Upper Extremity Artificial Limb Control as an Issue Related to Movement and Mobility in Daily Living

Stephen A. Wallace, David I. Anderson, Michael Trujillo, and Douglas L. Weeks

The 1992 NIH Research Planning Conference on Prosthetic and Orthotic Research for the 21st Century (Childress, 1992) recognized that the field of prosthetics lacks theoretical understanding and empirical studies on learning to control an upper-extremity prosthesis. We have addressed this problem using a novel approach in which persons without amputations are required to perform or learn basic motor tasks using a prosthetic simulator. The findings so far have three important implications for rehabilitation: (a) learning prosthetic control can be facilitated by general principles that have been shown to promote motor learning; (b) bilateral transfer can be used to enhance prosthetic limb control and minimize rejection; and (c) a voluntary closing terminal device has some advantages relative to a voluntary opening device.

In this paper, we provide an overview of some of the problems in the field of prosthetics and how our work is designed to address these problems. We point out that a major problem in this field is getting the new user to accept the prosthesis and to use the prosthesis in a number of functional motor tasks. Unfortunately, the high rejection rate of new users of the upper-extremity prosthesis continues to be a major problem. In addition, we will point out, as others in the field have noted, that prosthesis training for occupational and physical therapists is inadequate. We believe our work can potentially address this problem as well. Furthermore, there is little known about the motor control strategies of the prosthesis user across

Stephen Wallace, David Anderson, and Michael Trujillo are with the Department of Kinesiology at San Francisco State University. E-mail: Saw@sfsu.edu. Douglas Weeks is now with the Inland Northwest Health Services in Spokane, WA.
different areas of the workspace and across different tasks. Finally, little is known about the learning process, namely, how does a novice become a proficient and confident prosthesis user? Our aim has been, and continues to be, unraveling the processes that underlie the control and learning of different tasks that require reaching, grasping, transporting, and releasing objects, as well as the modulation of grip force. In this paper, we describe our work to date in these areas, emphasizing the use of a simulated prosthesis that has undergone several iterations over the last few years.

The notion that a simulated upper-extremity prosthesis might be a useful tool for research and a training tool for both therapists and PWAs is not new. Bittermann (1968) described such an appliance that, at the time, was apparently an integral part of medical training at the Maine Medical Center in Portland, Maine. This type of device can be found today in a few occupational therapy training programs, but we believe that its use in occupational or physical therapy curricula is minimal. This is surprising given the conversations we have had with several occupational therapists, prosthetists, and PWAs who feel strongly about its potential as a training tool. As Bitterman has argued, a simulated prosthesis can be used to help train physical and occupational therapists on the operational control of upper-extremity, body powered prostheses as well as providing insight into the physical and psychological challenges faced by the PWA. It could be useful to parents of children with amputations in sensitizing them to difficulties in operating the device. Bitterman speculated that the PWA might use the device on his/her sound side while awaiting fabrication of the actual prosthesis to gain insight into its use. This interesting idea serves as basis for some of our work on transfer of training to be described later. Thus, we are suggesting that the simulated prosthesis is an excellent tool for (a) investigating the learning of prosthetic control, (b) helping to train occupational and physical therapy students, and (c) initiating the training of people with recent amputations who are awaiting the fitting of their actual prosthesis.

The Rejection Rate of Upper-Extremity, Body Powered Prostheses

It is estimated that there are nearly 100,000 people with upper extremity amputations in the United States (LeBlanc, 1988; Atkins, 1989) and a similar number per capita in Canada (E. Lemaire, personal communication, October 11, 2002). In addition, most upper extremity amputations are below elbow, with a greater percentage of people with amputations using body powered artificial limbs, compared to externally powered prostheses such as myoelectrically controlled devices (D.S. Childress, personal communication, 1987; LeBlanc, 1988; Meier, 1992; Brandt & Pope, 1997). The latter point suggests that cost is an important issue in the choice of a prosthesis. Voluntary opening upper extremity prostheses are generally preferred over voluntary closing (e.g., Davies, Friz, & Clippinger, 1970). However, a major advantage of voluntary closing prostheses may be the ability to regulate grip force.

Unfortunately, there is an unusually high rejection rate of upper extremity prostheses (some estimates are as high as 50%) where rejection is typically defined as no or minimal use of the prosthesis by a person with an amputation during
activities of daily living (Burrough & Brook, 1991; Meier, 1992). A number of reasons for this high rejection rate have been cited (Burrough & Brook, 1991), but one of the more important contributing factors is the time between the amputation and the actual fitting of the prosthesis. The longer this time period without adequate training, the greater the chances of prosthesis rejection by the PWA. The advantages of early fitting, such as reduction of post operative pain, control of post surgical edema, early use of the prosthesis, early psychological adjustment to the disability, reduction of hospital time, and hopefully, higher rate of prosthetic acceptance, have been recognized for some time (Childress, Hampton, Lambert, Thompson, & Schrodt, 1969; Wilson, 1970).

Another factor is the type of training provided once fitting is accomplished. It is generally recognized that while the cable harnessing system of an upper-extremity body-powered prosthesis is relatively simple in design, it is nonetheless a difficult system to master by a person with an amputation (e.g., Meredith, Uellendahl, & Keagy, 1993). Some time ago, McKensie (1970, p. 331) said, “Learning to use an arm prosthesis never comes instinctively and its effective use is an acquired skill (italics ours), so much so that (when) no worthwhile return in the way of function is apparent to the user, rejection may result.” In fact, some occupational therapists claim that a large percentage of people with amputations lack the motor coordination necessary to effectively operate the device (C. Brammel, personal communication, 1994). To empirically determine the initial difficulty of using an upper-extremity prosthesis, we evaluated novice prosthetic users engaged in a reaching and grasping task using the simulated prosthesis (Wallace et al., 1999). The task required the participants to reach forward, grasp a small Fiberglas dowel, and place the dowel in a finishing hole. An analysis of movement time showed that novice prosthetic users were nearly three times as slow and much more variable in completing the motor task compared with their anatomical hand.

In a classic paper on the biomechanics of upper extremity prosthetic control, Taylor (1955) emphasized that “Too often there is a tendency to put undue faith in the marvels of the mechanism alone, when in fact it is the man-machine combination that determines performance.” Wilson (1970) also acknowledged that the time required for training depends, in part, on the degree of coordination of the patient. Our work to date suggests that the simulator may be used in innovative ways during the important time between amputation and fitting of a prosthesis to not only better familiarize the PWA with the prosthesis, but to also enhance the learning process itself (e.g. Bitterman, 1968).

Prosthetic Training for Therapists

In addition to practical concerns about the rates at which prostheses are rejected, others have been troubled by the inadequate prosthetic training of therapists, physicians, and surgeons. For example, Meier (1992) has remarked “... there probably is no therapist available who has had more than a few hours of classroom instruction in how to train the amputee to use this device (prosthesis)...” (p. 27). Similarly, a study on the curricula of every occupational therapy training program in the country by Atkins (1992) found that most of the teaching experience in prosthetics (and orthotics) is spent in lectures, laboratories,
viewing video tapes and listening to visiting speakers, and, therefore, little opportunity exists for the student to work directly with a patient being fitted with a prosthesis. As a result, the therapist does not have the opportunity to see the common problems experienced by the PWA and therefore cannot develop the observational skills to detect the causes of performance errors and provide feedback to correct them (a process recognized as critical for motor learning, e.g., Magill, 2004). One factor that has likely contributed to this situation is that relatively few numbers of upper extremity PWAs live in a given community, making it difficult for a student therapist to routinely work with a PWA who uses a prosthesis. We suggest that innovative use of simulators in physical and occupational therapy curricula could facilitate the training of student therapists. These strategies could include the use of the simulated prosthesis in the classroom to familiarize occupational/physical therapy students with the mechanics of the prosthesis and sensitize them to the difficulties and challenges faced by the person with an amputation who uses a prosthesis.

Control of Upper-Extremity, Body-Powered Prostheses

Unfortunately, there is little published work on the strategies used by experienced users of upper-extremity body-powered prostheses. Some studies have compared patterns of use between body-powered and myoelectric prostheses or between voluntary opening and voluntary closing prostheses. Fraser and Wing (1981) compared anticipatory grip formation of a prosthetic hand of a PWA to her sound side, and Gilad (1985) evaluated the time required to reach, move, position, and release objects by a group of people with amputations using two types of prehensors relative to a group of non-amputees using their anatomical upper-extremities. Others have determined the time taken to complete certain functional tasks for evaluating prosthetic performance (Kay & Peizer, 1958; Lamb, Dick, & Douglas, 1988; Stein & Walley, 1983; Wallace et al., 1999) and a handful of studies have compared the range of motions of myoelectric versus body-powered prostheses (e.g., Stein & Walley, 1983). Differences in shoulder and elbow behavior in unconstrained functional tasks and a constrained crank turning task using myoelectric prostheses have been shown (Popat et al., 1993). Popat et al. acknowledged the contribution of other body segments in accomplishing the movement tasks and recommended further research on the training of people with amputations in both constrained and unconstrained tasks. Recently, we performed a biomechanical analysis of the relative body motions of an experienced prosthetic user (Wallace, Weeks, & Foo, 2000). This work confirmed that patterns of coordination exist between several of the relative body motions as described by Atkins (1989). However, little is known about how these coordination patterns are learned over extended practice periods. Another area about which very little is known is the control and learning of grip force. The recent surge of interest in grip force control with the anatomical hand (see Johansson, 1996, for a review) could provide important insights into how this skill is accomplished by the prosthetic user. We intend to take advantage of the protocols recently developed to investigate anatomical hand functioning in our experiments on grip force control with a prosthesis.
Simulated Upper-Extremity Prosthesis for Research and Training

Over the last several years, we have developed several versions of a simulated prosthesis that mimics the capabilities of PWAs with different residual limb lengths using standard upper-extremity prostheses. The simulated prosthesis consists of a figure-9 harness fitted around the shoulder contralateral to the prosthesis (see Figure 1). In the most recent version of the prosthetic simulator, the harness is attached to a cable that runs across the back and upper-arm ipsilateral to the simulator and into a leather humeral cuff on the proximal portion of the simulator. From the humeral cuff, the cable runs the length of the simulator to interface with a Grip3 voluntary-closing (TRS Inc., Boulder, CO, model STG300) or voluntary opening prehensor identical to a regular terminal device (TRS Inc., Boulder, CO, model STG300). A Fiberglas frame was fabricated to represent the forearm portion of the prosthesis. To don the simulator, the participant first places the contralateral limb through the harness and then slips the forearm through the Fiberglas frame and into a stretchable nylon glove mounted within the frame, placing the hand just proximal

Figure 1 — A non-amputee participant using the original version of the prosthetic simulator.
to the terminal device. Placement of the hand in the glove disallows motion of the wrist to contribute to simulator movement.

Much effort has been devoted to developing a device that resembles an actual prosthesis in both fitting and function. We recognize that one limitation of the current simulator is that the terminal device, due to extra length of the individual’s hand, is located more distally compared to a normal prosthesis. We view this as a minimal limitation since the function of the prosthesis is not affected by this small length difference. Therefore, much can be learned about upper extremity prosthetic limb control from the simulated prosthesis. We are confident that findings from our current and future work will be useful in the development of training principles that could be incorporated into the training of both therapists and PWAs.

Learning How to Control the Prosthesis

In addition to the lack of research on how relative body motions are controlled during prosthetic manipulation, virtually no research exists on how this control emerges during the learning process, which is surprising given the multitude of functions human hands play in peoples’ everyday lives. Therapists use a number of training procedures to help familiarize a PWA with a newly fitted prosthesis and to help train the individual (e.g., Atkins, 1989) but the training procedures are based largely on educated guesses rather than empirical data. An early paper by Richardson and Lund (1959) documented a training procedure for children with amputations. They indicated that the child must be carefully led through several steps of learning how to control and coordinate upper extremity prostheses: (a) familiarization, (b) simple body motion demonstrations, (c) body control motion drills, (d) bilateral coordination training, (e) prehension and grip force control, (f) practice with ADL tasks, and finally, (g) independent performance without directions. Unfortunately, the training procedure is described without supporting data on either performance outcomes or movement quality. Shaperman (1960) speculated that the stages of learning of both normal and prosthetic prehension might be similar in children, but no actual research was reported. Meredith et al. (1993) reported the inability of two 2-year old children to voluntarily grasp and release objects even after 12 months of use with an upper-extremity, body-powered prosthesis! More success was apparently shown with a myoelectric device, but once again, no actual training data were reported. Atkins (1989) elaborated on an upper-extremity prosthetic training program for people with amputations used by occupational therapists; however, actual performance measures on the patients were not reported. A recent study by Lake (1997) showed that training with a prosthesis significantly increases functional use of the prosthesis as evaluated by pre and post training tests. However, no information was provided on the progression of the learning process, and blinding was not used to alleviate potential problems due to rater bias.

Thus, in contrast to the well-documented field of motor skill learning (see Magill, 2004, and Schmidt & Lee, 1999 for excellent reviews of variables that affect motor learning), which deals almost exclusively with people who do not have disabilities, the field of rehabilitation knows little about the performance and learning of upper-extremity prosthesis control. These past two years, we have made considerable progress addressing this issue. In an attempt to rectify this void in the literature on training routines, our efforts have examined two motor learning
principles for their application to training a prosthetic user to perform functional tasks with the prosthetic simulator.

Bilateral Transfer With an Upper-Limb Prosthetic Simulator

When humans learn a unimanual motor skill, the skill is typically subsequently performed with the preferred limb. However, there are instances in which the nonpreferred limb may be required to perform the task. The proficiency with which the nonpreferred limb performs the task gives rise to a question of theoretical and practical importance: Is the functional competency that was established through unimanual practice specific to the limb that was trained, or can the ability to produce the learned response be generalized so that the unpracticed contralateral limb has the capability to produce the response proficiently? This latter possibility has been long-supported by research with able-bodied individuals illustrating improved performance by an unpracticed limb following acquisition of the action with the contralateral limb (Cook, 1936). Performance improvement in the unpracticed limb following practice with the contralateral limb has been termed bilateral transfer of skill. The typical bilateral transfer experimental paradigm assesses pretest to posttest gains in an unpracticed limb as a function of intervening practice with the opposite limb. Transfer of functional competence across limbs has implications for rehabilitation following unilateral upper-extremity amputation when a preferred limb may not be available to perform a well-learned unimanual task. In the period of time prior to beginning to use the prosthesis, or as an adjunct to practice with the prosthesis, it is possible to fit the intact limb with a prosthetic simulator (Wallace et al., 1999) that mimics the control functions of the actual prosthetic device (See Figure 1). The person with an amputation may then practice with the prosthetic simulator on the intact limb to encourage formation of functional competency that may be transferred to the residual limb once practice with the actual prosthesis is initiated. Thus, practice soon after the amputation may be designed to promote bilateral transfer to the residual limb when use of the actual prosthetic device is initiated.

We recently published a study (Weeks, Wallace, & Anderson, 2003) examining bilateral transfer for several complex tasks that required subjects to learn to perform prehension skills with the simulator. Subjects performed three tasks at various points in the three-dimensional workspace that required manipulation of a variety of objects: a fine aiming task, an object transport task, and a switch toggle task. Able-bodied subjects (n = 42) were randomly assigned to one of three groups: a group that practiced with the simulator on the preferred limb and then transferred it to the nonpreferred limb, a group that practiced with the simulator on the nonpreferred limb and then transferred it to the preferred limb, or a control group. The two transfer groups underwent pretest trials, acquisition practice, posttest trials, and a 24-hour retention test, while the control group followed the same design with the exception of acquisition practice. The primary outcome measures were initiation time (IT: time elapsed from a signal to move until movement began) and movement time (MT) to perform the tasks. The results showed that both transfer groups significantly reduced IT and MT across all tasks from pretest to posttest and from pretest to retention test compared to the control group. Thus,
bilateral transfer was evident for movement initiation capability (represented by IT) immediately on transfer, and it persisted to the retention test. Transfer of movement execution ability, represented by MT, occurred after a period of time in which consolidation of learning was complete. We concluded that training unilaterally with a prosthetic simulator enhanced the ability of the unpracticed limb to operate the terminal device of a prosthesis in a temporally and spatially skillful manner. This finding has implications for rehabilitation of the individual with a unilateral upper-extremity amputation in that the time required to learn to use a prosthetic device may be decreased by using a bilateral transfer training paradigm. This type of training could allow a person with a recent amputation to practice functional skills with a simulator on the sound arm so that once the individual is fitted with an actual prosthesis, partial proficiency may be expected due to transfer of skill from previous practice with the simulator.

**Enhancing the Ability to Use an Upper-Extremity Prosthesis**

A contemporary perspective in motor learning research suggests that both retention and transfer of motor skill can be enhanced if active, effortful, problem solving is encouraged during the practice session. In essence, creating difficulty for the learner can enhance learning, even though such difficulty is often associated with poorer practice performance and a slower rate of improvement on the task or tasks. A classic illustration of this phenomenon is the contextual interference (CI) effect, where random practice of multiple task variations depresses performance during practice but facilitates performance in retention and transfer relative to a blocked practice schedule in which all of the practice on one task is completed before practice on the next task is initiated. Thus, the random practice schedule creates high contextual interference and such interference is beneficial for learning.

While there is reasonably strong support in the literature for using high contextual interference to facilitate the learning of laboratory tasks (and some sports tasks) in able-bodied individuals (Brady, 1998; Magill & Hall, 1990), the efficacy of the CI effect had not been examined for activities of daily living that might be practiced in a therapeutic setting until recently (Weeks, Anderson, & Wallace, 2003). The purpose of the Weeks et al. study was to contrast two different practice schedules for learning to use an upper-extremity prosthetic simulator with a voluntary-close terminal device. The intent was to determine an efficient practice schedule for learning to perform prehension skills that could be employed by people learning to use an actual prosthesis following amputation. Participants \((n = 48)\) were randomly distributed into two groups for skill acquisition training: those that practiced three different prehension tasks with the simulator in a random practice order or those that practiced the three tasks with the simulator under a blocked practice order. The three tasks practiced in acquisition were a rod-and-nut manipulation task, a pipe transport task, and an electrical plug insert task. During acquisition, the groups practiced the three tasks on two consecutive days. On the third day, two different tests of learning were administered: a retention test and an intertask transfer test. In the retention test, each of the same tasks practiced in acquisition were performed, while the intertask transfer test required participants to perform three new tasks chosen as analogs to the three tasks practiced in acquisition: a simulated feeding task, a sphere transport...
task, and a padlock opening task. The primary outcome measures were initiation time (IT: time elapsed from a signal to move until movement began) and movement time (MT) to perform the tasks. Both the random and blocked groups showed significant improvement in IT and MT to perform each task across the two days of acquisition. Thus, structured practice, regardless of degree of “randomness” inherent in the schedule, promoted functional use of the prosthesis. Both practice schedules were equally effective for promoting skill retention when the tasks performed were the same tasks practiced in acquisition. However, in intertask transfer, the random acquisition group demonstrated significantly greater proficiency in performing the new tasks than did the blocked acquisition group. Thus, individuals learning to use an upper-extremity prosthesis may better be able to transfer skill to new prehension tasks by practicing under random practice conditions. These findings have practical implications for structuring practice for individuals learning to use an upper extremity prosthesis. Because it is impossible for an individual with a recently-acquired prosthesis to practice all of the tasks necessary for daily living in therapy, the early practice context for learning to use the prosthesis functionally should focus on a task-oriented, nonrepetitive schedule, such as random practice, in order to facilitate transfer of learning to other tasks with similar qualities.

Assessing How Precision Grip Force Control Is Learned by the Prosthetic User

Our studies described so far have indicated that motor learning principles shown to influence learning of able-bodied individuals performing laboratory tasks can also be employed successfully to assist a prosthetic user with becoming skilled at using the prosthesis. These studies used spatial and temporal proficiency as outcome measures. Another aspect of skilled performance with a prosthesis that has not been extensively explored is that of grip force control. Becoming skilled at controlling grip force at the terminal device would certainly be an aspect of proficiency that could reduce frustration on the part of the prosthetic user, thereby increasing the potential for long-term use of the prosthesis.

We have recently completed two experiments that examined the differences in variability and error while attempting to produce static grip force with two opposing types of terminal devices. The first experiment was a case study analyzing how accurately a 38-year-old quadruple congenital amputee, who had been a VO user since beginning to use his body powered upper extremity prosthetic limbs as an infant, scaled grip force (Wallace, Connor, Trujillo & Anderson, 2003). However, our participant was asked to perform the task with a VC prehensor (which he had never used before), in addition to his VO prehensor. The experimental design thus consisted of two prehensors (VO and VC), two force parameters (high force = 10.5 newtons and low force = 0.49 newtons), two position parameters (a distal and proximal workspace-like positions) and two vision conditions (one with vision, the other without vision). Despite nearly 38 years of training with the VO, this participant was less variable with the VC prehensor while producing the high force level parameter and was also less variable while performing in the no-vision condition. The participant produced less error with the VC (compared with his own VO prehensor) in all conditions, a truly remarkable finding.
The second experiment examined the difference in variability and error while attempting to produce static grip force using the prosthetic simulator and two opposing types of terminal devices (Wallace, Trujillo, Connor, & Anderson, 2004). Ten able-bodied participants volunteered to take part in the experiment. The experimental design consisted of three effectors (VO, VC, and anatomical hand), three forces parameters (high = 10.5N, medium = 4.0N, and low = 0.49N), and two vision conditions (with vision and without vision). An analysis of variability and error revealed that the VC was less variable and more accurate than the VO for the low and medium force parameters. The VC closely followed the same trend as the anatomical hand for all conditions. These results tend to support our hypothesis that in many grip force tasks, the VC prosthesis offers some advantages to the user because of muscular effort-grip force compatibility (De Visser & Herder, 2000; Murphy, 1964; Plettenburg & Herder, 2003; Radocy, 1986). Specifically, to increase grip force output for the VC, the user must increase voluntary muscular force to increase cable tension, thus closing the prehensor. This type of control is consistent with anatomical hand function. However, with the VO device, to increase grip force of the prehensor, a decrease in voluntary muscular force is required. This type of control has been called counterintuitive by the above authors and, according to our hypothesis, will likely result in less accurate and more variable performance. The muscular effort-grip force compatibility hypothesis bears resemblance to the effects of stimulus-response incompatibility where greater movement preparation time is usually required relative to situations where the spatial relations among stimulus and response are compatible (e.g., Proctor & Reeve, 1990). Our results also have some commonality with the generally positive relation between force production and force variability found in rapid movements, as outlined in the impulse variability hypothesis (see Schmidt & Lee, 1999). However, in our experiments thus far, the target forces require sustained muscular effort over several seconds, and not rapid bursts of activity. Finally, our preliminary results reveal that the VO terminal device, while being useful for holding and transporting objects, may be less than desirable in those tasks requiring grip force modulation. Regardless of the terminal device, however, it is likely that considerable training is necessary to learn how to modulate grip pressure using a prosthesis.

While there has been a relatively large body of work published on precision grip force control (grip of an object between the distal aspects of the thumb and forefinger) in the anatomical hand (see Johansson, 1996, and Forssberg, 1998, for reviews), little is known about the regulation of grip force in a body-powered prosthesis for experienced users, and virtually nothing is known about how quickly control of grip force is learned. The issue of regulation of grip force is particularly relevant given that the fingers of an anatomical hand have a very large representation in the sensory and motor areas of the cortex, whereas the chest and shoulder, which are the anatomical control structures for a body-powered prosthesis, are poorly represented in this area of the brain and are not areas with high sensation capabilities. Thus, it is not clear whether regulation of precision grip force at the terminal device can be controlled with the same degree of finesse as that seen in the anatomical hand, even though we suspect the VC prosthesis is better designed for achieving this type of control.

For the anatomical hand, several studies have shown that characteristics of the object, such as object size, surface texture, and composition, subconsciously
influence the amount of grip force that will be generated to lift the object (e.g., Gordon, Forssberg, Johansson, & Westling, 1991; Johansson & Westling, 1988). We propose to examine four aspects of precision grip force control in prosthetic users previously examined in the anatomical hand: adaptation of grip force to the weight of an object to be lifted, adaptation of grip force to the texture of an object to be lifted, anticipatory changes in grip force applied to an object held aloft as the load requirements of the object is increased, and finally, the ability to accurately produce a desired grip force. These conditions will be examined in experienced and inexperienced prosthetic users to determine (a) whether experienced users use grip force control that is similar to that of the anatomical hand, and (b) the time course by which inexperienced users begin to exhibit grip force adaptations that are similar to the anatomical hand.

In addition to answering basic theoretical questions about the influence of long-term experience and the ability to learn grip force control, it is anticipated that our future work will have immediate practical application. The results will be useful to therapists and persons with amputations by providing them with data upon which realistic expectations about the rate of learning various aspects of prosthetic control can be gauged. In addition, therapists may be able to employ the training protocols used in each study to develop innovative strategies to help persons with recent amputations adjust to their disability, hopefully accept an upper-extremity prosthesis, and reduce the time required to develop effective grip force control with the prosthesis.

Summary

The rejection rate of upper extremity, body controlled prostheses is unusually high and not enough is known about how the control of these types of prostheses is learned or what strategies can be used to train therapist to address this situation. Currently, there is a paucity of evidence upon which clinical practice can be based, as even the most common rehabilitation interventions and procedures have not come under scientific scrutiny. Yet, it is generally recognized that rehabilitation practice and the field of prosthetics must shift to a paradigm based on scientific evidence if the needs of Americans with disabilities are going to be met adequately and cost effectively in the 21st century (Brandt & Pope, 1997). Our research program represents a continued attempt to respond to this challenge.

References


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