Capabilities
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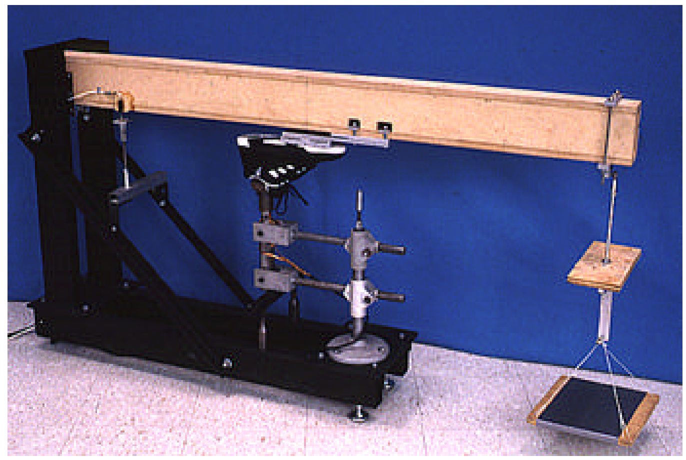

The photo on the left shows some of the ever-increasing number of prosthetic foot designs available to amputees today. Shown from left to right in that photo are: the Carbon Copy System III, the Seattle LightFoot and the SACH. The SACH foot has been available since approximately the end of World War II and, for many years was the standard prosthetic foot. Shown in the photo on the right,is the foot loading apparatus. Prosthetic feet are mounted in the apparatus to enable investigators to perform static and dynamic characteristics testing. Northwestern University RERC has tested over 15 models of prosthetic feet.

How do Dynamic Response Feet Affect Ambulation: The NURERC Research Project

There is evidence that dynamic response feet are gaining popularity with people who use them. This style of foot, according to many users, enables more natural gait and allows them to expand their activities. Until recently, this evidence has been anecdotal, based on personal preferences frequently expressed as, “it works well”, or “it has a good feel”. The Northwestern research uses quantitative analysis to try to determine what factors contribute to the satisfaction of users.

Fifteen models of feet have been tested

An ongoing research project at Northwestern University Rehabilitation Engineering Research Center, sponsored by the National Institute on Disability and Rehabilitation Research, is studying how these feet function and the role specific characteristics of dynamic response feet play in improving gait. The Northwestern University RERC team conducting the research on dynamic response feet includes Erick Knox, project director and Laura Miller, doctoral student under the direction of Dudley S. Childress, Ph.D. Previous studies, upon which his master’s thesis was based, were conducted by Alan Sandifer.

The project has tested 15 models of commercially available dynamic response feet in four different orientations -- analogous to heel contact, heel off, forefoot and opposite heel contact (terminal double support). Tests are also being conducted to determine how the mechanical characteristics of footwear affect the role of these feet in trans-tibial prosthetic gait.

New testing apparatus developed by RERP

Research methods include testing of mechanical characteristics using measurement apparatus, designed at Northwestern University RERC, and a study of people using the

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Dynamic Response Feet *(Continued from page 1)*

feet. Mechanical characteristics are studied in several ways. A specially designed foot loading apparatus, consisting of a steel support frame, prosthetic foot mounting jig and wooden loading beam enables the researchers to determine such factors as foot deflection, the total force on the foot and the center-of-pressure. Quasi-static load versus deflection tests were performed to investigate the stiffness and hysteresis properties of feet and shoes. Dynamic characterization tests, based on the sudden release of load on the foot, which then oscillated about a new equilibrium point, were also conducted. The data from the tests are enabling the research team to calculate the efficiency and timing of energy return.

To evaluate function of the dynamic response feet as they are being used by people with trans-tibial amputations, the Northwestern University RERC team has developed and installed sophisticated instrumentation for recording the many factors involved in human ambulation. Among the ambulation-related functions measured by the CODA (Cartesian Opto-Electronic Dynamic Anthropometer) is the X, Y, Z positions in space of joints so that significant amounts of data can be compiled on, for example, how the knee is moving. The team hopes to be able to use such data in the future to form hypotheses about if and how various characteristics of dynamic feet influence the overall process of walking.

How feet contribute to ambulation is very complex

Extensive and responsibly controlled research into how dynamic response feet function and how their characteristics contribute to the quality of human ambulation is a long, highly detailed process. “What makes a foot good is very complex”, said Erick Knox, Project Director. Characteristics such as flexibility and efficiency of energy return are known to contribute to the role prosthetic feet play in human ambulation. Flexibility, for example, may facilitate climbing stairs and stepping off curbs. Energy return may play a role in fatigue levels when using prosthetic feet for ambulation. Why and how much these characteristics affect ambulation can only be determined through disciplined research involving testing of many aspects. Continuing testing will include mechanical characterization of prosthetic feet and foot/shoe combinations for the heel contact and opposite-heel contact orientations.

The research at Northwestern has been aided by the fact that manufacturers of dynamic response feet have donated models of their products to be tested in the research project and used for instruction at the Northwestern University Prosthetic and Orthotic School. Dynamic response feet which have been tested include: Carbon Copy II, Carbon Copy III, College Park Foot and Ankle, Dynamic, Dynamic Pro, Flexwalk, Quantum, SACH, Safe II, Seattle Foot, Seattle Lightfoot, Springlite, STEN, Steplite Strider and Reflex VSP. The results of testing on various models will be made available to the manufacturer of that model as an aid to future design and development of the product. The Northwestern Research is not, however, designed to endorse any specific model of dynamic response foot.

Research will benefit users of this style of foot

When the Northwestern research is completed, it will result in a series of guidelines to give prosthetists a scientific basis for working with their clients to choose prosthetic feet more objectively, more accurately and with greater cost effectiveness. Characteristics defined and tested in the research may relate to the needs of individual people, allowing them to choose which foot most accurately provides the function they want. Results of tests are being analyzed, then published in professional journals and presented at meetings of research investigators as various stages of the testing are completed. This provides the Northwestern team with valuable feed-back from other investigators and adds to the overall base of knowledge about the role of dynamic response feet in ambulation.

The benefit of this research to the public will be a better understanding of prosthetic feet that will facilitate development of dynamic response feet with improved designs and performance that enable people to do more of the things they like to do. A person using a dynamic response foot may not think — nor care — about the fact that his foot is made of carbon fiber epoxy in a specific configuration and meets criteria determined by the Northwestern research. The real result from this research to the users of dynamic response feet will not be which features of the feet the users notice each day, but the functions facilitated by these feet. Benefits will more likely be expressed by users in terms such as, "I can walk farther without tiring", "I am not aware of the weight" or "I can keep up with the kids and the dog". ❖

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Subscription is free to all individuals interested in prosthetics and orthotics. For contribution guidelines and advertising inquiries, write to the address below. Address subscription information, address changes and other correspondence to: *Capabilities,* Northwestern University RERP, 345 E. Superior St., Room 1441, Chicago, IL 60611.

NURERC Consumer and Technical Advisory Panels Meet

On May 5, five members of the Consumer Advisory Panel and five members of the Technical Advisory Panel for the Northwestern University Rehabilitation Engineering Research Center and Prosthetic Research Laboratory spent a day packed with presentations about the research being conducted by the program. The meeting provided the opportunity for the researchers to gain input on how their laboratory and clinical work fits into the lives of consumers and other research organizations.

Consumer Advisory Panel members attending the meeting were: Mr. Bill Lintz, Architectural Precast, Inc.; Mr. Johnnie Pearson, North Carolina Division of Veterans Affairs; Ms. Margaret Pfrommer, Research Associate and Consumer Advocate, Northwestern University RERC; Ms. Linda Lee Ratto, Author, MINDmatters, Inc.; and Mr. Hector Torres. Members of the Technical Advisory Panel present were: Dr. Lawrence Carlson, University of Colorado; Dr. Robert Jaeger, Illinois Institute of Technology; Mr. James Kaiser, C.P., Scheck & Siress Orthotics and Prosthetics; Mr. Maurice LeBlanc, C.P., Packard Children's Hospital at Stanford University; and Mr. Michael Quigley C.P.O., Oakbrook Orthopedic Services, Ltd.

Review of Upper-Limb Prostheses Research

Following an overview of research topics and goals presented by Dudley S. Childress, Ph. D., Director of NURERC & PRL, the panel members saw graphic presentations of work in prosthetic upper limb research. Led by Craig Heckathorne, Edward Grahn and Richard F. ff. Weir, also staff members of NURERC & PRL, were joined by Jack Uellendahl and Yeonchi Wu, M.D., of the Rehabilitation Institute of Chicago staff, in discussions and demonstrations of PADSS (Prosthetic Arm Design & Simulation System), electric hand development, direct muscle attachment to control myoelectric prostheses and other related topics. Panel members were able to examine prototypes of a lighterweight hand and an electrical humeral rotator that are being developed by the department.

Next on the agenda was an overview of research in ambulation and aided-ambulation with the discussion again led by Dr. Childress. Topics covered included research into floor clearance and 4-bar-linkage knees, mechanics of prosthetic feet, influence of shoes on prosthetic feet, vertical shock pylon limbs, slow and ultra-slow walking, crutch ambulation and clinical experiences with the "Walkabout" ambulation orthosis for individuals with spinal cord injuries. Assisting Dr. Childress were: Steve Gard, Erick Knox, Laura Miller and Susan Visser, doctoral students, Laura Fenwick, Northwestern Prosthetic-Orthotic Center and Dr. Wu.

Before breaking for lunch, the group toured the Human Mechanics Measurement Laboratory. Under the leadership of Richmond Chan, students Joseph Licameli, Steve Borowski, Steve Gard, and Janet Jhoun demonstrated projects in gait analysis, BCOM (body center of motion) movement during walking, monitoring of bone movement during gait and study of standing. The demonstration explained how the laboratory's direct ultrasound ranging system and other sophisticated measurement methods are allowing the Northwestern research personnel to more accurately assess ambulation and human movement.

Computers Aid in Design, Fabrication and Teaching

In the afternoon, the group had the opportunity to explore how Northwestern is taking full advantage of the capabilities of computers, not only in research, but in teaching and information dissemination. John Steege showed the panel members how computers have enabled advanced computation of limb/prosthesis stress and use of new modeling techniques for prostheses. Also shown was the recent development of CAD/CAM (computer-aided design/computer assisted manufacture) production of limbs. This method, named "Squirt Shape" by the Northwestern staff, facilitates total fabrication of a limb in much shorter time than previous, manual processes. Mark Edwards, Northwestern Prosthetic-Orthotics Center, showed the interactive education program used by the school to allow students in various areas of prosthetic and orthotic practice to learn at their own rate. Edwards and his staff have created a program for the Macintosh computer that "talks" the student through such processes as measuring for a device, fitting the device and accounting for details in clinical work.

Since the goal of the Northwestern prosthetic/orthotic research, educational and clinical programs is to serve end users in the best possible manner, the sessions were concluded with a presentation by Bill Armstrong, RIC, about the direct service program he directs, which delivers assistive technology to people from the community. This program is another that grew out of the prosthetics research laboratory.

The fast flow of information about the Northwestern research projects stimulated discussion by the members of the Consumer and Technical Advisory Panels in the final ses-

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Consumer & Technical Panels Meet *(Continued from page 3)*

sion of the day. Most of the panel members in attendance had also been present at the last advisory panels meeting in October of 1993. The general feeling expressed by the panel members was pleasure at the progress that had been made on projects that had been mainly theoretical in 1993. One panel member, noted that a great deal of effort had been focused on a relatively small segment of the amputee population -- high-level bilateral arm amputees. However, the panel agreed, this focus had not only served this small population segment, but had produced data and prototypes that benefit all upper-limb amputees with innovation in prehensor weight, locking mechanisms and new diagnostic and selection procedures.

Another member of the Technical panel, complimented the Northwestern staff on the quality of the computer-graphic presentations generated for large amount of data. Members of the Consumer panel commented that dissemination of such data would increase the ability of the consumer to be more knowledgable about both new technology and expanded function. This, in turn, can help a consumer make more informed decisions about his or her use of prostheses and orthoses.

Panel Recommends Information Dissemination

Recommendations from the panels centered around the need to share the results of Northwestern University RERC's research with not only consumers, but other research personnel and facilities. The panels urged NURERC&PRL to share research findings with others through several channels:

- exchange of information through columns in newsletters published by such groups as the Amputee Coalition of America, AARP and sports groups;

- support of consumer groups in their quest for more advanced prosthetic and orthotic devices by supplying the most current technical information;

- act to develop formats and content for information on Northwestern research for publication on the World Wide Web on the Internet. ❖

Organization Spotlight

Amputee Coalition of America

By Carol Scholar

Mission

ACA's primary focus remains educational: education of amputees, professionals and government and regulatory agencies on amputee related issues and needs. A central value is empowerment of people to encourage full participation in all aspects of life and to become informed consumers.

Annual Consumer Meeting

The sixth annual Consumer Education, two and a half day meeting held in New Orleans in March 1995, was a huge success. Over 200 amputees and their families from across the United States attended educational workshops, issue-oriented sessions and social functions.

Newsletter

ACA currently has a mailing list of 30,000 people expected to rapidly grow with the upcoming release of a new, 48 page color magazine that will replace their current newsletter, *ACA in Motion.* The ACA also sells amputee related educational materials and videotapes and has created an "Amputee Bill of Rights and Responsibilities" document.

Database

ACA has created a database consisting of over 1,200 file entries on topics such as books, journals, amputee organizations/support groups, videos, newsletters, disability related camps, etc. They are constantly updating the bank with new resources. The ACA uses the database for information and referral purposes. Anyone seeking specific amputee-related information or wishing to make a contribution to this resource can call the ACA Headquarters at 615-524-8772, 1932 Alcoa Hwy., Suite 365, Knoxville, TN 37920.

Networking

ACA is interested in networking with other disability groups who share common interests and goals. They currently are networking with the Paralympic Games and will be an organizational sponsor of the international event in Atlanta.

Legislative Issues

ACA has been instrumental in monitoring and impacting systems that set policy affecting the delivery of service and products to amputees. ACA delegates were active in education of legislative players about the prosthetic needs of amputees during the recent health care reform efforts and continue to monitor the Washington scene closely. They are currently working on the issue of separate identification of Orthotic and Prosthetic products, rather than having them included in Durable Medical Equipment designations. ❖

Books —

Living in the State of Stuck: How Technology Impacts the Lives of People with Disabilities. Marcia J. Scherer, Cambridge, MA: Brookline Books, 1993. 189 pp. Cloth $32.95, Paper $24.95

People with disabilities who use and people who prescribe assistive technology will equally identify with many of the situations detailed in this book, based on a study to discover why people with disabilities frequently are dissatisfied with the assistive technology they have been provided or abandon that technology. In addition to recognizing examples of people or circumstances you've met in your experiences with assistive technology, Scherer's book will stimulate thoughts about how technology is evaluated and prescribed. The opening statement, "Technology is the answer, but that's not the question", sets the stage for starting to think about assistive technology in a broader context than just what function it restores or replaces. Quotes such as "one may learn to ambulate on artificial legs, but have nowhere to walk", summarizes the repeated theme of the book. For technology to be truly successful and accepted by the user, it must match that person's goals, life style and environment.

This book shows the reader who uses assistive technology that he or she does not have unique problems in acquiring satisfactory answers through technology. It's OK to reject solutions if they're not what suits your life-style and preference. It's OK to demand to try alternatives that may not be the prescriber's first choice. For the prescriber, designer and clinician, the book offers some new insights into working with the person with a disability as part of the team, whose mission is to find solutions through technology.

— & Periodicals

ACCENT on Living, P.O. Box 700, Bloomington, IL 61702. $10.00 per year, $17.50, two years.

This digest-sized quarterly carries articles on everything from home modification to sky divers with cerebral palsy and topics in between on health, recreation, jobs, hobbies and product reviews. Polls of readers' opinion of various topics are usually included in each issue. ACCENT also carries ads from about 100 providers of services and products per issue — an up-to-the-minute means to learn what's available in assistive technology.

Sports 'n' Spokes, 2111 E. Highland Ave., Suite 180, Phoenix, AZ 85016-4702. Bi-monthly $12.00 per year.

S'n'S gives complete coverage of all sports for people with disabilities from wheelchair basketball to skiing by amputees, blind and mono-skiers. In between are articles on fishing, scuba diving, rock climbing, rugby and other activities. Even if you don't think you're an athlete, S 'n' S will give you a new view on what people with disabilities do for recreation and challenge — and it's likely you may find an activity you or your friends want to try. Ads in S 'n' S are aimed at recreation, athletics and body building but include general assistive technology as well.

Exceptional Parent, 209 Harvard St., Ste 303, Brookline, MA 02146-5005. $24 per year. Monthly.

Families who have children with disabilities come together in the pages of this publication to share challenges and triumphs. The magazine is a support group in print. Articles on topics critical to families, such as insurance, estate planning, finding time for siblings and potential stress on marriages are written by both parents and professionals in each field. The "Letters" section is particularly well done and frequently serves as a method for parents whose child has a rare condition to find others in like situations. A good assortment of ads includes schools, residential facilities and other services in addition to assistive technology.

New Mobility, 23815 Stuart Ranch Road, P.O. Box 8987, Malibu, CA 90265.$ 18 per year. Bi-monthly.

"Disability Life Style . Culture and Resources", the theme of this magazine, is reflected in articles ranging from a wheelchair-using sheriff fighting for re-election to a choreographer, who happens to be quadriplegic, to how to access the Information Super Highway. The magazine challenges popular stereotypes of people with disabilities and is a forum for many different ideas and attitudes. Ads from a variety of suppliers of technology and services are included.

A.C.A. In-Motion, A Publication of the Amputee Coalition of America, 1932 Alcoa Hiway, Suite 365, Knoxville, TN 37920 (615) 524-8772. Price included in membership in the ACA: $25/year for individuals. $75/year for nonprofit/support groups.

This quarterly publication has article in a broad range of categories including emotional well-being, recreation, concerns of parents of children with amputations, medical news, legislative briefs and listing of resources for people with amputations. Advertisers give detailed presentations of prosthetic and orthotic devices.

Membership in ACA also includes access to a nationwide database dedicated to amputee resources and reduced annual meeting registration fees. ❖

Myoelectric Control: Brief History, Signal Origins, and Signal Processing

This paper was presented by Dudley S. Childress, Ph. D., Director of the Northwestern University PRL & RERC, at the International Society of Prosthetics & Orthotics World Congress, Melbourne, Australia in April 1995.

Brief History

Electrical aspects of muscle have been recognized since the work of Galvani (1790s). However, the existence of action potentials in human muscles was apparently not demonstrated until about 1880, and it was only after development of the string galvanometer that electricity from muscles could be reliably quantified. This instrument led to the demonstration of electromyography by H. Piper in Germany about 1910. Nevertheless, myoelectricity was apparently not widely known in English speaking countries until publication of a paper on the topic by E.D. Adrian in 1925. Naturally, many other people played important roles in the early development of knowledge concerning myoelectricity. The development of electronic amplifiers (vacuum tubes) during the 1930s enhanced the ability to record myoelectric activity and it was this technology that led to the first demonstration, in 1843, of myoelectric control of a hand prosthesis. Solid-state technology, which moved from transistors (1950s & 60s) to integrated circuits (1960s & 70s) to very large scale integration of systems on substrate (1980s & 90s), has brought myoelectric control to its current status.

First Myoelectric Prosthesis was Bench Mounted

Reinhold Reiter demonstrated the first myoelectric prosthesis in Munich (circa 1943) while he was a young student of physics. He tried to promote the concept, but the poor economic conditions in Germany immediately after WWII prohibited commercial development of the system, which consisted of vacuum tube amplifiers and a solenoid-actuated Hufnerhand. It was bench mounted and was designed to be used at work/activity location. It was a "single-site" system; that is, it used only one muscle to control opening and closing of the hand. Single-site myoelectric control did not appear again until R. Scott, in Canada, introduced this control principle during the early 1960s.

It is interesting to note that N. Weiner, regarded as the father of cybernetics, mentioned the myoelectric control concept in his well-known book in 1948. N. Berger, in 1952, also speculated on the possibility of using muscle electricity to control prostheses.

In London during the early 1950s, A. Nightingale and associates, independently of Reiter, developed a similar vacuum tube based system that demonstrated control of a prosthetic hook. This work continued for a number of years and ultimately led to an advanced design by A. Bottomley in the 1960s that was years ahead of its time.

During the late 1950s, V. Gurfinkel and several associates in Moscow spearheaded the development of the first myoelectrically controlled hand prosthesis that was transistorized and portable on the user. This system was demonstrated at a world exhibition in Brussels in 1959 and thereafter myoelectric control became well known to the rehabilitation community. Subsequent to this milestone event, R & D efforts related to myoelectric control mushroomed all over the globe. Suffice it to say that during the latter part of the 1960s, the Viennatone Hand, the first readily available commercial system, came to the market. The now dominant Otto Bock myoelectric hand system came on the scene soon thereafter. Nevertheless, in many countries widespread use of this approach to prosthesis control did not come about until the 1980s.

Origin of Signal

All living cells of the body are electrically negative on their inside with respect to their outside. This potential is a result of differences in chemical ion concentrations between the inside and the outside. Neurons use the depolarization of this potential as a means of communication (the action potential). Motor nerves have neurons running from the anterior aspect of the spinal cord to muscle fibers. The neuron and the fibers it connects with are called the "single motor unit". In muscles of the arm it is common for motor units to have several hundred muscle fibers associated with one neuron. When an action potential runs along the neuron to the motor unit fibres during muscle activation, the nerve action potential causes chemicals to be released at the myoneural junctions. These chemicals cause an electrical depolarizing wave to run along the muscle fibers of the single motor unit and this results in a twitch-like contraction of all the fibers of the single motor unit.

The electrical depolarization wave of the muscle fibers creates electrical current flow in the neighborhood of the motor unit. These currents, flowing through resistive body tissues cause voltages to be produced in the tissues. The tissues include the skin on the outer aspect of the body. Since muscular contraction involves many motor units being repeatedly and asynchronously depolarized, the electrical potential on the skin is a complex summation of the underlying electrical activity. Consequently, the signal is very irregular in shape. This is the surface myoelectric signal. This signal is often called the Electromyogram (EMG) because it was first recorded as a tracing on paper. The amplitude of this electrical signal is most sensitive to currents (voltage) from motor units that are closest to the pickup electrodes on the skin, but the amplitude also contains components from motor units that are further away, even from units in other muscles.

In general, the amplitude of the surface myoelectric signal increases as muscle force increases, although the increase is usually not linear with the force. The surface myoelectric signal is an alternating voltage that is rather "random" in nature. Consequently, it is usual to characterize it using statistical properties. However, if we do not have to think too precisely about this signal, we can think of peak-to-peak voltage values and of a kind of frequency of fluctuation. A rule-of-thumb for remembering the general amplitude and frequency of typical surface signals when a superficial muscle is modestly contracted is to "remember the number 100". This number serves well because the voltage between the positive and negative peaks of the signal is on the order of 100 microvolts; i.e., 100 millionths of a volt. Also, the mean frequency of oscillation of the signal is in the neighborhood of 100 cycles/sec. or 100 hz. The amplitude of the signal varies with muscular activity. (The "rule of thumb" is only a crude approximation.)

When the human hand is lost to amputation, a "phantom hand" remains accessible to the individual. When the individual thinks of moving this phantom hand, muscles remaining in the residual limb actually contract. The use of these myoelectric signals, which are related to the movement of the phantom hand, to control an artificial hand is a fundamental principle of myoelectric control of hand prostheses.

Signal Processing

The myoelectric signal on the surface of the skin is relatively small in amplitude (typically from a few hundred microvolts to zero volts). Since the noise level of most amplifiers is down at the level of a few microvolts, myoelectric signals as low as 5 to 10 microvolts may be used to activate prostheses.

There are many ways to process myoelectric signals for myoelectric control of a prosthesis. What follows is a kind of generic example of typical processing. Processing in actual systems may be somewhat different than what is described here. First of all the signal is usually amplified by a bandpass differential amplifier (solid state, of course). A bandpass amplifier is used because the signal is made up of frequencies from a small band of the spectrum and it is counterproductive to amplify in frequency ranges where no signal components exist. For example, most surface EMGs have frequencies mainly between 10 and 300 hz. Therefore, an attempt is made to amplify only in this region of the frequency spectrum. The signals are usually amplified by a factor of between 10,000 and 100,000. Differential amplifiers are used because they are designed to subtract environmental noise (e.g. electrical noise from motors, etc.) from the myoelectric signal.

Voltage Signals Transform into Plus or Minus Voltage

After amplification the enlarged alternating voltage signal can be transformed by electronic circuits into either a plus or a minus voltage (a kind of quasi D.C. voltage). After some of the fluctuations are taken out of the transformed signal through a process called smoothing, this voltage can be used to turn "on" an electronic switch which lets energy flow from a battery to the hand. If one muscle site is used to generate a plus voltage, this voltage can be used to activate electronic switches that will cause the hand to close. If it is arranged for a myoelectric activity from a second muscle site to generate a minus voltage within the circuit, this negative voltage can be used to activate electronic switching that will cause the battery to send electrical energy to open the hand. Consequently, myoelectric activity in one muscle will open the hand, while myoelectric activity in the other muscle will close the hand. The electronics can be designed so that if both muscles contract simultaneously, nothing will happen. Although operation to control an artificial hand has been described, myoelectric control from any available muscle sites can be used to control a variety of powered artificial joints (e.g. elbow, wrist, etc.). ❖

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Northwestern University Prosthetics Research Laboratory
and Rehabilitation Engineering Research Program

345 E. Superior Street, Room 1441
Chicago, Illinois 60611-4496
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