheelchair design serves to check the momentum of the trunk.

Generally speaking then, the major considerations of the mechanics of wheelchair propulsion are the minimization of resistance and the maximization of advantageous force application.

## Anatomical Considerations

The action taking place in the joints of the upper extremities consists essentially of flexion and extension (Steadward, 1978). The shoulder girdle cooperates with the arm movements by assisting in stabilizing the trunk and putting the gleno-humeral joint into favorable positions for the various actions of the humerus.

The anatomical requirements for competitive wheeling are displayed in Table I. The muscles listed in the table are considered to be the primary movers of the corresponding action and are also considered to be available for surface electromyography. In addition, the identified muscles are considered to be normally functioning in individuals with paraplegia, polio or lower extremity amputations.

In conclusion, little research effort has been centered on the kinesiological requirements of wheelchair propulsion. As a result, initial research should provide a basic knowledge of the parameters that characterize this movement. From the literature review it is evident that descriptive analysis utilizing current electromyographical techniques is the most logical approach for initial studies on wheelchair locomotion.

TABLE I
Anatomical Requirements for the Competitive Wheelchair Stroke

| JOINT | ACTION | MUSCLES |
|---|---|---|
| DRIVE PHASE | | |
| Shoulder | Abduction<br>Flexion<br>Depression | M.Deltoid<br>A.Deltoid<br>Trapezius |
| Elbow | Extension | Triceps |
| Wrist | Flexion-<br>ulnar deviation | Wrist<br>Flexors |
| RECOVERY PHASE | | |
| Shoulder | Abduction<br>Extension<br>Elevation | M.Deltoid<br>P.Deltoid<br>Trapezius |
| Elbow | Flexion | Biceps |
| Wrist | Extension-<br>radial deviation | Wrist<br>Extsrs |

# III. METHODOLOGY

## A. Subjects

The subjects were 10 male wheelchair athletes participating in the 1982 Pan American Wheelchair Games in Halifax, Nova Scotia, August 21 - 29. All subjects possessed a permanent, physical disability involving the lower limbs and/or trunk at a point below the thoracic one (T1) level. The athletes ranged in age from 21 to 35 years (mean = 27.3, SD = 5.2) and their experience in international track competitions ranged from 1 to 5 years (mean = 2.2, SD = 1.5), (see Table II). All subjects were considered to be in excellent physical condition and had no history of upper extremity injury.

## B. Apparatus

The instrumentation used in this study consisted of two systems: the EMG recording system and the cinematographic system.

### EMG Recording System

In order to examine the electrical activity of the muscle groups under study, a specially designed EMG

TABLE II
Subject Information

| SUBJECT | AGE | DISABILITY | CLASSIFICATION | INTER. EXPER. |
|---|---|---|---|---|
| 1 | 24 | Para | 2 | 1 |
| 2 | 27 | Para | 2 | 2 |
| 3 | 28 | Para | 2 | 1 |
| 4 | 35 | Para | 3 | 1 |
| 4 | 32 | Para | 3 | 1 |
| 5 | 29 | Para | 3 | 2 |
| 6 | 24 | Para | 4 | 4 |
| 7 | 26 | Para | 4 | 3 |
| 8 | 24 | Polio | 4 | 5 |
| 9 | 29 | Polio | 5 | 1 |
| 10 | 21 | Amputee | 5 | 1 |

apparatus was used. This system maximized high-level, artifact-free signals while minimizing physical impedence of the movement of the subject.

The system consisted of a remote pre-amplifier unit that was mounted on the back of the wheelchair seat of each subject. The pre-amplifier measured 13.0 cm by 6.5 cm by 4.0 cm and weighed 275 g. Thus, the compactness of the unit provided minimal interference to the subject during the activity. Housed within the unit were four independent low noise pre-amplifiers possessing the capacity of driving four independent signals over lightweight cable of up to 30 meters in length without impairing signal quality. Also contained in the pre-amplifier unit were four common-mode balancing circuits which permitted adjustments for varying skin contact resistance, tissue and electrode impedance.

A main amplifier provided further amplification and filtering of the electrical signals. The active filter system, containing 60 Hz notch filters, was available on each channel to minimize 60 cycle interference. In order to take best advantage of the dynamic range available on various recording devices, continuously variable gain controls for each channel permitted adjustments for signal amplitude.

All EMG signals were transmitted via cable to a Synchroscope SS-4211, two beam oscilloscope and were displayed simultaneously on its screen. Although the entire EMG apparatus had the capacity to monitor electrical activity from four different sources, only two channels (3 and 4) were utilized simultaneously during the study. This was due to the fact that the oscilloscope used during the testing only possessed 2-channel capability.

In order to examine the electrical activity of any particular muscle group, Hewlett Packard disposable monitoring electrodes (model # 1445C) were used. These electrodes were pre-gelled with Redux creme electrolyte. They contained a silver-silver chloride disc, one centimeter in diameter, along with a white foam adhesive pad, 5.5 centimeters in diameter. A total of ten pairs of electrodes along with one ground electrode were used on each subject.

### Cinematographic Recording System

A Photo-Sonics 16 mm 1PL high speed movie camera was used to photograph the subjects and the electromyograms. The camera was fitted with a 72 mm Angenieux 12-120 mm zoom lens, f 2.8-22. The lens was fitted with a Tiffen #1 di-optic split field lens filter. This lens permitted simultaneous sharp focus on the oscilloscope screen and on the subject.

The camera was also fitted with a Strobotac Timing Pulse Generator. This piece of equipment produced light traces along the perforated film edges for later calculation of camera speed.

## C. Testing Procedures

Procedures for this study included technical preparations and the testing preparations.

### Technical Preparations

All of the following preparations dealt with the camera and EMG equipment and were completed prior to the arrival of the subjects.

Initially, the wheelchair ergometer was placed in position so as to be perpendicular to the filming plane. In order to better stabilize the ergometer, two wooden boards were placed under the legs of the ergometer. The four legs were adjustable and as a result, the entire unit was made level with respect to the ground as indicated by a standard bubble level. Finally, the braking mechanism on the flywheel was removed to eliminate any possibility of resistance on the flywheel.

Before the camera was placed into position, a 400 foot reel of Eastman Ektachrome 7239 Video News Film, ASA 160, was loaded into the camera. Prior to loading, all film was kept refridgerated so as to maintain its quality.

Following the loading of the film, the 72 mm Angenieux zoom lens was fitted with the Tiffen split-field lens and attached to the camera body. The split-field lens was placed in a vertical position. The camera was then placed on a Quick-Set Tripod designed for high speed filming and secured. The charged battery pack and the timing pulse generator were secured to the legs of the tripod. The whole unit was then placed into position and height, position and location were measured, recorded and marked as indicated in Table III. A bubble level was used to check the horizontal position of the equipment.

The oscilloscope was also placed on the platform of a second tripod and secured. This arrangement allowed for vertical and horizontal adjustments in positioning of the scope. The unit was then placed into position so that optimal clarity of the screen was achieved. The height, position and location were also measured, recorded and marked (see Table III).

TABLE III
Aparratus Settings

| | | |
|---|---|---|
| 1. | Camera height | 1.08 meters (top of camera) |
| 2. | Oscilloscope height | 1.18 meters (top of scope) |
| 3. | Camera distace to subject | 13.18 meters (lens to wheel) |
| 4. | Camera distance to scope | 1.16 meters (lens to screen) |
| 5. | Frame rate | 100 frames per second |
| 6. | Shutter speed | 1/1200 second |
| 7. | Shutter angle | 30 degrees |
| 8. | F/stop | 2.2 |
| 9. | Lighting | Natural (sun) |
| 10. | Background | Grey wall |
| 11. | Reference point | Meter stick (50 cm markings) |
| 12. | Timing light | 100 Hz |
| 13. | Calibrated camera speed | Unavailable |

Light meter readings were then taken from the wheelchair, subject and oscilloscope screen with an Aschi Pentax Spotmeter V. Lens adjustments were then made, recorded and secured into place with adhesive tape (see Table III).

All filming was completed outdoors and, as a result, no artifical lighting was required. To optimize the clarity of the film record, the testing site was located so that the sun was predominantly behind the camera. While this provided satisfactory lighting conditions on the subject, it created a reflective glare on the oscilloscope screen. To alleviate the problem, a black plastic hood was devised and positioned around the screen to absorb excess light.

The EMG system was set up in the following manner. The oscilloscope was connected to an AC power supply and then to the central filter unit. The central filter unit was then connected to a separate power source. The remote pre-amplifier unit with a 15 meter cable was connected to the central filter system. A 9-volt transistor radio battery was then attached to the remote pre-amplifier. The voltage of the battery was monitored by a voltage meter and never allowed to fall below 8 volts.

The electrode harness was then connected to the remote pre-amplifier utilizing channels 3 and 4. It was found that the electrode leads of these channels provided the cleanest record of electrical activity. The two channels on the oscilloscope were then connected via cable to channels 3 and 4 on the central filter unit. Following this, the oscilloscope was adjusted for position, sweep, focus and intensity. The electrode harness was then disconnected during subject preparation.

## Testing Preparations

Each subject arrived at a predetermined time and brought his competitive wheelchair for use during the testing. Upon arrival the entire procedures of the study were explained to each subject. After acknowledging an understanding of the protocol, each athlete was requested to read and sign a consent and release form (see Appendix C). In addition, each subject was asked to complete a personal data form (see Appendix D).

The following procedures were used to place the surface electrodes on each subject. The subject removed all clothing from his upper body. Any body hair at the point of placement was shaved with a straight edge razor. The area was lightly abraided with emery cloth to remove any horny, dehydrated skin. Then each site was cleansed with alcohol and wiped dry with gauze.

Positioning of the electrodes was conducted according to the procedures outlined by Delgagi and Perotto (1980). Motor points of the muscles under examination were identified through Burdick's Motor Point Charts (1955). Surface electrodes were placed over ten muscle sites located on the upper right extremity and trunk region, two muscles at a time (see Table IV). The proximal placement was over the motor point and the distal placement was 3.5 cm away and along the longitudinal direction of the muscle fibers. The electrodes were secured to the skin by means of foam backed adhesive discs. Due to the strong adhesive quality of the discs, further adhesive material was not required to maintain electrode contact.

Following the application of the electrodes, the pre-amplifier unit was secured to the back of the seat of the subject's wheelchair with adhesive tape. The subject was then directed to the wheelchair ergometer and was assisted with regard to proper placement on the ergometer. Special care was taken to have the subject positioned so that extraneous chair movement was eliminated and to ensure that the ergometer itself did not interfer with the subject's stroking technique. Following proper positioning, the

TABLE IV
Electrode Placement

| | |
|---|---|
| Series #1 | Upper Trapezius; Middle Deltoid |
| Series #2 | Anterior Deltoid; Posterior Deltoid |
| Series #3 | Pectoralis Major; Latissimus Dorsi |
| Series #4 | Biceps Brachii; Triceps Brachii |
| Series #5 | Wrist Extensors; Wrist Flexors |
| Ground | Clavicle |

subject was permitted to practice stroking until he felt comfortable on the ergometer.

Once the subject felt comfortable and felt warmed up, the electrode leads for channels 3 and 4 along with the ground lead were connected to the electrodes for the first series. The order of placement of the electrode wires is listed in Table IV. This sequence was maintained throughout the testing. The entire electrode harness was the connected to the remote pre-amplifier unit fixed to the back of the wheelchair.

Prior to performing the activity, specific test measures as outlined by Delgagi and Perotto (1980) were used to verify proper electrode placement. At this point, any necessary adjustments to gains, filter settings and electrode placements were made to optimize high quality EMG traces.

Following the test maneuvers, the subject was asked to propel his wheelchair at the pace utilized in a 1500 meter track race. When the subject was at his 1500 meter pace, indicated by a verbal "OK", simultaneous filming and electromyographic tracings were recorded for approximately five seconds. The athlete was then requested to stop and the electrode leads were moved to the next sequence of muscles and the entire procedures repeated.

After the final sequence the subject was disconnected. The electrode harness was first removed from the remote pre-amplifier unit to free the subject of any electrical system. Next the lead wires were disconnected from the electrode discs. Finally, the surface electrodes were removed from the subject's skin, excess gel was removed and the skin checked for unusual signs of irritation. The subject was then removed from the ergometer and the remote pre-amplifier taken off the wheelchair.

## D. Treatment of Data

Thirty one thousand, one hundred and fifty frames of 16 mm film illustrating subject stroking pattern from a lateral view were available for analysis. The film also contained the EMG record.

A 16 mm Dynamic Frame Motion Picture Analyzer, model DF-16B, was used to analyze the film. A general overview of all the film was completed to assess its quality. The analysis then proceeded in the order the subjects were tested.

For each subject the timing light marks were used to determine actual camera speed. Then points of occurance of specific events, such as hand contact and hand release from the push rim were determined. These phasic events were identified by corresponding the frame in which the movement began and the frame in which it ended. The total number of frames required for each phase was then calculated and converted to units of time and the percentage of the total cycle. This process was repeated for three complete cycles of the movement during each of the five electrode placement sequences (see Appendix E).

Electromyographic activity was also determined for each subject. The EMG recordings were initially classified as either active or non-active based on criteria established by the investigator. In addition, the duration of EMG activity for each muscle was measured by identifying the frames in which activity began and ended. Three complete cycles for each muscle group were measured.

# IV. RESULTS

## A. Introduction

The descriptive analysis of the competitive wheelchair stroke reported here, involved the utilization of elite, wheelchair athletes performing a wheelchair racing event. Electromyographic and kinesiological data were taken from the 16 mm film record and are summarized in Tables V and VI, and in Figures 1 through 3. All data was collected solely by the investigator so as to avoid inter-individual differences in measurement.

Although the camera was equipped with a timing light for later calculation of actual frame speed, it was discovered after completion of filming that the device was not operating. Thus, the frame speed during data analysis was assumed to be the same as indicated by the camera (i.e. 100 fps). Although a precise knowledge of the film speed is desireable, it is accepted that various photographic parameters may be unobtainable or not known to any degree of accuracy and as a result, estimates are sufficient in many practical applications (Hyzer, 1977).

## B. Terminology

The film record was initially analyzed for the division of the competitive wheelchair stoking cycle into specific events which could act as points of reference for various phases and sub-phases. It was found that the reference points used by Steadward (1978) in his analysis of the wheelchair dash were of value in this study. Thus, the stroking cycle was divided as follows (see Table V and Figure 1):

*Drive Phase:* It is that period during which the hand was in contact with the push-rim of the wheelchair. It began the moment the hand contacted the push-rim and concluded the moment the hand broke contact with the rim.

*Recovery Phase:* It was that period during which the hand was not in contact with the push-rim and was moving to the next point of contact. This phase began the moment the hand broke contact with the push-rim and ended the moment the hand recontacted the push-rim.

The points of reference for the beginning and the ending of the component phases of the stroking cycle were defined as follows:

*Hand-Contact (HC)* - the moment at which the hand made contact with the push-rim.

*Hand-Release (HR)* - the moment at which the hand broke contact with the push-rim.

Further analysis of the film record indicated that division of the stroking cycle into sub-phases was not possible. Identification of specific events relating to various hand positions (i.e. palm contact or full grip) could not be adequately discerned. Thus, incorporation of more detailed data, such as sub-phases, appears to require more detailed filming techniques.

C. Sequence of Joint Excursions

Each kinesiological requirement (i.e. flexion, extension) was determined by a single method. The frame in which a particular body segment moved at a joint and the direction the joint moved defined the beginning of that joint movement. The end of the joint movement was defined as that frame in which the particular joint ceased to move or changed direction of movement. Table VI and Figure 2 illustrate the kinesiological aspects of the stroking cycle.

D. Sequence of EMG Activity

The film record was initially reviewed frame by frame for overall quality of the EMG record. It was found that during some of the EMG trials, EMG activity was absent from the oscilloscope screen for part of the stroking cycle and thus, was unobservable on the film record. This occurred randomly for approximately eight frames of the total stroke cycle (mean frames per stroke cycle = 55.03). Since eight to ten cycles of the stroke were filmed per electrode placement sequence, three complete cycles were available in which EMG activity could be monitored.

The electromyographical recordings were evaluated under two different sets of criteria. Action potentials were arbitrarily classified into one of two categories: active or non-active. Any deviation from the baseline that was less than 25% of the observed maximum intensity during the stroke cycle was considered non-active. In addition, the action potentials were further classified according to their consistency. For muscular activity to be considered consistent, 50% or more of the trials for each muscle had to be judged active (see figure 3).

Following the classification of the electrical activity, the duration of the activity was recorded. This was determined by identifying the frame in which the activity was present and the frame in which the activity ceased to be present. Both the classification and the duration of the EMG recordings were identified for three complete cycles of the stroke during each of the five sequences (see Appendix E).

TABLE V
Duration of Phases During Competitive
Wheelchair Stroke Cycle
( means of 30 stroking cycles )

| Phases | Duration (sec) Mean | S.D. | Percent of Cycle (%) Mean | S.D. |
|---|---|---|---|---|
| Drive Phase | 0.31 | 0.07 | 34.00 | 06.00 |
| Recovery Phase | 0.61 | 0.10 | 66.00 | 08.00 |
| Stroking Cycle | 0.92 | 0.12 | 100.00 | -- |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| UPPER EXTREMITY | Drive Phase | | | | Recovery Phase | | | | | | |
| PERCENT OF CYCLE (%) | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| CUMULATIVE TIME (sec) | .00 | .09 | .18 | .28 | .37 | .46 | .55 | .64 | .74 | .83 | .92 |

Figure 1. Illustration of events and phases of the competitive wheelchair stroke cycle (means of 30 stroking cycles).

TABLE VI
Joint Excursions During the Competitive Wheelchair Stroke Cycle
( means of 30 stroke cycles )

| Joint Excursion | Duration (sec) Mean | S.D. | Percent of Cycle (%) Mean | S.D. |
|---|---|---|---|---|
| Shoulder | | | | |
| Elevation | 0.49 | 0.09 | 53.23 | 07.30 |
| Depression | 0.41 | 0.08 | 46.77 | 06.84 |
| Flexion | 0.34 | 0.08 | 39.20 | 06.26 |
| Extension | 0.55 | 0.10 | 60.77 | 07.80 |
| Elbow | | | | |
| Flexion | 0.46 | 0.09 | 52.33 | 07.23 |
| Extension | 0.43 | 0.09 | 47.63 | 06.90 |
| Wrist | | | | |
| Flexion-ulnar deviation | 0.22 | 0.06 | 25.33 | 05.33 |
| Extension-radial deviation | 0.67 | 0.11 | 74.66 | 08.64 |
| Stroking Cycle | 0.92 | 0.12 | 100.00 | -- |

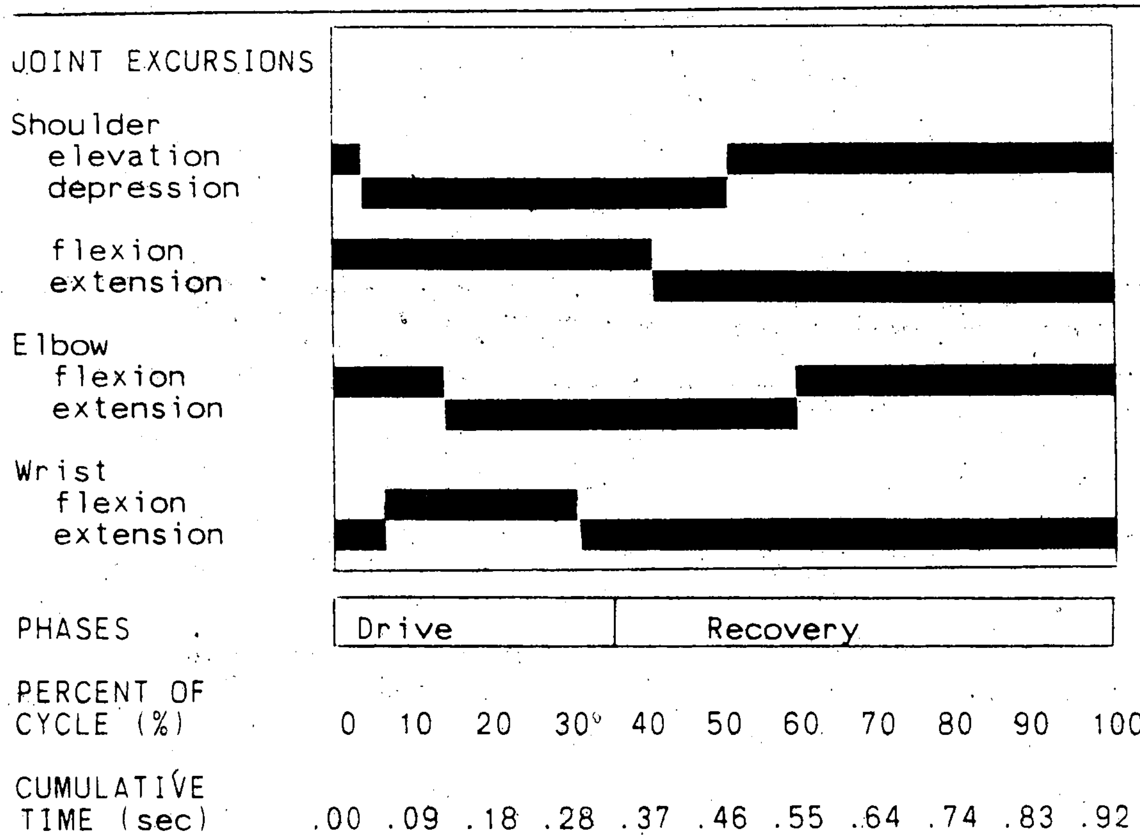


Figure 2. Graphic illustration of joint excursions during the competitve wheelchair stroke (means of 30 stroking cycles).

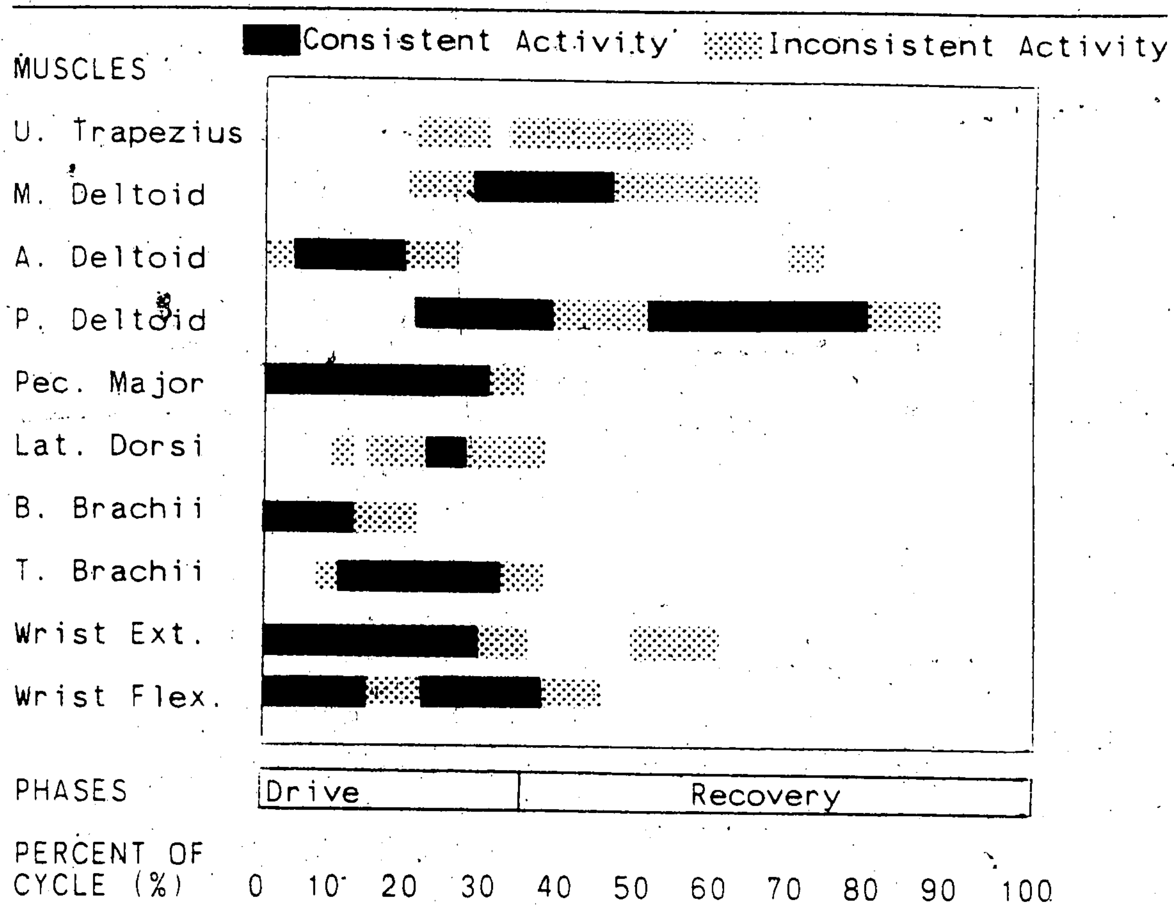


Figure 3. Graphic illustration of electromyographical sequence of active electrical activity during the competitive wheelchair stroke, expressed as percent activity during the stroking cycle (means of 30 stroking cycles).

## V. DISSCUSSION

### A. Introduction

The method of synchronizing high speed filming with electromyograms proved to be a satisfactory means of recording EMG and subject activity. By filming the lateral side of the subject and simultaneously filming electrical activity as projected on the oscilloscope screen, a single permanent record of all desired activity was achieved.

The use of the wheelchair ergometer to provide resistance for wheelchair locomotion established that it was a suitable testing instrument. The ergometer provided the means necessary for obtaining a competitive racing speed (i.e. a 1500 meter pace) with minimal spatial displacements. In addition, the resistance provided by the rollers on the ergometer was considered to be similar to that provided by a track surface. This was based on the fact that the subjects stated they noticed very little difference in the velocity of their wheels nor any difference in their stroking patterns while wheeling on the ergometer. Finally, the ergometer permitted the subject to be photographed in a relatively stationary position which optimized the precision of filming (i.e. perspective error, resolution etc.).

The points of reference for the various phases of the competitive wheelchair stroke were identified visually. This method proved to be satisfactory for decriptively analyzing the activity. The only area of difficulty occurred during the detection of the hand-release event. Since the subjects tended to follow the path of the rim during the initial phase of recovery, discerning the exact moment of breaking contact was defined as the first noticeable extension of the fingers from the rim.

## B. Terminology

Terminology designed to outline the methods of propelling a wheelchair is relatively recent and has been limited to competitive situations. The description by Spooner (1981) of the two phasic components of the stroke, the "push" phase and the "dead" phase, were based on the presence or absence of force application. While the application of force is a major consideration in wheelchair propulsion, it was considered inadequate for the functional description of the activity in this study. The term "push" may be inappropriate since during the push phase some pulling of the push-rim may occur in the initial stages of hand-contact. As well, the term "dead" for the period during which the hand is not in contact with the rim may well describe the lack of force application, but such a term also connotates that no other muscular action takes place during the dead phase. And since the analysis of force and torque were not being directly measured nor emphasized in this study, it was not feasible to base nomenclature on those parameters.

Steadward (1978) proposed wheelchair terminology that is more functionally meaningful. Steadward identified the two components of the stroking cycle as the "drive" phase and the "recovery" phase. These terms more adequately describe the actions of the upper extremity yet allow for individual idiosyncracies in the stroking patterns (i.e. such as pushing and pulling during the drive phase). Furthermore, the nomenclature is useful for describing the action of the different stroking techniques utilized in other competitive events such as basketball (Shaver, 1981).

Thus, the nomenclature put forward by Steadward was retained in this study. As indicated previously, the points of reference presented by Steadward, hand-contact (HC) and hand-release (HR), could be readily approximated by the naked eye and were applied to the stroking cycles in this study.

## C. Temporal Parameters

The temporal parameters were reported in Chapter IV. Generally, one complete cycle of the competitive wheelchair stroke took less than one second (mean = .92 sec). The phasic components, the drive phase and the recovery phase, represented approximately one third (mean = 0.31 sec) and two thirds (mean = 0.61 sec) of the stroking cycle, respectively. Although only the right, upper extremity was examined, it was assumed that since wheelchair propulsion involved the simultaneous movement of both upper extremities, the duration and percent of cycle values were similar in the left upper extremity.

Joint excursions were also identified and temporarily classified. Overall, shoulder elevation (mean = 0.49 sec) and extension (mean = 0.55 sec), elbow flexion (mean = 0.46 sec) and wrist extension/radial deviation (mean = 0.67 sec) took longer than the corresponding movement in the oppsite direction. As with the cyclic and phasic aspects of the stroke, it was assumed that the temporal components of the joint excursions were similar for both upper extremities.

The temporal parameters noted in this study were similar to those reported by Steadward (1978) as indicated in Tables VI and VII. The similarities were most noticeable in the relationship between corresponding parameters (i.e. drive vs. recovery phases and flexion vs. extension excursions) within each study. For example, in terms of duration (sec), the recovery phase was longer in the Steadward study as well as in this investigation. Similarily, joint excursions such as shoulder extension were relatively longer than shoulder flexion in both studies.

However, absolute values of the various temporal parameters differed noticeably. For example, a major difference in the duration of the drive phase of the stroking cycle was evident, 0.18 seconds reported by Steadward as compared to 0.31 seconds in this study. These differences may be attributed to the type of event performed by the subjects. The stroking technique would generally

TABLE VII
Duration of Phases and Joint Excursions
During the Wheelchair Dash
(means of 4 stroking cycles)
(Steadward, 1978)

| Parameter | Mean Duration (sec) | Mean Percent of Cycle (%) |
|---|---|---|
| Stroke Cycle | 0.80 | |
| Drive Phase | 0.18 | 22.57 |
| Recovery Phase | 0.62 | 77.44 |
| Shoulder Flexion | 0.33 | 41.50 |
| Shoulder Extension | 0.41 | 51.50 |
| Elbow Flexion | 0.34 | 42.25 |
| Elbow Extension | 0.13 | 15.75 |
| Wrist Flexion | 0.18 | 22.00 |
| Wrist Extension | 0.09 | 10.75 |

differ in a wheelchair dash event (i.e. 200 meters or less) where maximum speed is more important as compared to a wheelchair distance event (i.e. 1500 meters or longer) where economy of effort may be a more preferable objective.

Another contributing factor may have been wheelchair design. In the Steadward study subjects used standard wheelchairs whereas in this study subjects used highly modified versions of the standard wheelchair. As a result, factors such as body position and push-rim size would change the temporal aspects of the stroking cycle since the stroking requirements would differ.

The discussion of the temporal parameters of propelling a wheelchair relative to comparative information is limited due to the lack of research in this area. Further discussion of these parameters will be provided in terms of mechanical and anatomical considerations. Many factors influence the speed of wheelchair propulsion. Of particular interest in this study was the duration and frequency of force application.

Locomotion consists primarily of repetitive applications of force to constantly change the inertia of the body. To move effectively, these repetitive actions must be carried out with ease, power and efficiency. This results in maximizing force application while minimizing resistance. One method of maximizing force is by exerting the force through as great a distance as possible, provided undesireable forces are not introduced (Wells and Luttgen, 1976). Thus, in locomotive activities such as walking and running, the propulsive phases generally take up a greater percentage of the total cycle (Sprigings, 1974; Kramer, 1979). However, in this study as well as in the Steadward (1978) investigation, the propulsive phases of wheelchair locomotion were noticeably shorter in duration than the corresponding recovery phases. This may have been the result of several factors.

The initial suggestion was to lengthen the distance over which the force is applied to the push-rims. However, since the subjects utilized in this study were considered to be elite and to have devoted considerable time practicing the wheelchair stroke, it is likely they have maximized their period of force application as fully as possible. Furthermore, the design of the push-rim (i.e. 11 to 14 inch diameter) may anatomically limit their ability to extend the duration of the drive phase. This may be due to the lack of range of motion at the wrist and the inability to adequately grip the rim through the lower arc of the push-rim. As a result, minimizing the recovery period may be a more feasible approach. By shortening the distance in which the hand moved through the period of recovery without impeding the momentum of the limb or the wheelchair, an increase in the frequency of force application would be possible. Thus, the duration of the total stroking cycle would be decreased.

The order of occurance of specific events was consistent throughout each of the subject's stroking trials. However, specific moments of occurance, duration and percent of cycle varied slightly from trial to trial within the subject's performance. This indicates that the sequence of events identjfied were consistent and are thought to have been representative of the subject's normal competitive stroking pattern.

It is also of value to note that the sequential order of specific events was similar between subjects. However, the specific temporal values of the events were slightly more variable between the subjects than within the subjects. Nevertheless, the indication is that there are certain principles of wheelchair propulsion mechanics that are common to elite, paraplegic competitors despite the level of their disability. The slight and not-so-slight differences between athletes may be relatively unimportant idiosyncracies.

D. Joint Excursions

The description of the joint excursions observed in this study involved nominal classification only. Maximum and minimum ranges of motion were not analyzed with an electrogoniometer. The joint excursions of the upper right extremity identified in this study were similar to the kinesiological requirements put forward by this investigator and as presented by Steadward (1978). An outline of these movements is included below. Figure 2 and Table VI illustrate and describe the joint motions.

*Shoulder*

Elevation: Shoulder elevation began during the early part of the recovery phase and continued gradually throughout the rest of the phase and briefly into the early period of the drive phase. At hand-contact the shoulder was approaching maximal elevation for wheelchair propulsion. Maximal elevation occurred as the hand passed over the top of the push-rim during the drive phase.

Depression: After the hand passed over the top of the push-rim, rapid depression of the shoulder took place during the remainder of the drive phase. Depression continued into the early part of the recovery phase as the hand followed the path of the push-rim. However, the initial velocity of the motion gradually decreased following hand-release.

Flexion: Flexion of the shoulder occurred from an extended position and slightly before the moment of hand-contact. Following hand-contact, the shoulder underwent rapid flexion throughout the drive phase. Flexion terminated at a point just beyond the moment of hand release, placing the upper extremity in position with the midline of the body.

Extension: Shoulder extension began immediately following the end of shoulder flexion. The shoulder gradually extended throughout the recovery phase and ended just prior to hand-contact. At this point of extension, the upper arm was horizontal or slightly above horizontal.

*Elbow*

Flexion: Flexion of the elbow was initiated during the middle of the recovery phase, as the shoulder was extending. This flexion occurred gradually throughout the remainder of the recovery period and continued into the early part of the drive phase. Maximal flexion occurred at hand-contact.

Extension: Elbow extension occurred rapidly throughout the drive phase. Extension began as the hand moved downward on the push-rim and the elbow continued to be extended until approximately the middle of the recovery phase.

*Wrist*

Flexion and Ulnar-Deviation: Flexion and unlnar-deviation of the wrist occurred simultaneously and rapidly during the majority of the drive phase. This motion was initiated from an extended and radially deviated position. Maximal deviation and partial flexion were reached at the moment of hand-release.

Extension and Radial-Deviation: The initiation of wrist extension and radial-deviation occurred during the beginning of the recovery period. Extension occurred gradually during the remainder of the recovery phase and continued into the initial stages of the drive phase. It terminated as the hand passed over the highest point of the push-rim.

Generally, joint excursions occurring during the drive phase were of a shorter duration. In contrast, joint actions observed during the recovery phase were longer in duration. Visual analysis of maximum and minimum joint excursions indicated that the greatest range of motions occurred in shoulder and elbow flexion/extension.

## E. Electromyography

### Electrical Activity

Electrical activity was detected by surface electrodes placed over the belly of specific muscles, on/or near the motor point. The EMG was not integrated, thus, the activity recorded was a raw interference pattern. It was also recognized that the electromyogram represented a summation of electrical activity under the area of the surface electrodes.

Electromagnetic and physical interferences were considered to have been minimal during the filming and EMG recording. The testing location, an outdoor site, was considered to be relatively free of sources of electrostatic interference. Although the subjects were not familiar with the apparatus, the placement of the remote unit on the wheelchair minimized any detection of equipment. Only the electrodes and the wire leads were in direct contact with the subjects and the subjects indicated no discomfort nor hindrance by these components with respect to their normal stroking patterns.

Although Steadward (1978) electromyographically analyzed paraplegics performing the wheelchair dash, his investigation was primarily concerned with the electrical activity of various trunk musculature. Thus, comparison with the present study was not possible.

One of the major differences among EMG investigations has been the criteria utilized to define electrically active muscle. Generally, when integration is not used, electromyograms have been classified arbitrarily by visual evaluation (Waterland and Shambes, 1969). Graded scales based on numerical or percent maximums are frequently used. While such methods require the factor of judgement, and are thus controversial, arbitrary classification can provide a satisfactory method of measurement (Hall, 1970). In this study the use of integrated electromyograms to detect absolute values of electrical activity was not employed. Thus, criteria defining the amount of activity in the muscle relative to an arbitrary minimum and the consistency of electrially active muscles were considered more desireable.

Defining EMG activity in terms of being active and non-active has been utilized by Battye and Joseph (1966), Brandell (1973) and Kramer (1979). Of these investigators only Battye and Joseph, and Kramer specified a critical value. Respectively, these values were 15% and 25% of the maximal electrical interference of the muscle under study. It is evident that no established criteria for defining active and non-active electrical activity exists. As a result, after careful examination of the EMG record in this study, the criteria for electrically active muscle was established at a level that was at least 25% of the highest interference value for a particular muscle.

In the classification and description of human movement, it is acknowedged that precise analysis is not possible (Higgens, 1977). Though various descriptors and systems, such as EMG, enhance our analytic abilities, it must be understood that investigations such as this, are limited to providing a preliminary, basic framework for understanding human movement. Thus, the following analysis of electromyographical activity theoretically integrated the actions and functions of upper extremity muscles during wheelchair propulsion.

## EMG Analysis of the Stroking Cycle

The primary interest in this investigation was the muscular activity of the upper extremities during the stroking patterns involved in propelling a wheelchair. This will be considered in terms of the phases and the joint excursions already identified. Figure 4 summarizes these parameters.

*Drive Phase*

Hand-Contact: The functional demand of this particular event was the initiation of hand-rim contact without impeding the momentum of forward travel. At the moment of hand-contact, the wrist was extending, the elbow flexing and the shoulder was both flexing and elevating. Electrical activity at hand-contact was observed in the anterior deltoid, pectoralis major, biceps brachii and both the wrist extensors and flexors.

The anterior deltoid, though observed to be inconsistent at the moment of contact, and the pectoralis major were active to cooperatively flex the shoulder. The biceps brachii acted primarily to complete flexion at the elbow. The wrist extensors were active to prepare the hand for contact by extending the wrist along with moving it in a radial direction. Wrist flexor activity was observed due to the summation of electrical activity from the muscles responsible for flexing the fingers as the hand made contact. Along with these actions and uses, the wrist muscles also acted synergistically to stabilize the wrist for initial contact with the push-rim.

Drive: The hand had contacted and gripped the push-rim during the hand-contact period. The right upper extremeity now moved through the entire drive phase so as to apply the force necessary to maintain the momentum of the wheelchair. This was accomplished by initiating and maintaining rapid depression and flexion of the shoulder. Initially, as the hand was in a posterior position to the midline of the body, elbow flexion assisted in providing force to the push-rim. Then, after the hand passed the body midline, extension of the elbow assumed the responsibility for applying force. For similar reasons the wrist rapidly extended and then flexed as the driving phase progressed.

All the muscles under examination were active at some point during the driving phase. The anterior deltoid, pectoralis major, biceps brachii, and the wrist flexors and extensors were chiefly responsible for transfering force to the push-rim in the first part of the phase. These muscles served to move the upper extremity past the midline of the body and as this occurred, the remaining muscles became active (i.e. the upper trapezius, middle and posterior deltoid and the latissimus dorsi).

The most important muscles for continuation of force application were the triceps brachii and the wrist flexors. The triceps brachii was active throughout the latter two thirds of the drive phase as the upper extremity extended rapidly. The wrist flexors acted to maintain hand-contact and assist in providing a final transfer of force during the last half of the period.

The latissimus dorsi, though inconsistent, was active in the latter stages to assist in depressing the shoulder girdle. The continued activity of the pectoralis major as the hand passed the body midline was the result of the muscle preventing the shoulder girdle from being driven upward as the upper extremity applied force to the push-rim.

Finally, the upper trapezius and the middle and posterior deltoid were active as synergists in the last half of the phase to stabilize the shoulder as the transfer of force reached its maximum. In addition, the middle deltoid acted to abduct the upper extremity as the hand reached the lower arc of the push-rim. This was due to the fact that the path of the hand was observed to travel away from the body as a result of the camber of the wheel.

*Recovery Phase*

Hand Release: The functional demand of this event was the breaking of hand-rim contact so as not to effect the velocity of the wheelchair. At the point of release the shoulder was depressed and just completing flexion. The elbow was extended and the wrist was beginning to extend.

A number of muscles active in the latter stages of the drive phase continued to be responsible for the same actions as the hand broke contact with the push-rim. These included the upper trapezius, middle and posterior deltoid, and the wrist flexors.

Recovery: Following the hand's break-away from the push-rim, the right upper extremity moved through the recovery phase more slowly than hand movement during the drive phase. This was accomplished by elevating and extending the shoulder while gradually flexing the elbow and extending the wrist.

Electrical activity during the recovery phase was noticeably less than the drive phase. This was primarily attributed to two factors. In the drive phase the upper extremity was acting against a strong resistance (i.e. ground friction) as compared to the recovery phase in which the extremity was primarily resisting the forces of gravity.

Furthermore, since wheelchair propulsion involves the application of force via rapid movements, it may be classified as a ballistic movement (Wells and Luttgens, 1976). Wells and Lutgens state that ballistic movements are initiated by vigorous muscular contraction and completed by momentum. In wheelchair propulsion this momentum is partially terminated by allowing the arm to reach its limit of motion by the passive resistance of its ligaments and muscles. Thus, the conservation of momentum by the arm required less muscular activity during the recovery phase. The specific point during the recovery phase where muscle activity begins and momentum ends may be difficult to identify since the two are interrelated.

The most active muscle was the posterior deltoid which was responsible for extending the shoulder during recovery. Inconsistent activity was observed in the upper trapezius which was responsible for elevating the shoulder. This inconsistency was due to the fact that the subjects' push-rims varied in size. The smaller the diameter of the push-rim, the less elevation was required of the shoulder to ready the hand for contact on the rim. The middle deltoid, active during the first third of the phase, maintained the upper extremity in an abducted position so as to prohibit hand and arm contact with the push-rim and/or wheel. Finally, the wrist extensors were active in two bursts, as the wrist extended for the first time and later as the hand and fingers prepared for recontact on the push-rim.

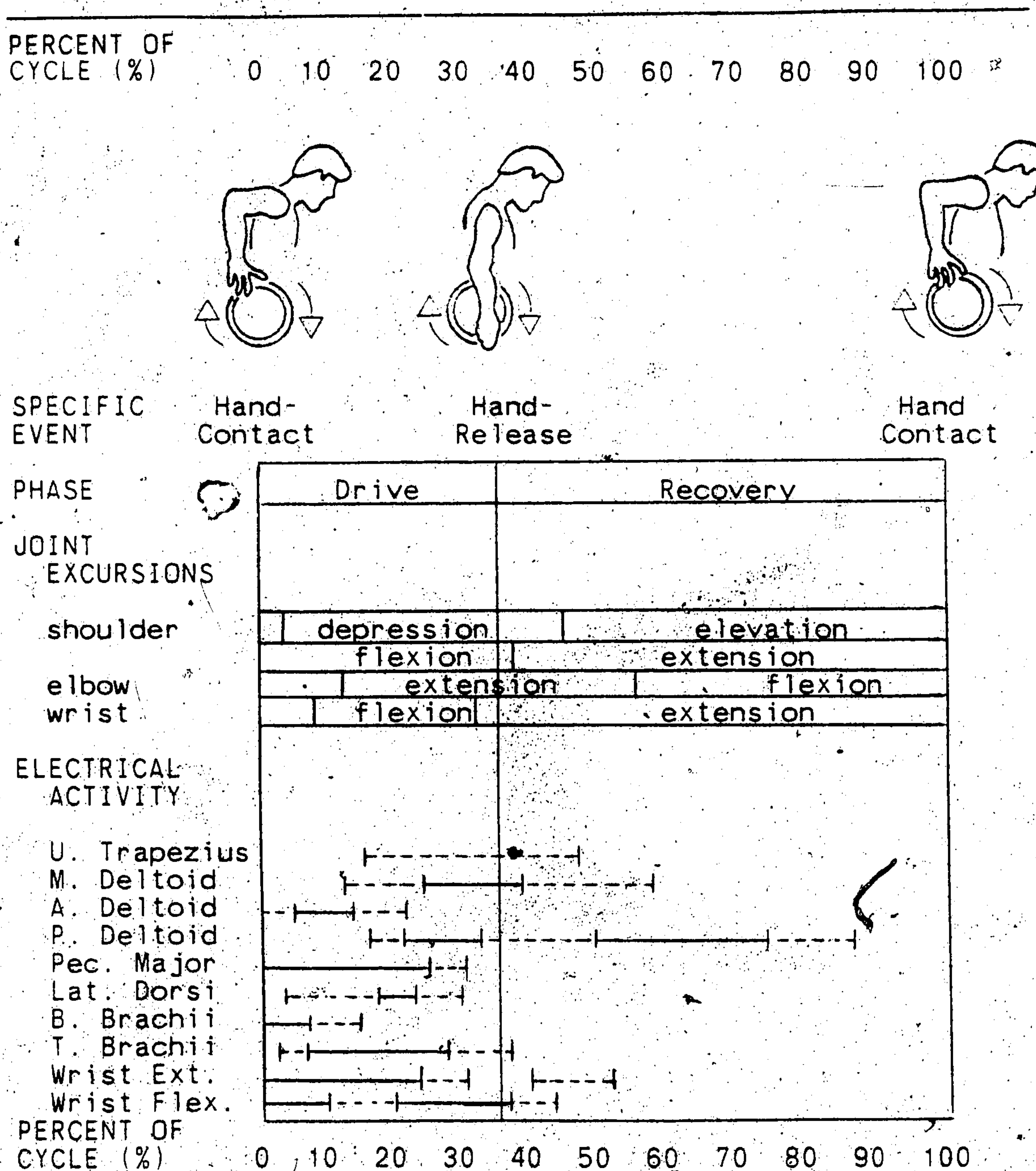


Figure 4. Summary of temporal, spatial and electromyographical parameters of the competitive wheelchair stroke cycle.

# VI. CONCLUSIONS AND RECOMMENDATIONS

## A. Conclusions

From the observations made in this investigation and within the delimitations and limitations of the gathering of data, the following conclusions appear justified:

1. The terms utilized for describing competitive wheelchair propulsion provide a functional description of specific events that occur in this method of locomotion.
2. In terms of seconds duration, the drive phase (0.31 sec) was noticeably shorter than the recovery phase(0o.61 sec).
3. The duration (sec) of corresponding joint excursions was similar in shoulder elevation and depression, and elbow flexion and extension. However, in shoulder flexion and extension, and in wrist flexion and extension the duration (sec) was noticeably different for the complimentary excursion. Both shoulder and wrist flexion were shorter than their counterparts.
4. The joint excursions identified as necessary in the kinesiological model for wheelchair propulsion were observed in this study.
5. The greatest ranges of motions were observed to occur at the shoulder during shoulder extension and at the elbow, also during extension.
6. The greatest amount of electrical activity in the muscles under investigation occurred during the drive phase. In addition, this activity was classified as the most

consistent.

## B. Recommendations

1. That further investigations of wheelchair propulsion be undertaken, utilizing larger numbers, females and athletes at different skill levels.
2. That further investigations on isolated muscles be undertaken to provide further information on the muscles' specific requirements for wheelchair propulsion.
3. That further investigations be carried out utilizing more sophsiticated camera techniques. The addition of one or two more cameras may allow for more information on sub-phases and other specific events.
4. That further investigations be carried out utilizing electronic analysis to provide additional information on various biomechanical parameters such as displacements, velocities and forces involved in the wheelchair stroke.

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## APPENDIX A: 4-CHANNEL EMG SYSTEM

FOUR INDEPENDENT LOW-NOISE PREAMPLIFIERS Each preamplifier contains 4 matched, selected low-noise field-effect transistors, in a balanced differential A.C.-coupled circuit featuring high common-mode rejection. Low noise deposited carbon resistors and mylar capacitors are used.

ELECTRODES
Each pair of EMG electrodes is supplied with a special common-mode balancing circuit which permits the operator to compensate for differences in skin-contact resistance, tissue impedance, electrode impedance, and minimizes the usual effects of electrolytic action or contact potentials developed at the electrode skin interface. As a result, surface skin electrodes can be used under most conditions, minimizing discomfort assosiated with subcutaneous needles.

SINGLE CABLE TO CENTRAL LOCATION
This cable is driven by a special ultra-low impedance circuit, featuring 4 pairs of matched, balanced, differential low-noise emitter followers and a 50-ohm driver transformer for each of the four channels. As a result, long cables can be used without degrading the signal quality, and crosstalk and interaction between the channels is undetectable. Additional lengths of cable up to 100 feet can be added without impairing the signals at the receiving end. Also, the low output impedance and relatively high level of the signal before it enters the cable is compatible with the future addition of a 4-channel F.M. transmitter and telemtry system, to eliminate the requirement for even one cable.

NO BLOCKING OR OFFSET PROBLEMS
Many popular EMG preamplifiers, such as the Grass P 15, are prone to an annoying total blockage of the signal following a high-level input signal, such as occurs when the subject or experimenter touches one electrode. Those circuits exhibit a fairly long period of time during which no information can be recorded and the experimenter must wait until the circuit stabilizes itself before he can proceed with the data collection. The F.E.T.-differential preamplifier circuitry developed here has a sufficiently wide dynamic range and rapidly enough equilibrating time constants that this effect is not seen. As a result, the experimenter may record continously, without interruptions due to blocking.

STANDARD 9-VOLT BATTERIES USED
These batteries are sufficiently standardized, easily obtained, and inexpensive, that it is considered preferable to simply install a new battery before a major data collection period, and be sure of battery condition. Batteries should be replaced when it falls below 8 volts, but the very low drain of the remote circuit should permit

long battery life. The use of a D.C. power supply at both remote transponder and central location permits total freedom from power lines, desirable for safety considerations, and also to eliminate hum problems entirely, as in a free-field situation away from power lines completely.

SIMPLIFIED OPERATION

Attention is directed to the physiological phenomena being recorded instead of to the equipment being used. It is extremely difficult to make hum-free recordings of muscle groups in large animals in an enviornment saturated with 60-cycle hum. Nevertheless, the entire circuitry, time constants, and human-engineering design of this system is directed at the simplification and dependability of relatively untrained personnel recording muscle groups from large animals in an unrestrained situation. Thus, the minimum number of controls are provided, and all controls required to optimize the recording of muscle acivity and exclude interference are already included, and where practical, are pre-set.

The operation is directed at timing of various muscle groups, rather than a measure of signal amplitude in absolute terms. Therefore, amplitude and gain calibration are made continuously variable, so that differences from subject to subject may be smoothly expanded to fill a full trace on the recording charts being used.

If calibration is required, it is a simple matter for the user to adjust the continuously-variable gain controls against a known external signal source, to set the gain of the equipment at any desired preset level. When this has been done, the knobs should not be touched altenatively, a marker may be set on the knob to permit return to a given gain setting. This system has the additional advantage that gain does not need to be 1, 10, 100 or 1000, but may be whatever value takes advantage best of the dynamic range available on the recording device, and may be set to be different on each channel as required.

BUILT-IN AUDIO AMPLIFICATION CHANNEL

This simplifies the operation by eliminating the requirement to connect an additional audio amplifier for monitor of EMG vesus hum. Simplifies the positioning and choice of EMG electrode placement. Permits use of any standard headphones out in the field, away from power lines without additional auxillary equipment. The same switch that controls the meter also controls the headphones. Thus, the operator has co-ordinated audio-visual information on the placement and proper signal output of any set of electrodes. A rapid and easy comparison of the activity of any muscle group compared to any other muscle group may be done simply by turning the knob to select which channel is to be monitored: 1, 2, 3, or 4. The sounds which appear in the headphones correspond to the signal shown on the meter.

LOW-IMPEDANCE, WIDE OUTPUT SWING, VARIABLE LEVEL OUTPUTS, 4 INDEPENDENT.

The outputs are 100 ohms, capable of a full 20-volt peak to peak swing, if required, and will drive low sensitive tape recorders or chart recorders to full excursion with ease. Hundreds of feet of shielded cable may be hung on these outputs without degrading signal quality if the situation demands. Each output is totally amd completely independent of the others, and is unaffected by the position of the meter and headphone monitor switch. All inputs and outputs operate continuously, and there is no time-sharing or time-division multiplexing, hence there is no ultrasonic component in the output to cause problems with beats or oscillations in the tape recorder equipment. All four outputs may be used at once or any combination thereof.

(Reference: Steadward, 1978)

# APPENDIX B: EQUIPMENT MANUFACTURERS

| | |
|---|---|
| Dynamic Frame Motion Picture Analyzer Model DF-16B | NAC Inc. Tokyo, Japan |
| Photo Sonics 1PL 16 mm Camera | Photo Sonics Inc. Burbank, Calif. |
| Angenieux 72 mm diameter, 12-120 zoom lens | Angenieux Corp. Paris, France |
| #1 Di-optic Split Field Lens Filter | Tiffen Corp. Germany |
| Strobatic Type 1531 Timing Pulse Generator | General Radio Co. Concord Mass. |
| Hewlett-Packard Disposable Monitoring Electrodes #1445C | Hewlett-Packard Medical Products Waltham, Mass. |
| Synchroscope #SS-4211 | Iwatsu Electric Co. Tokyo, Japan |
| Quickset Tripods | Photographic Analysis Ltd. Don Mills, Ontario |

## APPENDIX C: SUBJECT'S CONSENT FORM

Thank you for becoming a subject in this study. Please note that your participation is entirely voluntary and that you are free to withdraw yourself as a subject at any time during the course of this project.

The purpose of this study is to investigate the competitive wheelchair stroke as utilized by elite wheelchair athletes. The specific skill to be analyzed is the pushing technique used in various track events. On the basis of this analysis, a kinesiological description of the skill will be reported.

You will be requested to submit to the following procedures:

1) Cinematographical analysis
2) Electromyographical analysis

The cinematographical analysis will consist of each subject being filmed while performing the stroking pattern. This performance will take place in a laboratory-type envionment.

For the electromyographical analysis, you will be requested to permit the monitoring of electrical activity of seleced muscles by means of surface electrodes. You will be instructed in the complete operation and procedures of the electromyographical technique. In addition, you will be informed about the safety of the equipment and the precautions that will be taken to ensure safety. Please note however, that there are possible risks in using electromyographical equipment in that it is electrical, and the surface electrodes placed on the body surface could result in skin irritations.

The investigator will be present at all data collection sessions and will answer any inquiries subjects may have concerning the procedures. At the conclusion of the study, the results will be made available for your review.

Participation in this study is contingent upon the signed consent of each subject. Therefore, please read the statement below and sign where appropriate.

*I have read and understand the procedures of this study described above and I am aware of the potential risks involved. I understand that I may withdraw myself from participation at any time during the course of this investigation. I agree to participate as a subject in all phases of the study described above. In addition, I agree to allow any data taken of me in this study to be used in professional presentations and publications provided my identity remains anonymous.*

*Signed/Dated*________________________

# APPENDIX D: SUBJECT INFORMATION FORM

NAME ______________________________
ADDRESS ______________________________
CITY ______________________________
PROVINCE/STATE ______________________________
TELEPHONE (AREA CODE) ______________________________
BIRTHDATE ______________________________
TRACK AND FIELD CLASSIFICATION (I.S.M.G.) ______________________________
DATE OF INJURY AND LEVEL ______________________________
CAUSE OF INJURY ______________________________
YEARS OF EXPERIENCE IN WHEELCHAIR SPORTS ______________________________
INTERNATIONAL EXPERIENCE (COMPETITION AND YEAR) ______________________________
CURRENT COMPETETIVE EVENTS ______________________________
UPPER EXTREMITY INJURIES (PREVIOUS/CURRENT) ______________________________
______________________________
OTHER MEDICAL COMPLICATIONS ______________________________
______________________________
MEDICATIONS (TYPE/DOSEAGE) ______________________________
______________________________
PERCEPTION OF FEELINGS AT TIME OF TESTING ______________________________
______________________________
ELECTRODE PLACEMENT:

| SERIES #1 | SERIES #2 |
| --- | --- |
| 1. ______________ | 1. ______________ |
| 2. ______________ | 2. ______________ |
| 1. ______________ | 1. ______________ |
| 2. ______________ | 2. ______________ |
| 1. ______________ | |
| 2. ______________ | GROUND ______________ |

TIME (24 HOUR) ______________ DATE ______________

## APPENDIX E: DATA COLLECTION FORM

SUBJECT

---

ELECTROMYOGRAPHY

| | | | |
|---|---|---|---|
| 1. U. Trapezius | T-1 | 6. Lat. Dorsi | T-1 |
| | T-2 | | T-2 |
| | T-3 | | T-3 |
| 2. M. Deltoid | T-1 | 7. B. Brachii | T-1 |
| | T-2 | | T-2 |
| | T-3 | | T-3 |
| 3. A. Deltoid | T-1 | 8. T. Brachii | T-1 |
| | T-2 | | T-2 |
| | T-3 | | T-3 |
| 4. P. Deltoid | T-1 | 9. Wrist Extrs. | T-1 |
| | T-2 | | T-2 |
| | T-3 | | T-3 |
| 5. Pec. Major | T-1 | 10. Wrist Flexrs. | T-1 |
| | T-2 | | T-2 |
| | T-3 | | T-3 |

---

| JOINT EXCURSIONS | | S | F | D | % | | | S | F | D | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Shoulder: | | | | | | Elbow: | | | | | |
| elevation | T-1 | | | | | flexion | T-1 | | | | |
| | T-2 | | | | | | T-2 | | | | |
| | T-3 | | | | | | T-3 | | | | |
| depression | T-1 | | | | | extension | T-1 | | | | |
| | T-2 | | | | | | T-2 | | | | |
| | T-3 | | | | | | T-3 | | | | |
| Shoulder: | | | | | | Wrist: | | | | | |
| flexion | T-1 | | | | | flexion | T-1 | | | | |
| | T-2 | | | | | | T-2 | | | | |
| | T-3 | | | | | | T-3 | | | | |
| extension | T-1 | | | | | extension | T-1 | | | | |
| | T-2 | | | | | | T-2 | | | | |
| | T-3 | | | | | | T-3 | | | | |

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| PHASES: | HC | HR | HC |
|---|---|---|---|
| T-1 | | | |
| T-2 | | | |
| T-3 | | | |

COMMENTS

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