

Benefits and use of myoelectric arm prostheses
- outcomes, influencing factors and experiences

Dedication

To all patients and clinicians in prosthetic rehabilitation

Örebro Studies in Medicine 241



CATHRINE WIDEHAMMAR

**Benefits and use of myoelectric arm prostheses
- outcomes, influencing factors and experiences**

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Abstract

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People with acquired upper limb loss or congenital limb reduction deficiency are often offered a myoelectric prosthesis to compensate for the missing hand. A common problem is the non-use of prostheses, and lack of training has been suggested as a reason for this. Today, myoelectric prosthetic hands are available with multiple grips to benefit the users, but these benefits have yet to be confirmed in daily activities.

The overall aim of this thesis was to gather empirical evidence about the benefits and use of myoelectric arm prostheses, by investigating and describing the environmental factors influencing prosthesis use, describing a training method for the use of multi-grip prostheses and evaluating the effect of multi-grip hands in daily activities. The users' experience of environmental influences on prosthesis use were investigated in a survey (study I) and an interview study (study II). A scoping review of training methods for the use of multi-grip prostheses (study III) showed that training instructions are few and none were described in detail. Therefore, a new method for training, STAIR, was developed and described (study IV). This method was used when we investigated the benefits of multi-grip hands in a clinical trial (study V). We found that, after a period of structured training, users found the multi-grip prostheses beneficial for performing their daily activities and reducing their pain-related disability, and they reported an increase in prosthesis wearing time.

In conclusion, prosthesis users experience most environmental barriers from the physical environment and from the prosthesis itself. Positive environmental factors, such as training and support from health care professionals, facilitate their adaptation to the prosthesis. When a prosthesis feels like a part of the user, the negative impact from the surrounding environment decreases. With a structured training method, it is possible to learn how to operate a multi-grip prosthesis and use it in daily activities.

Keywords: upper limb, amputation, artificial limbs, rehabilitation, occupational therapy, environment, qualitative methods

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LIST OF PUBLICATIONS

This thesis is based on the following five papers, which are referred to in the text by their Roman numerals:

- I. Widehammar C, Lidström H, Hermansson L. Environmental barriers to participation and facilitators for use of three types of assistive technology devices. *Assist Technol.* 2019;31(2):68-76. doi: 10.1080/10400435.2017.1363828.
- II. Widehammar C, Janeslätt G, Pettersson I, Hermansson L. The influence of environment – experiences of users of myoelectric arm prosthesis, a qualitative study. *Prosthetics and Orthotics International* 2018, Vol. 42(1) 28 –36.
- III. Widehammar C, Lidström Holmqvist K, Hermansson L. Training for users of myoelectric multi-grip hand prostheses – a scoping review. Submitted.
- IV. Widehammar C, Lidström Holmqvist K, Eriksson K, Hermansson L. Stepwise Training for Users of Multi-grip Prosthetic Hands – An Occupational Therapy Method. Submitted.
- V. Widehammar C, Lidström Holmqvist K, Hioshi A, Lindner H, Hermansson L. Multi-grip prosthetic hands have positive effects on users' daily activities, pain and prosthesis use compared to single-grip myoelectric prostheses – a multiple baseline single-case study. Submitted.

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PREFACE

My clinical experience as an occupational therapist in the field of hand rehabilitation has taught me that, for most people, well-functioning hands are a prerequisite to be able to live an active and independent life. However, after I started working at the Limb Deficiency and Arm Prosthesis Centre at Örebro University Hospital, I realized that people can also live active and independent lives without hands. The children I meet at the clinic who were born without hands are amazing at finding ways to be active and perform different activities just like their friends, but with their own way of doing it. Some bimanual activities can still be hard to perform without two hands, and therefore, our clinic offers various types of assistive technology devices to enable all patients, both children and adults, to be independent and to feel that they can be involved in society like anyone else. One of the most ingenious assistive technology devices that we frequently offer is the myoelectric hand prosthesis. Since the prosthesis is worn on the body, it is always ready to be used when a grip function is needed for any activity. The user's hand function can, in principle, be compensated with a myoelectric prosthesis, but I have also realized that many prostheses are never used. They have limitations related to comfort, design and function. The leading technicians and engineers at the prosthetic companies are trying to develop the functionality of their prostheses; they have their own ideas about what could be useful, and their ideas may not always correspond with what prosthesis users want and need. I felt it was important that someone should listen to the users, to their experiences and their wishes. Thus, the starting point of my doctoral research was to interview prosthesis users.

My work continued at the clinic as prostheses with more advanced multi-grip functions became available. They are expensive and their usefulness has been questioned. When we started to prescribe the multi-grip hands at the clinic, we wanted our patients to really learn how to use them and benefit from them. Even though we searched carefully, we did not find a sufficiently detailed training method to guide the patients, and this was the reason for the development of our own training method, STAIR. To gain more insights into the new multi-grip prostheses, we decided to evaluate their usefulness in a clinical trial. This thesis contains the users', clinicians' and researchers' collective knowledge about the benefits and use of myoelectric prostheses.

Cathrine Widehammar

INTRODUCTION

People with upper limb loss

All around the world there are people of all ages who are missing one or several limbs. Limb loss has a variety of causes, usually categorized as either congenital limb reduction deficiency or acquired amputation. This thesis focuses on people with upper limb loss in either category. All the included studies were conducted with adult participants, although many of them had had their limb loss since birth.

The extent of limb loss varies, and minor reductions of the limb, such as partial finger amputations are most common.¹ However, since this thesis is about the benefits and use of myoelectric prostheses, it only deals with people with major limb loss, for which the person can use a myoelectric prosthesis to compensate for the loss of a hand. A major limb loss may occur at different levels, usually described as transcarpal (hand or wrist level), transradial (forearm level), or transhumeral (upper arm level).¹ All three levels of major limb loss are represented by the participants in the included studies.

Congenital upper limb reduction deficiency

Approximately 50 children with congenital limb reduction deficiency are born every year in Sweden.² The earliest report of the birth prevalence of limb deficiency originated from the Swedish medical birth registry, with rates of 4.5 per 10,000 births with a single malformation.³ The prevalence rate has been stable since records began in Sweden, and the prevalence worldwide is similar. Other countries and continents report similar prevalence rates, for example Norway, Japan and Canada reported 4.15–5.6 per 10 000 births.⁴⁻⁶ They also reported, in agreement with other studies, a higher proportion of upper than lower limb defects (approximately 65% upper limb), and the right side is affected slightly more often than the left side. The size of the reduction varies, and small reductions are more common.

Congenital upper limb reduction deficiency (also called *congenital amputation*) may be the result of genetic factors, the constriction of fibrous bands within the membrane that surrounds the developing fetus (amniotic band syndrome), exposure to teratogenic substances or other, unknown, causes.⁶⁻⁸

Acquired upper limb amputations

Acquired upper limb amputations are rare in Sweden. Yearly in Sweden, approximately 4 per 100,000 inhabitants suffer an upper limb amputation, and most of them have small reductions.⁹ A distinction is made between *medical amputations* performed by a surgeon (caused by sepsis, tumours or circulation disorders) and *acquired amputations* caused by accidents. War injuries are acquired amputations that are rare in Sweden but they are the main reason for amputation in other parts of the world.¹⁰ As immigration to Sweden from war-torn countries has increased, the number of Swedish inhabitants with arm amputations may also have increased; certainly among the patients who attend our clinic for prosthetic rehabilitation, amputations caused by war injuries have increased during recent years.

Theoretical frameworks

Two theoretical frameworks form the basis of this thesis: the Canadian Model of Occupational Performance (CMOP),¹¹ and the International Classification of Functioning, Disability and Health (ICF).¹² In the first studies, I and II, the ICF definition of environment was used (see below). Further, the ICF forms the basis of both the outcome measures used in study I and the interview guide used in study II. The CMOP underlies the development of the person-centred and activity-focused training method in study IV. In study V, the CMOP inspired the outcome measure Canadian Occupational Performance Measure, COPM,¹³ which is used to compare two different types of prosthetic hands by evaluating the participant's occupational performance and satisfaction with performance. Further, the COPM was used to personalize the training offered to the participants in study V.

The International Classification of Functioning, Disability and Health

The ICF is a framework developed by the World Health Organization (WHO) to increase understanding of health and how different disabilities can impact a person's life. It describes functioning from the perspectives of body structure, activity and participation, in interaction with the surrounding environmental and personal factors. Health is defined by the WHO as a state of complete physical, psychological and social well-being, not only absence of illness or disability.

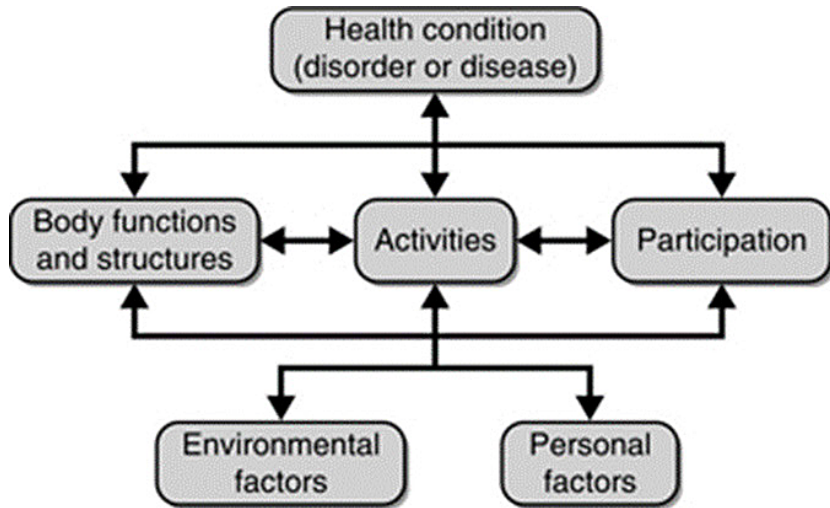


Figure 1. The International Classification of Functioning, Disability and Health model: interactions between ICF components (World Health Organization)

Here follows a short description of the ICF model from the perspective of a person with upper limb loss.

The body structure of a person with congenital upper limb loss or acquired amputation differs from a person born with two hands. But how does the loss of a hand impact a person’s health? For some people it has no impact at all, but for the majority of people with upper limb loss it impacts their body balance. Further, it increases the risk of musculoskeletal pain due to compensatory movements or overload in the existing hand.¹⁴

Activity restriction due to limb reduction can impact a person’s health. People who lose a hand in an accident immediately realize that many activities are hard to perform with only one hand. In the case of bilateral amputation, the limitations are even greater. Therefore, prostheses are often offered to compensate for the loss of hands and to enable activity performance.¹

People who are born without hands are used to compensating for this, and they often find strategies that enable them to live an active life without a prosthesis. Nonetheless, prostheses are commonly used by people with congenital upper limb loss, because bimanual activities can be hard to perform without two hands, and prostheses can prevent overload problems in the contralateral hand.^{15, 16}

Participation is complex and can be described both from the perspective of attendance and involvement.¹⁷ People with congenital or acquired limb reduction may not always participate on equal terms as people with two hands, as they may avoid bimanual activities that are hard to perform without two hands. A prosthesis or other assistive technology devices can facilitate participation in such activities at home, at work and in society.¹⁸

Personal factors such as self-confidence, self-esteem and coping strategies have great impact on the experience of good health. Upper limb loss is a visible disability, which can be experienced as stressful and stigmatizing, especially in social settings with new people.¹⁹⁻²²

The environment is something all people have to relate to, and how it is perceived is highly individual. According to the ICF model, the environment can be perceived as both hindering and facilitating. The model divides the environment into five different areas:

1. **The natural environment** (for example, climate)
2. **Products and technology** (for example, assistive technology, prostheses)
3. **Support and relationships** (for example, friends and family)
4. **Attitudes** (for example, other people's attitudes, societal attitudes)
5. **Services, systems and policies** (for example, laws governing the prescription of assistive technology)

If the environment is adapted in a facilitating way, people with disabilities may feel a complete physical, psychological and social well-being.¹² There is a lack of research into how the environment influences myoelectric prosthesis use.

The Canadian Model of Occupational Performance

The CMOP is a person-centred and occupation-focused occupational therapy model. The model describes the interaction between a person and the environment when performing activities. Within occupational therapy, activities are also called occupations.¹¹ The dimension of spirituality is also included in this model.

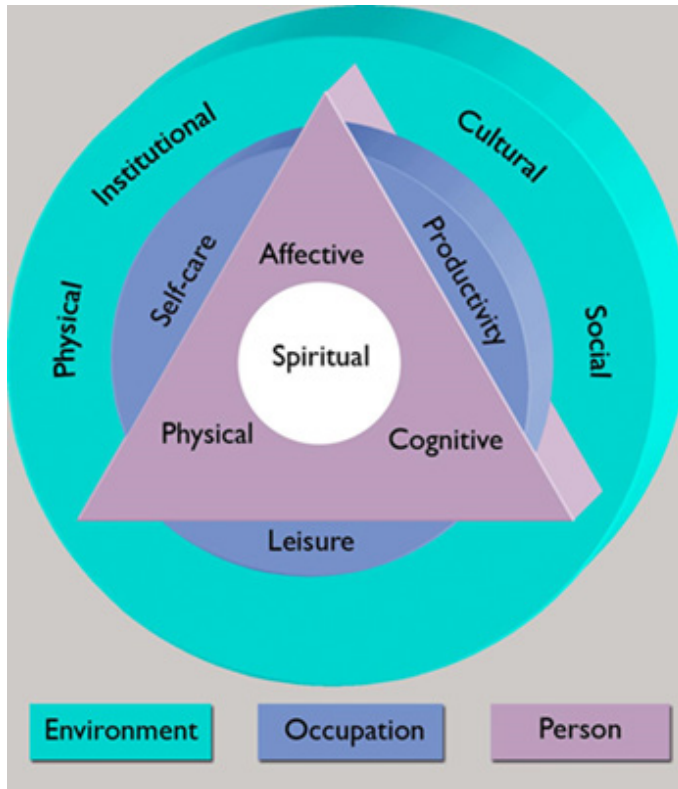


Figure 2. The Canadian Model of Occupational Performance (Townsend et al., 1997, 2002).

Spirituality influences personal beliefs and may also affect an individual's identity. For a person with upper limb loss, personal beliefs and identity may affect whether he or she feels disabled or not. Identity and beliefs can also affect a person's attitude to assistive devices and prosthesis use. Some

feel like their normal self when using a prosthesis²³, while others feels that using a prosthesis hides their true identity as a person with limb loss.²⁴ Furthermore, according to CMOP, a person's individual habits and roles affect what kind of activities (occupations) the person wants and needs to perform. The activities can be performed within the different areas of self-care, productivity or leisure. These activities are performed in a context and are strongly affected by the surrounding environment. The environment includes not only the physical aspect of environment, but also the institutional, cultural and social aspects of environment. For a person who uses a lower limb prosthesis, it is obvious that the physical environment may impact their prosthesis use.²⁵ The physical environment may also influence the use of upper limb prostheses, but this has not yet been confirmed in research studies. The institutional environment has a great impact on persons with upper or lower limb loss who want a prosthesis, since the prescription of a prosthesis is regulated by laws and policies.²⁶ The cultural and social environment influence, among other things, the extent to which people with upper limb loss feel accepted and included in society.²³

This conceptual model, CMOP, forms the basis of a goal-setting instrument that measures changes in the individual's activity performance over time, which is used by occupational therapists to ensure person-centred interventions. The instrument is named Canadian Occupational Performance Measure (COPM)¹³ after the conceptual model, and is validated and widely used across the world.²⁷⁻²⁹ The COPM was used in study IV and V to personalize the training, and in study V, the Swedish version of COPM^{27,30} was one of the outcome measures. For more details, see the Methods section.

Rehabilitation of people with upper limb loss

Congenital limb loss

For children who are born without one or both hands, prosthetic rehabilitation is an option that their parents have to decide on. It is recommended to start early, at the age of 6–8 months, with a passive prosthesis to familiarize the child with the prosthesis socket and to get used to the extension of the residual arm that a prosthesis brings.³¹ Around the age of three years, the child can have a prosthesis with an active hand.³² Training is required to learn how to use the prosthesis in everyday life. Once the child has learned how to control and use a prosthesis, the skill is for life; it is similar to learning to ride a bike. The contact with healthcare is usually lifelong, to get help and service with the supplied prosthesis.

Acquired amputation

To address all aspects of care in rehabilitation for people with acquired amputations, a team approach is required with multiple disciplines including medical, surgical, rehabilitation and prosthetic expertise. The multidisciplinary care team may for example consist of surgeons, certified prosthetists, a psychologist, physical therapists and occupational therapists.¹⁰ The consequences of arm amputation are often life-changing and depend on the level of amputation and hand dominance. All areas of life are affected: the family, social life with friends, interests and working life. For most people, losing an arm brings a great sorrow, and depression is common among people with upper limb amputations.^{33, 34} In traumatically amputated people, post-traumatic stress symptoms may occur. The psychological support from the interdisciplinary care team helps to deal with depressions and traumatic stress. Physical consequences following upper limb amputation include musculoskeletal pain, phantom limb pain and stump pain.³⁵ The person's body symmetry is changed and, over time, many people with upper limb amputation experience pain in the contralateral limb and trunk, due to compensatory movements.¹⁴ The loss of an arm may affect their balance, and the overuse of the contralateral limb is also a problem.^{15, 16} To restore body balance and relieve the contralateral limb or hand, the interdisciplinary care team offers prosthetic rehabilitation.³⁶

Moreover, a common wish from individuals with an acquired amputation is to replace the missing limb with a prosthetic hand. Before a prosthesis

fitting starts, pre-prosthetic rehabilitation with oedema management, limb shaping, desensitization and pain management is needed. In addition, training of strength and range of motion is important to be able to bear the weight of a prosthesis. Prosthetic fitting within one to three months, or as soon as possible after amputation, is recommended.¹⁰ When a prosthesis with a suitable socket has been made, the prosthetic training starts. A person who is newly amputated needs a lot of training, first just to bear the weight of the prosthesis and to integrate the prosthesis into his or her body structure, in other words, to wear it in a natural way. Training continues with controlling the prosthesis functions, and learning to use them in daily activities.^{36, 37}

Prostheses

Different types of prostheses

Depending on the user's level of amputation (transcarpal, transradial or transhumeral), the prosthesis will have a different number of parts, such as an elbow, a wrist and a terminal device (the prosthetic hand).^{37, 38} The different control systems in combination with different hands constitute five main groups of commonly used prosthetic hands.³⁷

1. Cosmetic or passive functional
2. Body-powered or cable-driven
3. Electrically powered (myoelectric or switch control)
4. Hybrid (combination of body-powered and electric)
5. Activity-specific (designed for a specific task, such as skiing.)

The three prosthetic hands that are most commonly used at our clinic can be seen in figure 3. The main focus in this thesis is on the myoelectric hands.



Figure 3. Three of the most commonly used prostheses in our clinic. From the left side a cosmetic prosthesis, a myoelectric controlled prosthesis and an activity-specific prosthesis designed for skiing.

Myoelectric-controlled prostheses

The name myoelectric prosthesis originates from the control system used. The most common system is two-site control, which consists of two electrodes, one for the extensor muscle and one for the flexor muscle.³⁹ The muscles are used to control the electrically driven hand. By contracting the muscle of the residual limb, the electrical signals in the muscle are captured by the electrodes in the prosthesis socket. The electrodes identify the muscle contractions and activate a motor that can open or close the prosthetic hand. The conventional myoelectric prosthetic hand can open and close the

hand by moving the thumb away from or towards the index finger and middle finger. This function enables the user to grasp objects. With some practice, the user learns how to control the speed and the grip force, and the prosthetic hand can be used almost as easily as a real hand. The standard myoelectric prosthesis is the most commonly used prosthetic hand in high-income countries.³⁸ This simple technology is now also referred to as a single-grip hand since the development of more advanced technology with multiple grip functions.³⁸ See figure 4 for examples of single-grip and multi-grip hands.



Figure 4. To the left a single-grip prosthetic hand with three moveable fingers, also shown with its protective inner sleeve. To the right a multi-grip prosthetic hand with five moveable fingers, shown with and without a cosmetic glove.

Multi-grip hands

The more advanced myoelectric prosthetic hands have various grip functions and can move all five fingers. These prosthetic hands have several designations, including multifunctional hands, multi-articulated hands, advanced myoelectric hands and hands with multi-grip functions. In this thesis they will be referred to as multi-grip hands. In these hands, the thumb can be used in either the opposed or non-opposed position, which enables a more ergonomic movement pattern for the user.⁴⁰ The different positions of the fingers further enable the user to perform tasks requiring fine motor skills, which the standard single-grip hand may be too clumsy to perform. Multi-grip hands are designed either to look more natural or to look more robotic, in accordance with different users' wishes. Despite the improved functions compared to the simpler single-grip hands, the usability of multi-

grip hands in daily life has not been confirmed.⁴¹⁻⁴⁴ Thus, more studies are needed to establish the benefits and use of myoelectric multi-grip hands.

Multi-grip hands can be operated by the same two-site electrode system as the conventional single-grip hands, but increased cognitive load has been reported as a disadvantage.⁴⁵ A system that uses several electrodes to operate the hand, called pattern recognition, was developed to decrease this cognitive load and simplify control of the hand⁴⁶ but, so far, pattern recognition systems are very expensive, and too expensive for general use. Furthermore, the pattern recognition system requires extra space in the prosthesis socket, which is sometimes lacking, depending on the user's residual limb length. There have been suggestions that only a pattern recognition system can enable optimal use of hands with multi-grip functions and that conventional two-site electrode control is insufficient;⁴⁷ however, this has not been borne out in research studies.

Use of upper limb prostheses

There are various reasons for people to use an upper limb prosthesis. Some people only care about its functionality, while others want both a nice appearance and useful function in a prosthesis. For some people, appearance is most important and they often choose to use a cosmetic prosthesis with a passive hand. Although the fingers cannot be moved, the hand can still be very useful as support and assistance. Furthermore, the length and weight of a passive prosthesis improves balance and posture. The appearance of a passive or cosmetic prosthesis can also be very helpful for blending in, in social situations. Clearly, a prosthesis without functionality actually has many functions, and can therefore be called 'passive functional', as Johnson and Mansfield categorized the passive prosthetic hand.³⁷

Most people with upper limb reduction want a grip function and use a prosthesis with an active hand. However, some users of a prosthesis with a grip function only wear the prosthesis as a passive hand, without taking advantage of the functionality. It is not obvious that this can be classified as using the prosthesis, since the grip function is not used. Similarly, there are users who have the new multi-grip prostheses and do not use the multi-grip functions.⁴⁷ In conclusion, *use* is a complex concept with individual variations and may thus best be defined by the individual users themselves.

Embodiment

Embodiment has been described as the integration of a device, such as a prosthesis, into the user's body representation, meaning that the user feels that the device is a part of his or her body.⁴⁸⁻⁵⁰ Another looser interpretation of embodiment is the acceptance of a device, which encompasses the feeling of owning, controlling and locating the device without the need to constantly look at it.⁵¹ This means that the embodiment of the prosthesis enables an intuitive and natural use of the prosthetic hand. Both upper and lower limb prosthesis users have reported embodiment,⁵² which may be an indication of optimal use of a body-worn assistive device. Users of other kinds of assistive technology devices have also described the experience of embodiment. For example, people who use powered wheelchairs have reported that the wheelchair feels like their legs.^{52,53} Rehabilitation (training to use the assistive technology device) is facilitated by embodiment of the device, and there have been several attempts to demonstrate the phenomenon. In one laboratory study, a person with transradial upper limb amputation demonstrably experienced embodiment of a physical arm prosthesis, with the help of visible motor control, visible tactile feedback and visible prosthesis control.⁵⁴ Since embodiment demonstrably exists and has an impact on the use of prostheses and other assistive technologies, the prescription process should perhaps include embodiment in some way.

Assistive technology

A commonly used definition of assistive technology is provided by the International Standards Organization.⁵⁵ According to this definition, assistive technology can be any product, especially produced or generally available, that is used to maintain, increase or improve the functional capabilities of individuals with disabilities. This thesis focuses on advanced electronic technology devices, and the main focus is on myoelectric hand prostheses. In the first study, two other advanced electronic technology devices were included: powered wheelchairs and electronic planning devices. They all have in common that they are technically advanced and need information and training for optimal use.

Many people with disability are dependent on well-functioning assistive technology devices to enable their involvement in everyday activities, both at home and in society.⁵⁶ For people with disability, participation is therefore greatly dependent on the prescription of assistive technology

devices, but it is also critical that the devices work properly and that the recipients know how to operate them.^{57, 58}

The availability of assistive technology varies around the world.⁵⁹ In Sweden, most assistive technology devices are funded by the government, and the prescription process is regulated by laws and ordinances.⁶⁰ This means that many people in Sweden have access to assistive technology regardless of their financial status. The question is whether they use the technology, and if not, how this affects their opportunities to be active and participate in society.

Use of assistive technology

An assistive technology device has to be worth using, otherwise it will not be used.⁶¹ The benefit of such a device is thus strongly connected to its perceived usability. The usability of a product is defined by the International Standards Organization⁵⁵ as the extent to which a product can be used with effectiveness and efficiency to achieve specific goals with satisfaction in a specified context of use. Hence, the usability of an assistive technology device impacts the user's performance of activities and participation in everyday life.⁶²

Another explanation of the usability concept is that a product is worth using if it satisfies the user's needs in terms of its *relevance*, *efficiency*, *learnability* and *satisfaction*.⁶¹ In other words, the assistive technology has to facilitate the performance of an activity or task, and furthermore, the device needs to be effective and it must be easy to learn how to use it. Satisfaction with the product includes the individual's own attitude towards the device. However, other people's reactions are also important and influence the use of assistive technology devices. Therefore, the design of the device is important. The design must suit the users' needs, not only in terms of functionality but also how they want to be perceived by the surrounding society. If the assistive technology does not meet these needs, it will probably not be used. Why do some people choose to use their assistive technology devices and others not? Could the surrounding environment in some way contribute to improving the use of the devices?

Non-use of assistive technology

Many assistive technology devices are unfortunately not used.^{63, 64} The extent of use varies between different types of devices. Mobility aids such as powered scooters, wheelchairs and lower limb prostheses seem to be used to a greater extent than other types of devices.^{63, 65}

The use of upper limb prostheses varies widely between countries and between studies.^{63, 64, 66, 67} In one review, the reported rejection rates for upper limb prostheses varied from 12% to 75%.⁶⁴ The reported rejection rates of myoelectric prostheses at the Örebro prosthetic rehabilitation clinic are 12% for children⁶⁸ and in Sweden, United Kingdom and Canada 2–12% for adults,⁶⁹ compared with rejection rates at other clinics of 49–75% for children^{70, 71} and 13–20% for adults.^{64, 72} Why do we have these differences between countries and clinics?

The reported reasons for rejection of upper limb prostheses are diverse, but they have been described in a recent scoping review and summarized as lack of comfort and function.⁷³ A lack of comfort and function and the heavy weight of the prosthesis were reported as reasons for prosthesis rejection in another recent paper.⁶⁷ In that survey, 33% of the prosthesis users had been offered 20 hours of prosthetic training, and those who claimed that the training had been useful did not abandon their prosthesis. Indeed, insufficient training in prosthesis use is another commonly reported possible reason for abandonment.^{44, 74} Since prosthesis abandonment differs between countries, the amount of training and the content of training that is offered probably varies as well. It would therefore be illuminating to explore what training is being offered to users of myoelectric prostheses.

Occupational therapy

The main assignment for occupational therapists is to enable activity and participation for people with disabilities.¹¹ The mission is to enable all people to have the same rights to be active at home, in school, at work and during leisure time. To achieve this, various occupational therapy interventions are available, and one of the most common solutions is to prescribe an assistive technology device that facilitates people's performance of activities. The prescription process includes not only provision of assistive technology devices but also information about their specific functions, training in how to use them, follow-up and, if needed, maintenance.⁷⁵ The prescription process for powered wheelchairs is often structured and may

be compared with the process of getting a driving licence. Could this structured prescription process be the reason for the low rate of abandonment of powered wheelchairs? If so, users of other assistive technology devices may benefit from a similar structured process.

Occupational therapy for prosthesis users

The prescription process for myoelectric prosthetic hands is similar to other assistive technology devices: fitting, information, training, follow-up and maintenance.⁷⁶ Several professions are involved in the prosthetic rehabilitation team and there is a close collaboration between occupational therapists and certified prosthetists.³⁷ The prosthetic rehabilitation team may also include technicians and physiotherapists.¹⁰

Information about the prosthesis functions is often given at the time of fitting the prosthesis by the occupational therapist and the certified prosthetist. In Sweden, the design and fabrication of the prosthesis is the prosthetist's responsibility and the training to use the prosthesis is the occupational therapist's responsibility. In other countries, this training may be offered by different clinicians, such as certified prosthetists or physiotherapists, although the occupational therapist is the most common.³⁷ Training to use a myoelectric prosthesis is divided into separate phases: pre-prosthetic phase (for adults, if it is their first prosthesis), integration phase, control training phase and activity performance phase.⁷⁶ These are outlined below.

The pre-prosthetic phase involves physical therapy to preparing the body to wear a prosthesis and control training without a prosthesis to practice activation of the myoelectrodes that are used for controlling the grip function of the prosthetic hand.³⁷ The strengthening of the body and training to increase the range of motion in the arm and shoulder is sometimes led by a physiotherapist. The control training is commonly led by the occupational therapist and performed with a myo-tester, sometimes with visual feedback from a computer screen.³⁷ The purpose is to practise muscle contractions in the stump for activating the myoelectrodes in the prosthesis socket to control the opening and closing of the prosthetic hand.

The integration phase includes learning to wear the prosthesis in a natural and relaxed way. For a new prosthesis user, integration also involves getting used to the weight of the prosthesis. A wearing schedule is recommended,

with the wearing time slowly increasing from one hour per day to two hours, and so on until the prosthesis is used all day.⁷⁶

The control training phase with the prosthesis involves practising myoelectric control, in other words, activating the electrodes in the prosthesis socket to open and close the prosthetic hand.⁷⁶ The user is taught to control the grip function to grasp, hold of and release objects. This includes learning to open the hand a little or widely, to grasp objects with different shapes and textures and to control the grip force, that is, not holding the object so hard that it breaks but hard enough to not drop it. This is easiest to practise when sitting at a table with support for the arm, but it also has to be mastered when standing up and walking around, because the prosthesis is going to be used in the person's daily life.

The activity performance phase is the most important training phase for the user, since the reason for having a prosthesis is to improve the performance of daily activities. It is preferable to practice the performance of activities that are important and meaningful to the user, which may be related to home, work or leisure.⁷⁶ In order to be able to perform daily activities naturally and effectively with a prosthesis, many skills need to be practised. The user must, for example, coordinate both hands when performing the activity, and must be able to hold objects without looking at them.

These phases illustrate what the person with upper limb loss has to learn to be able to use a myoelectric prosthesis in daily life. A question that arises is how the treating occupational therapist should teach the patient all these skills in the most effective way.

Evidence-based practice

Clinicians are expected to deliver good and equal healthcare to their patients, and this should be their aim. But do clinicians deliver the best healthcare, and what evidence do they have for their practices? Evidence-based practice is established as a fundamental element and key indicator of high-quality patient care.⁷⁷ The combination of the best research evidence, clinical expertise and patients' values and preferences gives the best conditions for good and equal healthcare. However, the prerequisite for being able to find the best evidence for practice is not entirely feasible for occupational therapists who work in prosthetic rehabilitation. Evidence-based guidelines for rehabilitation of upper limb loss are few,¹⁰ and it is

unclear whether evidence-based methods for occupational therapy training in prosthesis use even exist.



Figure 5. The three components of evidence-based practice.

RATIONALE

For people with disabilities, assistive technology devices can change a state of dependence into independence and turn a feeling of not being involved into participation. Nevertheless, research shows that many assistive technology devices are abandoned. Hence, it is important to investigate factors that may hinder or facilitate assistive technology use. Are there differences between disability groups concerning the use of assistive technology and whether the users feel they can participate in society?

Prosthesis use is proven to prevent the overload problems that many people with upper limb loss suffer from, which is why health care professionals recommend it. Despite the known benefits of prosthesis use, prosthesis abandonment is a problem that is reported to a varying extent in different countries and clinics. Why do we have these differences? Why do some people choose to use their prosthesis and others not?

What factors may influence prosthesis use? Most studies on prosthesis abandonment investigate personal factors, such as aetiology, age or gender. How environmental factors influence prosthesis use has not been studied. Given that the environment has a great impact on how people experience health and well-being, it may therefore be important to study its influence on prosthesis use.

To increase the use of prostheses, their usability needs to be improved. Even though the functionality in prosthetic hands has been expanded in recent years to include multi-grip functions, studies report that the functions in the new prostheses are not used to a great extent. Are the users offered proper training to be able to use these multi-grip functions? The best training method for the use of multi-grip functions needs to be established in order to provide evidence-based prosthetic rehabilitation for people with upper limb loss.

The usability of the new multi-grip hands in daily life has been studied with varying results. They have improved functions compared to the simpler single-grip hands, but it has not been confirmed whether they are more beneficial for use in daily activities. The benefits of multi-grip functions need to be studied further if clinicians are to be able to recommend these prosthetic hands to their patients.

In conclusion, we know that the use of a prosthesis can prevent pain and that prosthesis abandonment is a problem that varies between countries and clinics. We also know that the environment has an impact on how people experience health and well-being, but we do not know how the environment influences prosthesis use. Further, we know neither which training method is best for users of multi-grip prosthetic hands, nor whether multi-grip hands are more beneficial to use in daily activities than single-grip hands.

AIMS

The overall aim of this thesis was to gather empirical evidence about the benefits and use of myoelectric arm prostheses, by investigating and describing the influencing environmental factors for prosthesis use, describe a training method for the use of multi-grip prostheses and evaluating the effect of the new multi-grip hands compared to single-grip prostheses.

The specific aims of papers I–V were:

- I. To describe and compare the presence of environmental barriers to participation and facilitators for assistive technology use, and to examine the relation among barriers to participation, facilitators for AT use, and the frequency of AT use as experienced by users of three different types of devices.
- II. To describe users' experiences of how environmental factors influenced their use of a myoelectric arm prosthesis.
- III. To critically examine the content of published sources for training of users with myoelectric multi-grip hand prostheses.
- IV. To design and describe a comprehensive training method for myoelectric prosthesis training.
- V. To evaluate the effect of multi-grip hands on the performance of daily activities, musculoskeletal-related pain and prostheses skill and use, in comparison to single-grip hands. A secondary aim was to study the ability to learn and use the multi grip hand functions.

METHODS

Design

To fulfil the overarching aim of the thesis, different designs were used in all studies. These are described in table 1 below.

Table 1. Overview of designs and methods

Study	Design	Sample	Data collection	Analysis
I	Cross-sectional	Users of three types of devices n=156	Questionnaires	Non-parametric statistics
II	Qualitative descriptive	Prosthesis users n=13	Individual interviews	Qualitative content analysis, inductive
III	Scoping review	Published articles and user manuals n=9	Structured database search	Manifest content analysis
IV	Descriptive method article	n.a.	n.a.	n.a.
V	Multiple baseline single-case AB design	Prosthesis users n=9	Questionnaires Performance tests Video recording	Visual analysis Multilevel linear regression

Participants

Participants were recruited for study I, II and V. The participants in study I were 156 individuals with at least one year of experience as users of one of the three assistive device types: myoelectric hand prosthesis, powered mobility device (powered wheelchair) or electronic planning device. The participants with myoelectric prostheses were recruited from an outpatient prosthetic clinic with a national uptake, and the other device groups were recruited from three centres for service and delivery of assistive technology devices in central Sweden. The prosthesis users in study I were asked in the invitation letter whether they also wanted to participate in an interview study, study II. Thirteen participants agreed to participate in both studies. They were men and women, with a broad age range, with either congenital or acquired limb loss. Six participants reported using their prosthesis at least 8 hours per day (classified as *daily use*) and the remaining seven participants used their prosthesis less frequently (classified as *non-daily use*).

In study V, the nine prosthesis users who changed from a conventional myoelectric prosthetic hand to a multi-grip prosthetic hand at the earlier mentioned outpatient clinic between 2017 and 2020 were asked to participate, and all agreed to take part. Both people with congenital and acquired limb loss participated. Four were daily prosthesis users and five were non-daily users. Two of the participants in study V had earlier participated in study I, and one of them participated in all three studies I, II and V. See table 2.

Table 2. Demographic data for the study participants.

	MEP	Study I PMD	ATC	Study II	Study V
Sex, n					
female	19	35	34	4	4
male	32	23	13	9	5
Age, years					
Mean (SD)	41(17)	54 (15)	42(14)		
Median (range)				33 (20–74)	26(18–59)
ICD diagnosis, n					
V Mental disorder			31		
VI Nervous system		39	8		
XIII Musculoskeletal		10			
XVI I Congenital LL	31			8	7
XIX Injury, Amputation	20	3		5	2
Prosthesis/AT use, n					
daily (8 hours/day)	41	37	41	6	4
non-daily	10	21	6	7	5
Experience of AT use					
Median years (range)	23	7	4	23 (2–30)	18 (1–46)

Abbreviations: MEP = myoelectric prosthesis, PMD = powered mobility device, ATC = assistive technology for cognition, SD = standard deviation, LL = limb loss, AT = assistive technology.

Data collection

The five studies used a range of data collection methods: questionnaires, face-to-face interviews, a structured database search, functional assessments and filming. Below follows a description for each study.

Data collection procedure study I

Two questionnaires, described below, were sent by regular mail to individuals who had at least one year's experience as a user of one of the three assistive technology devices: myoelectric hand prosthesis, powered wheelchair or electronic planning device. Based on an earlier study⁷⁸ using the CHIEF-S questionnaire, our goal was to recruit 50 individuals for each assistive technology group. The individuals were recruited from centres for

service and delivery of assistive technology in three different counties in Sweden. The users of myoelectric prosthesis were recruited from an outpatient prosthetic clinic with a national uptake. Each sample group was stratified according to age to ensure representation from people of different ages. The questionnaires were sent together with information about the study and an invitation to participate. All non-responders received one reminder, and in total 156 persons (response rate 61%) agreed to participate.

Questionnaires study I

The Swedish version of the **Craig Hospital Inventory of Environmental Factors (CHIEF-S)**⁷⁸ was used to investigate environmental barriers to participation in daily activities for people with disabilities. The focus of the CHIEF-S is on quantification of the experienced barriers to participation, divided into five subscales: *attitudes/support*, *service /assistance*, *physical/structural*, *work/school* and *policies*. The respondents rate the frequency of 25 barriers using the following scale: 0 = never, 1 = less frequently than once per month, 2 = monthly, 3 = weekly and 4 = daily. The magnitude of the barrier is rated as either 1 = a small problem, or 2 = a large problem. The total CHIEF-S score is calculated as the mean product of the frequency and magnitude of all non-missing questions. A total score of 0 indicates no barriers to participation and higher score indicates more barriers.

A study-specific questionnaire based on the ICF environmental factors was used to measure environmental facilitators for participation. This questionnaire had been used earlier in a study of environmental impact on assistive technology use.⁷⁹ The seven questions were based on the ICF classification of environmental factors: support from relatives, support from professionals, encouragement from relatives, encouragement from professionals, support from social services, support from authorities & organizations, support from rules & regulations. The questions were rated according to how facilitating the factor was for assistive technology use, using the following scale: 1 = not facilitating at all, 2 = little, 3 = moderate, 4 = much and 5 = very much.

Data collection procedure study II

This study used semi-structured interviews. All interviews started with demographic questions before the main question, and the broad meaning of

the term *environment* was explained to the participants. The participants were asked to reflect on whether the environment influenced their prosthesis use and, if so, in what way, impeding or facilitating. An interview guide, with keywords taken from the environmental factors in the ICF, was used as a checklist to ensure that all different aspects of the environment were covered. The interviewer posed probing questions to deepen the conversation and the interviews lasted on average 45 minutes (range 23–110). All thirteen interviews were performed according to the participants' own choice of time and place: the majority were conducted face to face and three by phone. The doctoral student CW conducted all interviews. She had at the time of the interviews no prior caring relation to the participants. All interviews were audio recorded and transcribed verbatim by CW.

Data collection procedure study III

To find published sources for training users of myoelectric multi-grip hand prostheses, a structured literature search was conducted in the databases PubMed, CINAHL and the Allied and Complementary Medicine Database (AMED). The search covered the period 2007–2020 using the search terms: “upper extremity” OR “upper extremities” OR “upper limb” OR “upper limbs” OR “hand” OR “hands” OR “arm” OR “arms” AND “occupational therapy” OR “rehabilitation” OR “training” AND “artificial limbs” OR “artificial arm” OR “artificial hand” OR “prosthesis” OR “prostheses” OR “prosthetic” OR “myoelectric” OR “myo electric”. PubMed MeSH terms used were: upper extremity, occupational therapy, rehabilitation, and artificial limbs. CINAHL major and minor heading terms used were: upper extremity+, occupational therapy+, limb prosthesis and myoelectric prosthesis. In addition, a grey literature search was made among multi-grip prosthesis manufacturers to find descriptive user manuals with training instructions for multi-grip prostheses.

Original English-language, peer-reviewed research articles describing training instructions for users of multi-grip myoelectric prostheses, or a combination of multi-grip myoelectric prostheses and other types of prostheses, and user manuals from manufacturers of multi-grip myoelectric prostheses were included. Exclusion criteria were: articles focusing only on conventional myoelectric prostheses, body-powered prostheses, passive prostheses, foot-controlled prostheses or multi-grip prosthesis prototypes not available on the market. Articles that did not describe any training with

a prosthesis involved were also excluded. The search resulted in 2,005 peer-reviewed articles and four user manuals. After duplicates were removed, 1,528 remained. Titles and abstracts were screened, and 88 articles and four manuals were reviewed in full text. Finally, nine sources, five articles and four user manuals, were included in the analyses.

Data collection procedure study IV

The results from the scoping review (study III), the previously published descriptions of training programmes for users of myoelectric prosthetic hands, and the lack of descriptions for integration and training in daily activities were all taken into consideration in the development of the training method. We aimed to integrate the results from the scoping review with a person-centred treatment philosophy, CMOP,¹¹ and the structured training SIRS for children,³¹ which is also used in our clinic for adult patients, as well as our clinical experience as occupational therapists. To be able to develop the training method, a group was formed of experienced occupational therapists, three from the prosthetic rehabilitation field (CW, KE, LH) and one from neurorehabilitation (KLH).

Data collection procedure study V

A range of methods was used, all at a national prosthetic outpatient clinic in Örebro, Sweden: semi-structured interviews (COPM), questionnaires (PDI, study-specific questionnaire), performance tests and filming, as described in the following sections. The researcher CW collected all the data. The intervention, fitting and training to use a multi-grip hand were provided by an occupational therapist from the outpatient clinic; for most participants this was another occupational therapist than CW. Baseline data (Phase A) were collected before starting the fitting of a multi-grip hand prosthesis. Follow-up data (Phase B) were collected on the second day of fitting the multi-grip hand and after 2 weeks, 1, 2, 3 and 6 months. (See figure 6.)

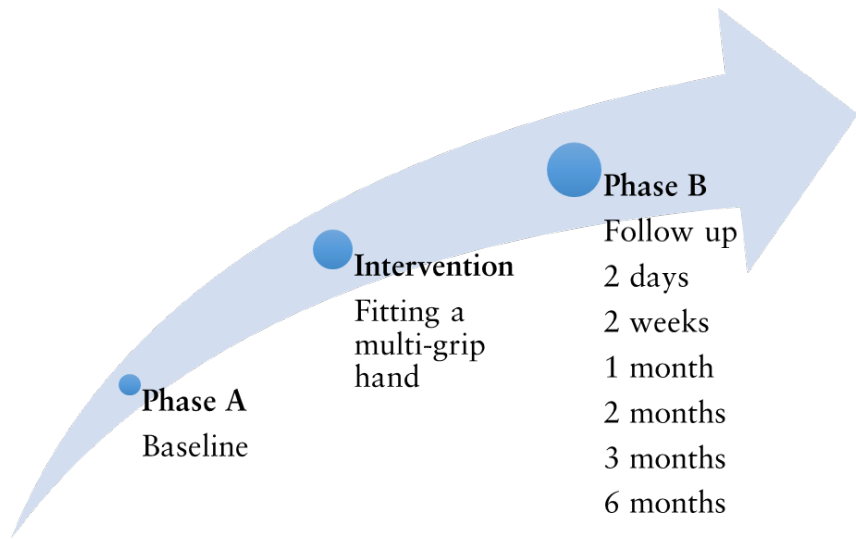


Figure 6. The different steps of the intervention and the research process: Phase A (baseline), Intervention (fitting a multi-grip hand) and Phase B (follow-up).

The face-to-face COPM interviews were conducted at baseline and at the follow-ups after 1, 2, 3 and 6 months. The PDI questionnaire was also administered at baseline and at 1, 2, 3 and 6 months. The participants' self-reported prosthesis wearing time (hours per day) was collected at baseline and at all follow-ups, and subjective usefulness and frequency of actual use of the different grip types was collected at the 6-month follow-up. The prosthesis wearing time and use of grip types were collected via the study-specific questionnaire. Performance on the modified SHAP test was measured at all the follow-ups, as was performance on the ACMC assessment, which was filmed and rated by an expert observer. One participant felt uncomfortable with being filmed and was allowed to perform the test without the camera.

Clinical assessments study V

The Canadian Occupational Performance Measure (COPM)¹³ was used to measure performance of daily activities. This generic instrument measures an individual's self-perception of changes over time in his or her

performance of individually selected daily life activities. We used the validated Swedish version.^{27, 30} Through a semi-structured interview, the individual identifies activity problems in the areas of self-care, productivity and leisure. The five most important activity problems are then scored according to the individual's performance of the activity using a 1–10 scale, where 1 indicates poor performance and 10 indicates very good performance; the individual then rates his or her satisfaction with this performance, also on a 1–10 scale, where 1 indicates low satisfaction and 10 indicates high satisfaction. The weighted scores for performance and satisfaction with performance are added separately to create two summative mean total scores.

The **Assessment of Capacity for Myoelectric Control (ACMC)**^{80, 81} was used to measure the individual's ability to operate the different prosthetic hands. The ACMC is an observational assessment. The individual performs an activity and an observer assesses the individual's capacity for control of the prosthesis for that activity. The assessment is based on 22 items on a 0–3 scale, resulting in 22 raw scores. The raw scores are processed through the ACMC website resulting in an overall score transformed by Rasch analysis to ACMC units ranging from 0–100. Higher scores indicate higher ability. The ACMC is validated for conventional myoelectric prosthesis use and is a widely used instrument.

The **Southampton Hand Assessment Procedure (SHAP)**⁸² is a performance-based test used to measure hand function and validated for the assessment of the effectiveness of upper limb prostheses. The original SHAP test comprises six light and six heavy geometric objects and 14 activities of daily living. The performance of each task is timed by the patients themselves. The original SHAP test was modified and used to measure the participants' ability to move objects and switch between grip types. In the modified SHAP test, five geometric objects were used, see figure 7. Participants were instructed to switch grip type between each object. The time to move all objects to the correct slot was timed by the participant and registered separately for light objects and heavy objects. Time was measured in seconds by pushing the blue timer button in the centre of the board; a shorter recorded time indicates easier performance.

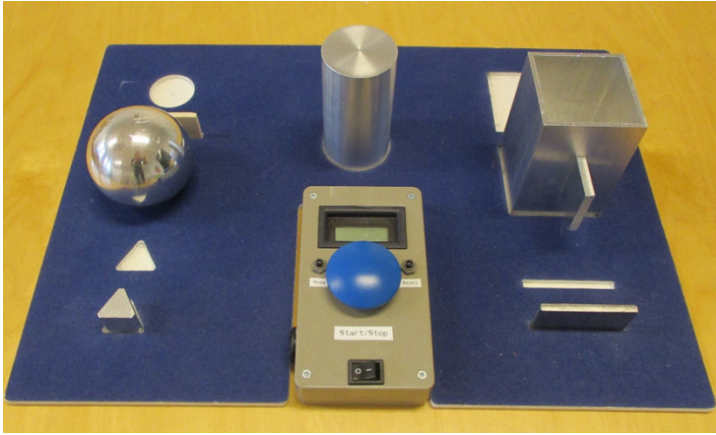


Figure 7. The modified SHAP board with heavy objects and a timer with a blue button.

Questionnaires study V

The **Pain Disability Index (PDI)**⁸³ is a generic instrument that has shown good construct validity and was developed to measure how prolonged pain impacts participation in essential daily life activities. The individual rates the level of experienced disability when performing seven different daily life activities on a 0–10 scale, where 0 = no disability and 10 = worst disability. The seven responses are summed to a total score, where a low score indicates no obstacles for participation in daily life activities.

A **study-specific questionnaire** was used for reporting prosthesis wearing time and the perceived usefulness and actual use of different grip types, as well as for collecting demographic data. Wearing time was reported in hours per day. The actual use of the eleven different grip types was rated on a four-point scale, where 1 = not used, 2 = used a little, 3 = used often and 4 = used to the maximum. The usefulness of each grip type was rated on a four-point scale, where 1 = not useful, 2 = slightly useful, 3 = very useful and 4 = extremely useful.

Data analysis

The analysis methods varied across the studies, from qualitative manifest or inductive content analysis to quantitative parametric or non-parametric statistics, visual analyses and multilevel linear regression.

Data analysis study I

We used descriptive statistics for the demographic data and to assess the data for normal distribution. The data distribution of the CHIEF-S scores was highly skewed, and therefore we used non-parametric statistics for both the CHIEF-S scores and the study-specific environmental facilitators score. The barriers and facilitators data were analysed both within and between the three assistive technology groups. To test for significance, we used a Kruskal–Wallis test and a 2-tailed Mann–Whitney U test. The correlation between barriers to participation and frequency of assistive technology use, and between facilitators for assistive technology use and frequency of use were analysed with Spearman's rank order correlation test. Statistical significance was set at $p < 0.05$, and the analyses were performed with IBM SPSS statistics, version 22.

Data analysis study II

The interviews were analysed with qualitative content analysis, using an inductive approach.⁸⁴ The transcripts with raw data from the 13 interviews were read by CW, who abstracted meaning units that were labelled with a code. In total, 157 codes concerning the environment or prosthesis use were labelled and organized into 14 initial categories. During the analysis process, comparing the categories for differences and similarities, some of them were merged, resulting in the final manifest content which consisted of four categories. To ensure credibility during this process, investigator triangulation was used by three of the authors (CW, LH and IP). Two of the interviews were jointly coded and the categorization process was first analysed individually by the three researchers and then jointly discussed. The three authors also jointly interpreted the overarching theme by contrasting the results and searching for differences and similarities in statements and demographic characteristics between the participants. The computer program NVivo 10 was used to monitor and handle the data during the analysis.

Data analysis study III

To be able to extract data in a systematic way, a data charting matrix was jointly developed by the authors (CW, KLH and LH). The matrix was based on the established phases of pre-prosthetic and prosthetic training; if further training phases occurred in any of the sources, the authors were open to adding them to the matrix, but no further phases were found. Descriptions of multi-grip training at each of the established training phases were extracted. The content from the nine included sources was first independently categorized by all three authors and then jointly discussed. The categorization was based on how clearly each phase was described, ranging from: *Mentioned* – only mentioned in the text, with no examples or descriptions of how to guide the training; *Briefly* – a brief description with a few examples but lacking instructions for specifically what should be done and what material to use; *Well* – well described, any instructor can follow the procedure and guide the training.

Development process study IV

We included all phases of training in the new training method: pre-prosthetic preparation, integration, control training and training in daily activities. We also wrote detailed instruction for of how to conduct the training and what materials to use. The stepwise training with increasing degree of difficulty used in SIRS was used as a basis. New steps adapted to multi-grip functions were added and others were removed. The content of the various training steps was revised, and an inventory of appropriate objects to use for the training was chosen. The group of therapists continuously discussed the development of the training method, and changes were made, until we came to consensus. The new training method finally resulted in 13 steps and was named Stepwise Training for an Advanced and Integrated prosthetic Routine (STAIR). The feasibility of the STAIR method was tested for multi-grip prosthetic hands in a clinical trial (study V) and with different types of prosthetic hands during the ongoing clinical work at our outpatient clinic.

Data analysis study V

Visual analysis⁸⁵ and multi-level linear regression models⁸⁶ were used to assess changes in the COPM, PDI, ACMC and modified SHAP scores. In the multilevel models, level 2 represented the individual and level 1 represented follow-up time, which was nested within level 2. Random intercept and slope, unstructured covariance and maximum likelihood

methods were used. Given our small sample size, the analyses were repeated using restricted maximum likelihood with alternative computational methods for the calculation of degrees of freedom, such as the Kenward–Roger procedure.⁸⁷ We present the results obtained from the maximum likelihood method, since estimates were similar between different methods. Follow-up time was used as a categorical variable, with Phase A as the reference. The coefficients indicate differences in scores between baseline and each follow-up time in phase B. P-values lower than 0.05 were considered statistically significant. Because PDI and the modified SHAP showed non-constant variability of errors across follow-up time, the analyses were repeated using log transformation (for modified SHAP) and square-root transformation (for PDI). As the conclusion remained the same, results from untransformed data are presented. The perceived usefulness and self-reported actual use of the different grip types were calculated as the percentage of participants giving each ranking. Data analysis was performed using Stata SE 16.

ETHICAL CONSIDERATIONS

All studies in this thesis follow the Declaration of Helsinki ethical principles for medical research involving human subjects.⁸⁸ Studies I, II and V were approved by the Regional Ethics Committee in Uppsala, Sweden. (Study I – II: 2012/275, study V: 2017/315) Study III was a scoping review of published material, which meant that ethical approval was not needed. However, the ethical principles also apply for a literature review in the sense of how the data collection was performed in the included studies. Therefore, the ethical reporting in each included source was also reviewed; the results confirmed that the studies had applied ethical principles and the sources were consequently included. As study IV was a method article with no human subjects involved, no ethical approval was needed.

All participants received both verbal and written information about the respective study. They were informed that participation was voluntary and that they could end their participation at any time without explanation. They were also informed that their decision to participate or not, would not influence the healthcare services or their relation to the clinical team. Before data collection started, all participants signed a written consent.

In studies I and II, the researcher who performed the data collection, CW, had no prior relation to the participants. The interviews in study II were performed according to the participants' own choice of time and place. Some interviews were conducted in the participant's own home or workplace, and some in the clinic or by phone due to their distant location. Our intention with this was to make the participants feel safe to talk openly, even about things they were dissatisfied with. The small discomfort that an interview may have caused is outweighed by the benefit that the study has provided for developing care for people with upper limb loss.

In study V, there were several ethical dilemmas to deal with. We designed the study to avoid most of them. When asking a patient to evaluate a new product, in this case a prosthesis with multi-grip functions, it feels unethical to make the participant return the new prosthesis after the data collection period of six months is finished. Therefore, we did not ask patients to try this new product unless they had a verified need of the multi-grip functions, which is a requirement to get an approval from their home region to have such a prosthesis. Consequently, all participants had an approval and could

keep the prosthesis after finishing their participation in the study. This made the total time for the data collection for study V very long. We also knew from earlier research and clinical experience that the multi-grip hand had problems with durability. There was a high risk that hands would break, and participants would be without functioning hands. Therefore, we organized a system with temporary hands for each participant in case of breakdowns. We also allowed everyone to keep their old myoelectric prosthesis with a single-grip hand, to use if the multi-grip hand broke down. They were allowed to use their old hand if there were things they could not perform with the new hand, since they had to live their ordinary lives during the six months' data collection. To force the participants to only use a multi-grip hand was judged as not ethically defensible, especially for a period as long as six months.

To maintain as objective an attitude as possible towards the research, we tried to keep the data collection and the clinical services separated, by having the regular occupational therapist give the training instructions and a researcher (CW) conduct the data collection. Due to periods of sick leave during the COVID-19 pandemic, this could unfortunately not be followed for some of the participants. The researcher CW, who is one of four occupational therapists working at the clinic, then had to both give training instructions and collect data for three of the participants. This may have influenced these patients' choice to participate in the study.

Filming may be a sensitive data collection method. Therefore, extra attention was paid to willingness to volunteer. One of the participants did not feel comfortable with being filmed and was therefore allowed to perform the test without the camera. None of the other participants expressed or in other way showed that they disliked being filmed.

It is not ethically justifiable for a clinician to prescribe a prosthesis and not offer proper training in how to use it. In study V, we offered an extensive amount of training to our participants, who really learned to use the multi-grip functions. This training required several visits to the clinic. The inconvenience that the many visits to the clinic may have caused the participants is compensated by the thorough training they received and the support in using the multi-grip hands, as well as the good service in connection with breakdowns of the hands. The training method that was tested and the multi-grip experiences from this study will also be of benefit

to other people with upper limb loss in the future. Thus, the usefulness of the study outweighs the discomfort it may have caused.

In conclusion, the benefits for persons with upper limb loss and the results contributing to evidence for prosthetic rehabilitation outweigh the risks and possible disadvantages for the persons who participated in studies I, II and V.

RESULTS

The overall aim, to investigate and describe the influencing environmental factors for myoelectric prosthesis use, to develop a training method for using multi-grip prostheses and to evaluate the effect of the new multi-grip hands compared to single-grip prostheses, is now fulfilled and the results are summarized below.

The influencing environmental factors for prosthesis use were both barriers and facilitators, but embodiment of the prosthesis was found to reduce the negative impact from the environment. Reported barriers were the physical environment, the design and functionality of the prosthesis, and the lack of regulatory support. Reported facilitators were support from family and health care (encouragement and training).

Existing training instructions for the use of multi-grip myoelectric prosthesis were found to be few and not described in sufficient detail. Therefore, the STAIR training method was developed. The method describes all established training phases for teaching users how to operate a myoelectric prosthesis with multi-grip functions, with detailed instructions for the therapist.

Multi-grip hands were found to have positive effects on the performance of daily activities and satisfaction with performance, in comparison with single-grip hands. Pain-related disability reduced after using a multi-grip hand for six months. Most participants learned to operate a multi-grip hand as efficiently as the single-grip hand or better, and many of the grip types were used six months after fitting.

Results study I

Compared to other users of assistive technology devices, users of prosthesis report few environmental barriers hindering their prosthesis use.

Environmental barriers to participation

For all three groups of assistive technology users, most problems were reported in the subscale physical/structural environment, followed by barriers in the subscales services/assistance and attitudes/support. Compared to the other two groups of assistive technology users, the prosthesis users reported significantly less impact from environmental

barriers in all subscales except work/school. For the prosthesis users, the greatest barriers to participation were the items *natural environment* and *policies government*. The users of powered mobility devices also reported the greatest barriers for participation from the item *natural environment*. Their second greatest barrier was the item *design of community*. The users of assistive technology for cognition reported significantly more barriers than the other assistive technology groups. Their greatest barriers for participation were in the items *surroundings* and *information*. See table 3.

Table 3. Environmental barriers to participation reported in the CHIEF-S questionnaire, grouped by type of assistive technology used.

Environmental context	Total	MEP	PMD	ATC	P-value
CHIEF-S product scores	n=156	n=51	n=58	n=47	
Attitude / Support	0.20	0.00	0.20	0.80	<0.01
Service / Assistance	0.37	0.00	0.62	1.17	<0.01
Physical / Structural	0.67	0.00	1.33	2.00	<0.01
Work / School	0.00	0.00	0.00	0.00	N.S.
Policies	0.00	0.00	0.13	0.75	<0.01
CHIEF-S Total	0.52	0.12	0.62	1.56	<0.01

The table shows median frequency–magnitude product scores for each CHIEF-S subscale and for the total score. The Kruskal–Wallis test was used, and $p < 0.05$ was considered significant. Abbreviations: MEP = myoelectric prosthesis, PMD = powered mobility device, ATC = assistive technology for cognition, N.S. = not significant.

The relation between barriers to participation and frequency of assistive technology use was also analysed. For the prosthesis users there was a significant correlation between barriers and frequency of prosthesis use ($r = 0.30$, $p < 0.038$), with the frequent users reporting fewer barriers than the less frequent users. The frequent users of powered mobility devices also reported fewer barriers than the less frequent users. In contrast, the frequent users of assistive technology for cognition reported the most barriers. See figure 8.

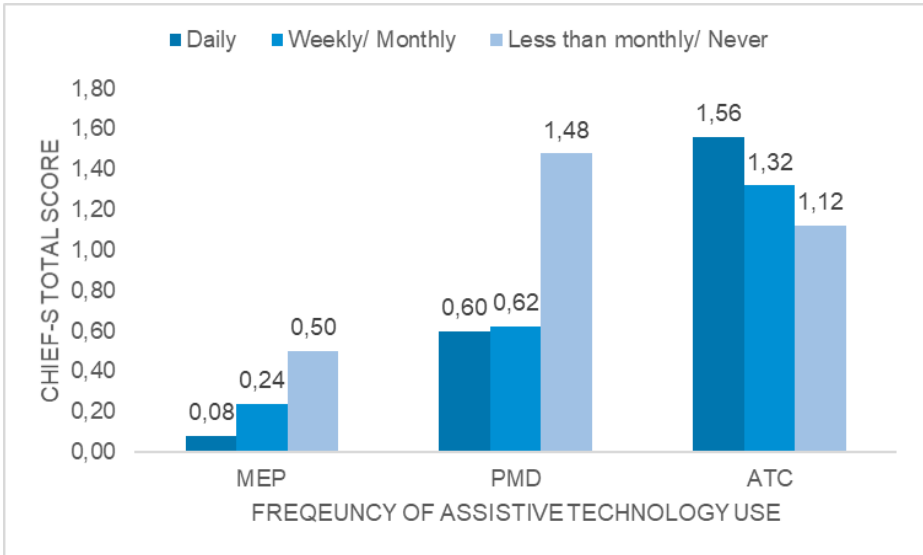


Figure 8. Distribution of reported levels of environmental barriers according to frequency of assistive technology use, grouped by type of assistive technology. Abbreviations: MEP = myoelectric prosthesis, PMD = powered mobility device, ATC = assistive technology for cognition.

Facilitators for assistive technology use

The study-specific questionnaire on facilitators showed that support from *relatives* and *professionals* were rated highly by all three groups of assistive technology users, whereas *rules and regulations* and *authorities and organizations* were reported as least supportive for assistive technology use. The prosthesis users and the users of powered mobility devices reported receiving more support than the users of assistive technology for cognition. See table 4.

Table 4. Environmental facilitators for assistive technology use, grouped by type of assistive technology used.

Environmental facilitator	Total n=156	MEP n=51	PMD n=58	ATC n=47	p-value
Support from relatives	4	4	4	2.5	<0.001
Support from professionals	4	4	4	3	N.S.
Encouragement from relatives	4	4	4	3	<0.001
Encouragement from professionals	3	3	3	4	N.S.
Support from social services	3	3	3	2	0.048
Support from authorities & organizations	2	2.5	2	1	N.S.
Support from rules & regulations	2	2	3	1	0.045

The table shows median scores on a 5-point scale. The Kruskal–Wallis test was used, and $p < 0.05$ was considered significant. Abbreviations: MEP = myoelectric prosthesis, PMD = powered mobility device, ATC = assistive technology for cognition, N.S. = not significant.

Results study II

The qualitative content analysis of the transcribed interviews resulted in four categories and an overarching theme. The categories were manifest and supported by quotations to illustrate the participants' various experiences of environmental influence on prosthesis use. The four categories were: **Prosthesis function**, **Other people's attitudes**, **Support from family and healthcare** and **Individual's attitude and strategies**. The overarching theme is the authors' interpretation of the participants' expressed opinions about the prosthesis itself and the different ways of adapting to prosthesis use. The daily users talked in terms of '*the prosthesis is a part of me*' and '*I can't function without it*', which we interpret as embodiment of the prosthesis. The non-daily users all said '*the prosthesis never became a part of me*' or '*I never felt comfortable with it*'. These different ways of adapting to prosthesis use influenced their perceptions and experiences of the environmental barriers and facilitators they were exposed to every day,

which resulted in the overarching theme, “Various degrees of embodiment lead to different experiences of environmental barriers and facilitators.”

Prosthesis function

All participants experienced limitations in the prosthesis function. The daily users found the most limitations; however, this did not stop them from using the prosthesis frequently. They needed the prosthesis for daily activities, in social situations, for body balance and for long term ergonomic benefits. The non-daily users, in contrast, indicated that the limitations in the functionality and appearance of the prosthesis were the greatest barriers to using it. All participants wanted improvements in the functionality of the prosthesis and development of the design. They wished for a less heavy prosthesis, with a quieter motor, in smaller sizes and with a more natural appearance.

Other people's attitudes

Other people's attitudes were perceived both as a barrier and as a facilitator in terms of prosthesis use. For the daily users, the prosthesis helped them to draw attention away from their disability and blend in, in social settings. They felt uncomfortable if they were not wearing their prosthesis in public.

I also always use my prosthesis when I'm with people I do not know, even indoors. That is, I don't want other people to stare at me and all that ... (Daily user)

In contrast, the non-daily users felt that the prosthesis gave them unwanted attention in social settings. They had not integrated the prosthesis into their body language, and the prosthesis itself received the attention.

I'd rather be without it; I feel so stiff and unnatural with it, and then people stare. (Non-daily user)

Regardless of whether the prosthesis was used or not, all participants expressed that they wanted to be like, look like or act like everyone else. Similar to most people in society, no one wanted to stand out. Neither did they liked to feel disabled. Some participants felt discriminated by other people's attitudes when they were offered help that they did not need or ask for.

Support from family and healthcare

All daily users described how they had been supported by their families to use the prosthesis. Some of the non-daily users lacked social support for prosthesis use while others stated that they neither wanted support nor missed it. The support from local health care systems varied among the participants. Some lacked support, while others trained intensively, which had a corresponding effect on prosthesis use.

I moved from a big city to a small town, and there wasn't the same support to learn how to use it there that I had all my life. It disappeared completely. It was a setback. I stopped using the prosthesis altogether because it became really weird. I didn't get any support in this, and I became a prosthesis opponent instead. (Non-daily user)

I trained like a maniac when I was a child. In retrospect, as with any other exercise, this was a foundation for something that became very good. So I live my life today virtually trouble-free from my disability. (Daily user)

Individual's attitude and strategies

The participants had chosen different strategies to adapt to their environment, and these strategies had an impact on their prosthesis use and how the environment affected them. The daily users adapted by using the prosthesis when performing two-handed activities, and the non-daily users adapted, for example, by using their residual limb, trunk or teeth to compensate for the loss of a hand. Some of the non-daily users adapted by avoiding things in life, ordinary activities that other people engaged in but that they could not because of their limb deficiency.

I have friends who play golf and think it's really fun, so I have been very eager to play golf, but at the same time, I feel as though it's not my thing. It's too difficult, too hard to do it, and so I have chosen to avoid golf instead. (Non-daily user)

The participants' motivation for learning to use the prosthesis varied, and seemed important for daily prosthesis use. The non-daily users found it difficult to learn how to wear and use the prosthesis. Some thought that their age had an impact on their learning ability. However, there were also

highly motivated participants who received their prosthesis late in life and in time became skilled users.

In the beginning when I shelled eggs, they always smashed. That's probably the biggest mistake you make then, that you pinch too hard. But now I have learned to hold things, yes, by feeling, if you can call it that, through the prosthesis.
(Daily user)

Results study III

Nine sources were included in the full text review, five published articles and four user manuals from manufacturers, describing myoelectric training with multi-grip prosthesis. How well the training is described from each source is categorized in table 5.

Of the nine sources, only one³⁷ mentioned all phases of training, and no source described all phases well. The least described phase was integration training, which was only mentioned by two sources.^{37, 40} Control training was described by eight sources and well described by two of them, namely, the Ottobock user manuals for the multi-grip hands bebionic and Michelangelo.^{89, 90} Activity performance training is mentioned or briefly described by seven of the sources, but not well described by any of them. None of the sources presented guidance on how to practise multi-grip functions or switch between grip functions in real-life daily activities.

Table 5. Data synthesis: level of detail in descriptions of each training phase

Source Year, Author	Prosthesis type	PRE- PROSTHETIC TRAINING		PROSTHETIC TRAINING		
		Physical training	Signals training	Integration training	Control training with prosthesis	Activity performance training
2020 Ottobock ²⁶	bebionic	well described	-	-	well described	briefly described
2020 Touch Bionics by Össur ²⁷	i-limb	-	-	-	mentioned	briefly described
2020 Ottobock ²⁸	Michelangelo	briefly described	-	-	well described	briefly described
2020 TASKA by Fillauer ²⁹	TASKA hand	-	-	-	-	mentioned
2018 Resnik ³⁰	i-limb	-	briefly described	mentioned	briefly described	briefly described
2018 Resnik ³¹	DEKA EMG-PR	-	mentioned	-	mentioned	mentioned
2015 Roche ³²	Michelangelo	-	briefly described	-	mentioned	-
2014 Swanson Johnson & Mansfield ³³	Conv./ Multi-grip	briefly described	well described	mentioned	briefly described	briefly described
2009 Kuiken ³⁴	DEKA EMG-PR	-	mentioned	-	mentioned	-

Key to description levels: - = not described at all; mentioned = only mentioned in the text with no examples and no description of how to guide the training; briefly described = a brief description with a few examples but lacking instructions for what specifically should be done and what materials to use; well described = any instructor could follow the described procedure and guide the training. Abbreviations: DEKA EMG-PR= DEKA arm with EMG pattern recognition control; Conv. = conventional myoelectric prosthesis; Multi-grip = prosthesis with multiple grip functions.

Results study IV - the training method STAIR

The training method STAIR was developed to enable prescription of the new multi-grip technology in a structured and meticulous way. The method includes all phases of prosthetic training. The first phase is pre-prosthetic preparation and the remaining three phases, Integration, Structured control training and Activity performance, encompass the 13 steps after prosthetic

fitting, see table 6. The steps are described in detail, covering how to perform them and what materials to use, so that any therapist may follow the instructions. The method gives instructions for teaching patients to use a prosthesis with multi-grip functions, but it can be used for training to use any kind of prosthesis, passive or myoelectric; however, only the first two steps in STAIR are used to instruct a user of a passive prosthesis.

Table 6. Overview of the STAIR steps

Training phase	STAIR step
Integration	1 Wear the prosthesis
	2 Use as support and assistance
Structured control training	3 Control basic hand movements
	4 Indirect grasping
	5 Switch between grip types and grip patterns
	6 Select grip type to grip objects
Activity performance	7 Use a power grip in bimanual tasks
	8 Use a precision grip in bimanual tasks
	9 Use individually chosen grip types in bimanual tasks
	10 Adjust grip force
	11 Use the hand with the arm in various positions
	12 Manipulate objects
	13 Flow, timing, coordination

Pre-prosthetic preparation

Prior to prosthetic fitting, the patient's needs are assessed to decide on the appropriate prosthetic hand type. We recommend a person-centred interview, to capture the activities that are important for the patient, and which of these the patient needs to perform with a prosthesis. The pre-prosthetic preparation also involves physical therapy and training of the muscle signals.

Integration - practise wearing the prosthesis

The goal of **step 1** in STAIR is that the patient integrates the prosthesis into his or her body image and wears it in a natural way when sitting, standing and walking. **Step 2** involves using the prosthesis for support, for example when rising from a sitting to a standing position, and using it for assistance, such as securing the paper when writing.

Structured control training

The focus in **step 3** is to control basic hand movements, to open and close the hand. This is performed in both sitting and standing positions, with and without support and with the arm in different positions. **Step 4** teaches indirect grasping, meaning placing objects in the prosthesis with the sound hand. **Step 5 and 6** are intended for users of advanced prostheses with multiple grip functions. Switching between grip types and grip patterns is practised with and without a range of objects. See figure 9.



Figure 9. Structured control training step 6: select grip type to grip different objects with a bionic multi-grip hand.

Activity performance - practise daily activities

When the patient knows how to control and shift between grip types, the training continues with learning to perform activities of daily living. We recommend using activities that are meaningful to the patient, that is, the activities that were identified in the person-centred interview. The patient is taught in **step 7** to use a power grip in bimanual tasks, and in **step 8** to apply a precision grip when performing a simple task. In **step 9** the patient practises using individually chosen grip types when performing a chosen bimanual activity. In **step 10** the patient practises adjusting the grip force and learns to grasp and hold without damaging fragile or breakable objects. **Step 11** involves the ability to control the grip functions with the arm in various positions and to adjust the wrist and elbow into the most ergonomic position when performing an activity. In **step 12** the patient's ability to manipulate objects is fine-tuned by repeatedly grasping and releasing an object. The last step, **step 13**, focuses on flow, timing and coordination, with and without visual feedback. To perform an activity with flow, the patient needs to coordinate both hands and grip with precision timing, meaning that the hand opens just the right amount and at the right time.

Results study V

Compared to myoelectric single-grip hands, the multi-grip hands were found to be more useful in individually chosen activities. Pain-related disability decreased after fitting with a multi-grip hand. The participants learned to shift between grip types efficiently and they used many of the optional grips.

Performance and satisfaction with performance in daily activities increased for all participants according to the visual analyses. Multi-level analyses showed significant improvement of performance and satisfaction scores. After six months, the performance score on average increased by 4.2 points ($p < 0.001$) and satisfaction with performance scores increased by 5.0 points ($p < 0.001$). See figure 10.

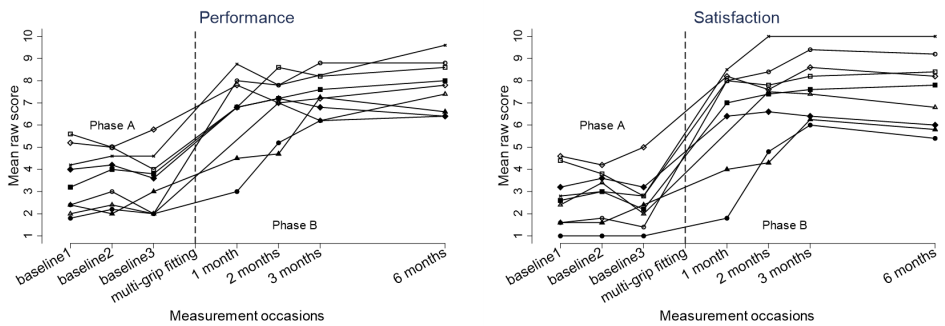


Figure 10. Visual analyses of subjective quality of performance and satisfaction with performance, as measured with the Canadian Occupational Performance Measure (COPM), plotted for the nine participants across measurement occasions. Raw scores range from 1–10, with higher scores indicating higher performance or greater satisfaction with performance.

Reported pain-related disability declined after fitting with a multi-grip hand. At the 6-month follow-up, the number of participants with pain-related disability had decreased from five to two. See figure 11.

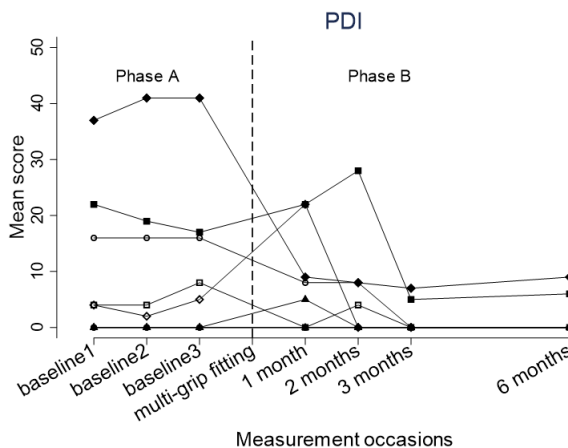


Figure 11. Visual analysis of Pain Disability Index (PDI) scores for the nine participants, plotted across measurement occasions. Higher scores indicate more pain-related limitations in the performance of daily activities. The four participants who were pain-free at baseline have overlapping lines.

Prosthesis skill and use declined after fitting with a multi-grip hand. However, after completing the training, most of the participants learned to operate the multi-grip hand as efficiently as their single-grip hand or better; this can be seen in the visual analysis of the ACMC scores in figure 12. Multilevel analyses showed that, at the 6-month follow-up, the mean time to perform the modified SHAP was 6 seconds slower for the light objects ($p=0.421$) and 3 seconds faster for the heavy objects ($p=0.668$) compared to baseline with the single grip hand.

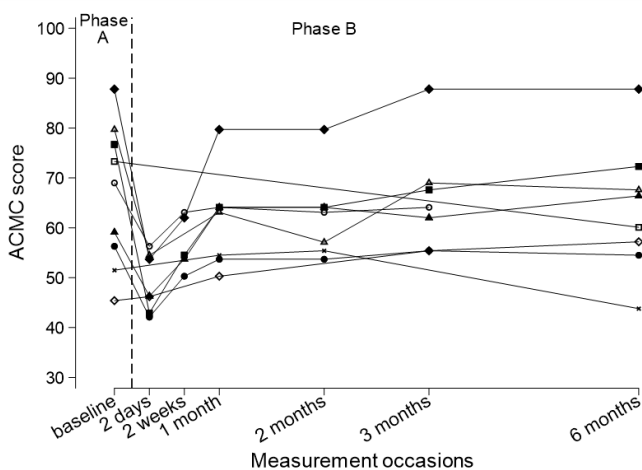


Figure 12. Visual analysis of skill in myoelectric prosthesis use, as measured with Assessment of Capacity for Myoelectric Control (ACMC) scores for the nine participants, plotted across measurement occasions. A higher score indicates greater skill in myoelectric prosthesis use. Most participants decreased in skill after the fitting of a multi-grip hand but regained their skill after using the hand for 3 months.

The actual use and perceived usefulness of multiple grip features showed positive results. The participants increased their self-reported prosthesis wearing time after switching to a multi-grip hand, from a mean of 6.9 hours a day with their single-grip hand to 8.8 hours a day at the 6-month follow-up. They used on average 8 out of the 11 available grip types (range 7–10). Grip types that were considered most useful and used were the power grip, tripod pinch and lateral pinch.

A **secondary finding** was the poor durability of the multi-grip hands. The median number of repairs was 1 (range 1–5) during the six months of the trial, and no participant was free from technical problems with the device.

DISCUSSION

The overall aim of this thesis was to gain insights into the benefits and use of myoelectric arm prostheses. The results from the included studies show that multiple factors influence the use of myoelectric prostheses. The physical, institutional, cultural and social aspects of the environment all have an impact on the usability of the prostheses and consequently on to what extent people with limb loss actually use them and benefit from using them. The benefits of myoelectric prostheses and the factors that influence how they are actually used will now be discussed.

Factors influencing who benefits from myoelectric prostheses

Several benefits of using a myoelectric prosthesis have been described earlier. A prosthesis may restore body balance, compensate for grip function³⁶ and prevent overload of the contralateral hand.^{14, 16, 91, 92} Moreover, a prosthesis may enable participation in society and help people with limb loss to blend in, to be like everyone else.^{18, 23} These benefits only occur if the prosthesis is actually worn, and for this, its usability is crucial.

Usability is a complex concept, including goal fulfillment with effectiveness, efficiency and satisfaction in a specific context of use for a specified user of a product.⁵⁵ Another explanation of usability is that a product is worth using if it satisfies the user's needs in terms of its **relevance, efficiency, learnability** and **satisfaction**.⁶¹ These four factors definitely have significance for prosthesis use. However, since the prosthesis is a body-worn assistive device, there is one more aspect with a significant impact on use, namely, **embodiment**, or adaptation to the prosthesis. How all these factors influence the use of a myoelectric hand prosthesis, and thus also the benefits of using it, has been studied in this thesis through the users' experience (studies I–II), earlier research with a focus on training to use the prosthesis (study III) and outcomes from a clinical trial (studies IV–V). They are considered in turn below.

Relevance for use

An assistive technology device has to facilitate the performance of an activity or task to feel relevant for use.⁶¹ For people with upper limb loss, a myoelectric prosthesis can fulfil this requirement, and thereby also enable participation in society.³⁶ The low level of prosthesis abandonment reported in study I indicates that most participants indeed found their prosthesis

relevant for use. The results from studies I and II show that using a prosthesis can improve their participation in society, since the daily users of prostheses reported few barriers to participation, and they claimed that their prosthesis helped them to do everything that other people can do. In contrast, the non-users in study II sometimes avoided activities they could not perform with only one hand.

The newer myoelectric prosthetic hands have been developed with multiple grip functions to make them more relevant for use, and thus more appealing to non-users. Earlier studies have questioned the benefits of using multi-grip prostheses in daily activities,⁴¹⁻⁴⁴ but the results from study V demonstrated that multi-grip prostheses can be beneficial for the performance of daily activities that users found hard to perform with a single-grip prosthesis. In addition, several of the participants in study V found that using the multi-grip prosthesis reduced the pain-related disability they experienced from using a single-grip prosthetic hand. This is in line with results from earlier studies showing that avoiding pain justifies the use of a prosthesis.¹⁴ The participants in study V also increased their wearing time, which suggests that the multi-grip prosthesis was relevant and beneficial to use.

Efficiency of use

An assistive technology device needs to be efficient when it is used, otherwise it may be abandoned.⁶¹ Many people with limb loss abandon their prosthesis due to lack of comfort and function.⁷³ Poor functionality hampers efficiency of use, and in study II the participants wished for better functionality in their prostheses. The participants in study V were fitted with a prosthesis with multiple grip types, giving greater functionality than their previous myoelectric hands, and they were more satisfied with how they performed activities with the new multi-grip technology. This is in contrast to the results from earlier research claiming that single-grip hands are more efficient to use in daily activities.^{41, 42, 93} In study V, all participants had access to both types of prosthetic hand but most participants preferred the multi-grip hands, indicating that this type of hand was perceived as efficient to use. However, for the participants who had multiple breakdowns, the multi-grip prosthesis was not experienced as especially efficient.

The results from studies I and II showed that the physical environment had a negative impact on the efficiency of prosthesis use. For example, hot

weather affected the socket comfort and electrode function, while cold weather impaired the durability of the batteries.

Another aspect that may strongly affect the efficiency of a prosthesis is the user's proficiency in operating the hand. Earlier research has suggested that the increased cognitive load that results from the use of multiple functions in a prosthesis may be a reason for not using these functions.⁴⁷ To reduce the cognitive burden when learning a new skill, repetition and practice are needed,⁹⁴ and repetition was therefore included in the structured training method STAIR, developed in study IV.

Learnability

The technology needs to be easy to learn how to use, otherwise it may never be used.⁶¹ The importance of training has earlier been highlighted as crucial for prosthesis use.^{74,95} This could be seen in study II, where some of the non-daily users lacked support and training from their local healthcare providers and never learned how to use their prosthesis. Earlier research found that the users of multi-grip prostheses did not use the new functions to any great extent.⁴⁷ The poor descriptions of how to use a multi-grip hand that were found in the scoping review (study III) may explain why multi-grip prostheses are not used to their full potential. Poor descriptions may also give poor guidance to the clinician and thus inferior training for the patients who are prescribed a multi-grip prosthesis. However, our findings show that, with the structured and person-centred training method STAIR (study IV), the participants learned to operate the multi-grip hand. The person-centred training enabled them to practise using the prosthesis in activities that were important to them and in the contexts where the prosthesis was going to be used. Unlike the training performed in a laboratory environment, the person-centred STAIR training helps the patient to benefit from the prosthesis in daily life activities. The results from the modified SHAP test and the ACMC assessment showed that the participants learned to use their multi-grip prosthesis as efficiently as their previous single-grip prosthesis, or better (study V). Even though STAIR seemed to be effective, evidence for alternative training methods is lacking. Future research may compare different training methods and evaluate the users' performance before and after the training, to establish which method is most effective for prosthesis users.

Satisfaction

If the assistive technology device is going to be used, the design must suit the users' needs, including how they like to be perceived by the surrounding society.⁶¹ Appearance versus function has been an issue in prosthetic rehabilitation,^{20, 96} and most of the participants in study II wanted both. The appearance of the old single-grip prostheses is not entirely natural, and therefore these prostheses were rejected by some of the participants. Some of the new multi-grip prostheses have a robotic look and are not manufactured in small sizes, which makes them especially difficult for women to accept.⁹⁷ For many women, the hands fail completely to match their feminine identity and needs. The bionic multi-grip hand, in contrast, has a more natural appearance when wearing a glove, compared to both the robotic-looking multi-grip hands and the single-grip hands. In social activities, such as shaking hands, satisfaction with performance increased significantly for the participants in study V after being fitted with the more natural-looking multi-grip hand. This result strengthens the idea that satisfaction with the appearance of a prosthesis is important for its acceptance and use, and since people vary in their physical characteristics, lifestyle, needs and preferences, there should be a range of prostheses to satisfy different users.

Another aspect is their satisfaction with the functionality of the prosthesis. As many as 86 different factors are listed in an extensive overview of user-relevant factors determining prosthesis choice in persons with upper limb loss.⁹⁸ This reinforces the need for an individual and person-centered prescription process, and for prostheses adapted to different needs.

Embodiment

Prostheses today have two basic kinds of design: either a natural-looking hand or one with a robotic or tool-like appearance. Regardless of whether the prosthesis feels like a hand or a tool, its use is facilitated by adaptation or integration to the user's body image.⁵⁴ Study I found a correlation between environmental barriers and frequency of use, showing that daily users, who had adapted well to the prosthesis and perhaps embodied it, experienced few environmental barriers to participation.

Despite the importance of embodiment, integration and adaptation, the lack of descriptions of the integration training phase for multi-grip hands in the literature (study III) indicates that today's prosthetic rehabilitation is not

focusing on integration and adaptation. If the users lack the right training to adapt to the prosthesis, this may be a reason for the high rates of prosthesis abandonment.^{40, 67} Our findings show that a prosthesis that is embodied is unlikely to be abandoned, since all the daily users in study II expressed the feeling that the prosthesis was a part of them, something they could not function without. They had adapted the prosthesis into their body language and used it intuitively and naturally. A conclusion may be that the integration training phase is important and therefore has its place in the training method STAIR (study IV).

Methodological considerations

Several methodological measures have been taken to strengthen the quality of the included studies. The validity and reliability of the two studies with a quantitative approach (I and V) will now be considered, as well as the trustworthiness of the studies with a qualitative approach (II, III and IV), using the four trustworthiness criteria: credibility, dependability, conformability and transferability.⁹⁹ The three main research questions, **environmental influence, multi-grip training and effect of a multi-grip hand on daily activities**, will now be discussed to consider the strengths and possible limitations that may have affected the results.

The influence of environmental factors on prosthesis use (study I, II)

Both quantitative and qualitative designs were used to investigate environmental influences on myoelectric prosthesis use, studies I and II. A qualitative design is preferable when studying an unexplored area,⁹⁹ which corresponds well to the influence of the environment on myoelectric prosthesis use. The transferability of study II is limited due to the small sample size, but the fact that we also investigated the same topic from a quantitative perspective (study I) may have strengthened the validity and credibility of the findings; this dual approach may also have increased the generalizability of our results to other similar populations of people with upper limb loss.

To examine the influencing factors, environmental barriers and facilitators, in study I we used the CHIEF-S questionnaire for the barriers and a questionnaire based on the ICF environmental factors for the facilitating factors. The questionnaire for facilitating factors was not validated, which may be a weakness. However, it had been used before in a Swedish context to examine environmental facilitators.⁷⁹ Other available questionnaires that

examined both barriers and facilitators, such as the Facilitators and Barriers Survey,¹⁰⁰ or the Measure of the Quality of the Environment,¹⁰¹ would have been much more extensive, but these were not validated for the Swedish context or for assistive technology device use. The CHIEF-S is validated for people with disabilities in a Swedish context and was therefore judged as the most appropriate choice.⁷⁸

A possible weakness is the analysis of the questionnaire which asked about facilitators. There were only a few significant differences between the groups. This questionnaire uses a simple five-point ordinal scale, whereas the more sensitive CHIEF-S produces interval-level data. Since the CHIEF-S questionnaire is validated, we used it for calculating the study power. In retrospect, the questionnaire on facilitators probably needs more power (more participants) than CHIEF-S to achieve significant results.

It is a challenge to conduct a survey with people who have cognitive impairments and thus use cognitive assistive technology. Therefore, in study I we offered the participants help from their local therapist. If the participant found it hard to fill out the questionnaires, a structured interview was offered instead, with help from the participant's prescriber of the assistive technology. This ensured a higher response rate than expected from this group of assistive technology users, which increased the reliability and validity of study I.

To ensure the credibility of study II, we aimed to have a varied sample of participants.⁹⁹ Both men and women participated, spanning a broad age range. Congenital and acquired limb loss at different levels were represented, but a potential weakness is the lack of women with acquired amputation. There are generally very few women with acquired amputations in society,^{92, 102} and none of them showed an interest in participating. However, there were equal numbers of men and women with congenital limb reduction deficiency, and the women included daily prosthesis users and non-daily users, which may contribute to the female perspective of the influence of the environment on prosthesis use. Overall, there are few research studies on female perspectives on prosthesis use,⁹⁷ and the extent and nature of gender differences is something for future research to address.

In study II we took several measures to ensure the credibility of the study. An interview guide was used to strengthen the dependability of the data and to ensure that the interviews were held in a similar way.⁹⁹ Furthermore, all interviews were conducted by the same researcher, CW. She was an experienced occupational therapist but inexperienced within prosthetic rehabilitation and had no earlier relation to the participants, which strengthened the conformability (objectivity) of the study. Additionally, all interviews were audio recorded and transcribed verbatim by CW, which further strengthened the conformability. Due to long distances for some participants to travel to the clinic, three of the interviews were conducted by phone. The lack of visual information such as eye contact and body language may be a limitation, since face-to-face interviews are preferable. Nonetheless, those three interviews were long with rich descriptions, which might compensate for the lack of visual information.

To ensure the credibility of the analysis in study II, investigator triangulation¹⁰³ was performed three times during the analysis process. The triangulation was performed by CW and two experienced researchers (LH and IP) during the coding, categorization and interpretation of the theme. The experienced researchers had complementary expertise: LH had long experience as a researcher and occupational therapist in prosthetic rehabilitation, and IP was an occupational therapist and researcher with expertise in qualitative methods. Their different qualifications and pre-understanding brought a broader perspective into the analysis and increased the credibility of the analysis process.

Training instructions for multi-grip prosthesis use (study III, IV)

Published training instructions for multi-grip hands are few, and many of the published research articles refer to the manufacturers' user manuals for training instructions for multi-grip functions. Therefore, we choose to perform a scoping review to investigate what training methods are recommended for users of multi-grip prosthesis (study III).¹⁰⁴ The method we followed uses a structured search strategy and allows grey literature (user manuals) to be included as well. The systematic search gave only five research articles, but by including the user manuals, we almost doubled our sources for the review, which gave a richer and more valid result. We chose this scoping review approach because our aim was to describe data from persistent published sources that can contribute to the evidence base and easily be found by clinicians searching for a method. A possible limitation

with this approach is that we didn't ask clinicians what method they currently use for training patients with multi-grip prosthesis.

To strengthen the validity of study III, CW performed the literature search together with a research librarian who had expertise in searching research literature. This thorough search and the results from the scoping review were used in study IV. The comprehensiveness of the search ensured that all important elements of training were taken into account in the new training method STAIR, which strengthens the validity of the new method.

To ensure the credibility of the analysis in study III, we used triangulation¹⁰³ by three researchers with different qualifications, CW, KLH and LH. The three authors read all sources independently before discussing them to reach consensus. One of the experienced researchers, KLH, is an occupational therapist from the neuro-rehabilitation field with no preunderstanding for myoelectric prosthesis training. This brought objectivity into the analysis process in a positive way, since preunderstanding of a field may make it harder to consider other perspectives in the analysis.

Two of the four authors who developed the new training method STAIR (study IV), CW and KE, were clinicians working at the Limb Deficiency and Arm Prosthesis Centre at Örebro University Hospital. In the analysis of which skills are most important to practise and what materials should be used, their clinical experience contributed to making the method feasible. Furthermore, the continuous testing of the method in clinical practice facilitated the analysis process and the development of the new method.

The effect of multi-grip hands on daily activities and pain (study V)

A single-case design was chosen for the last study, with a multiple baseline AB design, which is preferable for studying changes over time, especially for technology-based interventions, such as prosthesis fitting.^{85, 105, 106} Behavioural changes take time, and to be able to study changes in the participants' activity performance and pain-related disability, the follow-up time was long: six months after the intervention. An equal time between all follow-up occasions may have been ideal, but one-month intervals would fail to capture changes in the first weeks, and shorter intervals would mean an impractical number of follow-up visits during the six-month study period. Many of the participants had to travel a long distance to the clinic, and take time off from school or work. Therefore, we had to balance the

number of follow-ups. As we assumed that most changes would occur in the beginning of the treatment, the time points for follow-ups were set closer in the beginning. This assumption was borne out in the data and could be captured and described by the chosen design. A limitation is that we do not know whether there were any changes during the period between the 3-month and 6-month follow-ups, but the data would suggest that, for most participants, this period is very stable. Single-case design is also preferable for small study samples.⁸⁵ Our sample was large enough to analyse the results also on a group level with multi-level linear regression,⁸⁵ which strengthens the validity of our results. A possible limitation, due to the small population, is that we could not afford to pilot the study design and feasibility of the tests before starting the data collection, and small changes had to be made after the first three participants; these were that the modified SHAP test was performed in a sitting position instead of standing and that a study specific questionnaire about environmental factors influence on prosthesis use was removed.

People with upper limb loss are rare in Sweden,^{3, 9} and those who have a verified need for the new multi-grip prosthesis technology are few. Only patients who had a verified need for multi-grip functions and an approval from their home region to have such a prosthesis were asked to participate in study V. Therefore, the recruitment of participants took several years, and could have been accomplished faster if everyone who visited the clinic could be invited to take part. However, it would have been unethical to equip people with new multi-grip prostheses that would have to be returned after the end of the data collection. This resulted in a predominantly young sample, who were interested in new technology, had asked about new hands and also had a verified need for the functions. The generalizability of the results is thus restricted to the younger population. Both men and women with congenital and acquired limb loss were represented though, which expands the generalizability. In future studies, it will be important to invite people of all ages to participate.

In study V, several outcome measurements were used, carefully selected to measure activity performance, pain, proficiency or actual use of the prosthesis, without making the participants too exhausted. We chose to use the COPM to measure the effect of multi-grip functions in daily activities, compared to single-grip prosthesis. Our results are more positive than previous studies on the effects of multi-grip hands in daily activities.^{41-44, 93.}

^{107, 108} The previous studies have used questionnaires such as Disability of the Arm, Shoulder and Hand (DASH)¹⁰⁹, or the Orthotics and Prosthetics Users' Survey (OPUS)¹¹⁰. As we have used the COPM,¹³ comparisons between our results and the results of previous studies are therefore difficult, which may be considered a limitation. However, these questionnaires are not person-centred and may therefore ask about activities that the prosthesis user may never want or need to perform. Thus, a person-centred evaluation method, such as COPM, ought to be most appropriate when measuring a person's performance of daily activities, and this strengthens the internal validity of study V.

A possible limitation in study V is the modification of the validated SHAP test. To be able to measure the time for switching between different grip types, we had to modify the validated and commonly used SHAP.⁸² There is no available test for measuring switching between grip types, and the modified test seemed to serve this purpose well, as the participants were instructed thoroughly in which grip type to use for each object. Without the verbal instruction, they could have performed the test faster without switching between grip types. As in the original SHAP version, the participants themselves clocked the time of the test by pressing a button to start and stop the timer, which improved the reliability of the modified SHAP. The SHAP test has been criticized for learning effects,¹¹¹ so, to avoid these learning effects, we ensured at least two weeks between data collections for both the performance tests (modified SHAP and APMC), which strengthens the reliability of these results.

To ensure the objectivity and reliability for the data collection in study V, we aimed to have a treating occupational therapist who gave the training instructions and a different person, a researcher, who collected the data at each visit. For a majority of the participants, we succeeded. The researcher CW collected all data for all participants. Due to sickness among the occupational therapists during the COVID-19 pandemic, four of the participants had to get some of the training from CW, which may have led to more positive results. However, a strict research protocol was used, which contributed to consistency in data collection and training, which strengthens the objectivity and reliability of study V.

In study V, the participants' performance of the APMC activities was filmed in order to blind the researcher (HL), who watched the films in a random

order when assessing the scores. This blinding strengthens the validity of the APMC scores. A further measure to strengthen the validity of the results in study V was to conduct sensitivity analyses; these showed similar results between different multilevel linear regression model methods.

CONCLUSION

Compared to users of other kinds of assistive technology, the users of hand prostheses reported few environmental barriers for use. The barriers they did experience concerned the physical and institutional environment and in particular the prosthesis functionality, design and prescription. Embodiment of the prosthesis was reported to reduce environmental barriers and facilitate use.

There are few well-documented descriptions of how to teach patients to learn and use a multi-grip prosthesis in daily life. Our new training method, STAIR, has a special focus on integration training to promote the embodiment of the prosthesis, as well as practising the performance of activities to promote use of the multi-grip functions in daily life.

Multi-grip prostheses have a positive effect on the performance of daily activities, pain-related disability and prosthesis use compared to single-grip hands. The learnability and embodiment of the multi-grip prosthesis seems to be facilitated by the structured training method STAIR.

CLINICAL IMPLICATIONS

- Healthcare professionals can facilitate the use of a myoelectric prosthesis by giving the patient support and training. Support early in the rehabilitation process may result in positive coping strategies and facilitate the adaptation to the prosthesis.
- The structured and person-centred training method STAIR facilitates training for people with upper limb loss who have been prescribed a prosthesis. With the STAIR method, people learn how to use all the functions in their myoelectric prosthesis, which may facilitate use in daily life.
- To enable activity performance and participation for users of prosthetic hands, it is important to have the possibility to prescribe more than one type of hand. Multi-grip hands have a better appearance and allow for ergonomic movements, but they are less durable and may not be suitable for heavy physical activities compared to single-grip hands. Hence, people with upper limb loss may need to have access to both types of hands to be able to do whatever they need and want to do in life.
- My hope is that this thesis will contribute both with scientific evidence and with patient values and preferences to develop and refine rehabilitation for people with upper limb loss. This would benefit the patients, the occupational therapists and other clinicians in the field of prosthetic rehabilitation.

SAMMANFATTNING PÅ SVENSKA

I Sverige är det årligen 2.6/10 000 levande födda barn som saknar hand eller en del av handen och ca 4 personer/100 000 förlorar en hand genom amputation. Dessa personer erbjuds ofta en myoelektrisk protes, ett kroppsbundet hjälpmedel med greppfunktion, för att kompensera för avsaknaden av en hand. Protesen ska öka möjligheten att leva ett aktivt liv och vara delaktig i samhället, vilket i sin tur kan bidra till förbättrad hälsa och livskvalitet. De vanligaste myoelektriska proteserna kan gripa mindre föremål mellan tummen, pek- och långfingret och större föremål med hela handen. Protesanvändaren öppnar eller stänger proteshanden genom att spänna sträck- respektive böjmusklerna på armen. Muskelsignalerna fångas upp av hudelektroder inuti proteshylsan och leds till en motor som i sin tur aktiverar proteshanden. Det krävs en del träning för att användaren ska lära sig kontrollera protesen och använda den i dagliga aktiviteter.

Avsikten med myoelektriska proteser är att de ska underlätta livet för personer med armamputation, men studier visar att proteserna ofta inte används. Användningsgraden varierar mellan 12–75%. Vår omgivning påverkar i hög grad hur vi människor upplever vår hälsa och kan också påverka om proteser används eller inte. Protesens funktion och design bör också motsvara förväntningar och behov för att den ska bli använd. Avhandlingens övergripande syfte är att öka kunskapen om vad som påverkar att personer med armamputation använder myoelektrisk protes och har nytta av den.

För att undersöka hur omgivningen påverkar användning av protes gjordes både en enkätstudie (Studie 1) och en intervjustudie (Studie 2) med personer som fått myoelektrisk protes förskrivet. Studie 1 visar att den fysiska miljön upplevs mest hindrande och att protesanvändare inte får tillräckligt stöd från myndigheter, genom lagar och förordningar. Resultatet i studie 2 visar att stöd och uppmuntran från familj och professionella inom sjukvården underlättar användning av protes. Protesens funktion och design har brister som påverkar användningen negativt, men när protesen känns som en del av kroppen och används på ett naturligt sätt minskar negativ påverkan från omgivningen, vilket i sin tur underlättar användningen av protes. För att proteserna i högre grad ska komma till användning kan vi inom sjukvården bidra med stöd och träning.

För att möta brister i design och funktion har det de senaste åren utvecklats mer avancerade multi-grepp händer där användaren kan växla mellan olika typer av grepp eller positioner, men det finns delade meningar om de bättre motsvarar användarnas behov. Det är inte heller tillräckligt undersökt och beskrivet hur man bäst lär sig använda funktionerna i de nya multi-grepp proteserna. Flera studier de senaste åren rapporterar att funktionerna i multi-grepp proteserna inte används. Frågan är om protesanvändare får tillräcklig träning för att lära sig använda de nya funktionerna? För att ta reda på vilken träning som rekommenderas för användare av multi-grepp proteser gjordes en scoping review (Studie 3). Resultatet visade att instruktioner för att träna patienter att använda multi-grepp funktioner var otillräckligt beskrivna. Det som var minst beskrivet var träning för att integrera protesen i rörelse-mönstret och användning av multi-grepp funktioner i dagliga aktiviteter. En strukturerad metod för träning i protesanvändning, Stepwise Training for an Advanced and Integrated prosthetic Routine (STAIR), utvecklades (Studie 4) där en del av träningen är särskilt inriktad på användning av protes med multi-grepp funktion.

För att studera nyttan och användningen av en multi-grepp hand som provas ut med stöd i form av träning enligt STAIR, genomfördes en klinisk studie med single-case, AB-design (Studie 5). Resultatet visade att multi-grepp funktionerna ökade möjligheten att utföra dagliga aktiviteter och minskade belastningsrelaterad smärta. Patienterna lärde sig att styra och använda sin protes effektivt och många av funktionerna i multi-grepp händerna användes fortfarande 6 månader efter utprovningen, vilket visar att användarna hade nytta av dem.

Sammanfattningsvis är det flera faktorer i omgivningen som har betydelse för om myoelektriska proteser används eller inte. Positiva faktorer som stöd och träning från sjukvården kan underlätta anpassningen till protesen, och den strukturerade träningsmetoden STAIR gör det lättare att lära sig protesens funktioner. En protes med fler funktioner kan öka möjligheten att utföra dagliga aktiviteter, och kunna göra allt som alla andra.

Min förhoppning är att denna avhandling kan bidra med vetenskapligt bevis för att utveckla rehabiliteringen för personer som saknar en eller båda händerna och vill använda protes. Detta skulle gynna både patienterna, arbetsterapeuterna och andra kliniker inom protesrehabilitering.

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