Training for users of myoelectric multigrip hand prostheses: a scoping review

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Abstract

Background: Training is crucial to develop the ability to operate a myoelectric prosthetic hand and use it in daily life. Multigrip prostheses, with their wider repertoire of functions, require further training. Because studies show that prosthesis abandonment is an issue and the advanced functions are not used to the expected extent, the question of what training should be offered to patients arises. If the available training methods were synthesized, the training could be improved to the benefit of the people who are fitted with a multigrip prosthesis.

Objective: To critically examine the content of published sources for training of users with myoelectric multigrip hand prostheses.

Study design: Scoping review.

Methods: A literature search covering the period 2007–2020 in the databases PubMed, CINAHL, and Allied and Complementary Medicine Database, as well as gray literature from prosthesis manufacturers, identified 2,005 sources. After full-text review of 88 articles and four user manuals from manufacturers, nine sources were included and analyzed in their entirety.

Results: We found few descriptions of multigrip prosthesis training, and no source described all training phases in detail. Integration of the prosthesis and training in daily activities was described least. Few sources actually described how to perform training in multigrip functions, and none described how to integrate these functions in daily life.

Conclusions: Existing training instructions for using multigrip prosthetic hands are inadequate, providing poor guidance to clinicians and insufficient training for patients. Further research is needed into the efficiency of various training methods.

Keywords

upper limb, amputation, rehabilitation, occupational therapy

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Background

People with congenital or acquired arm amputations are often offered myoelectric prostheses to compensate for loss of body structure,1 to achieve body balance, and to prevent problems with compensatory overloading in the contralateral arm.2 In addition to these benefits from prosthesis use, a myoelectric prosthesis can enhance independence and participation in daily life, which may bring an improved quality of life for people with arm amputations.1

Myoelectrically controlled prosthetic hands have been available since the late 1960s.3 The fitting procedure is characterized by a team approach, involving both prosthetists and therapists to build a prosthesis and provide training for the patient to operate and use the prosthetic hand.4 To develop the ability to operate a prosthetic hand and use it in daily life, training is crucial.5 Training for users of conventional myoelectric prosthetic hands has been described since the 1980s, when these hands became more commonly available.4,6-9 The conventional myoelectric hand has a single motor that controls the thumb, index finger, and middle finger to form a power grip or a pinch grip, depending on the object and the precision needed to get a secure grasp. In 2007, the first commercially available multigrip hand, the i-limb,10 was launched. Multigrip hands typically have several motors, which enables separate movement of the fingers to achieve several types of grasps or positions of the hand. Today, there are many hands with multiple grip functions on the market. There is a growing interest in multigrip hand prostheses, and besides the i-limb hand, a recent narrative review11 mentions the Michelangelo hand,12 the TASKA hand,13 the bebionic hand,14 the Vincent hand,15 and the LUKE arm,16 but more hands have become available since that review. The new multigrip technology expands the user’s potential abilities. However, further training may be required to be able to use the additional functions in the multigrip hands.

Myoelectric prostheses are used to a widely varying degree, from daily use of the functions to only wearing the prosthesis occasionally or wearing it frequently but not using its functions at all, and several studies suggest that one reason could be insufficient training.17-19 Prosthesis abandonment because of dissatisfaction with the functionality is also a commonly reported problem.20
Another concern is the difficulty in learning to control the prosthetic functions to achieve full usage of the device. It has been reported that the additional functions are not used in the multigrip hands.21 This is a concern that needs to be addressed.

In the process of fitting patients with multigrip prosthetic hands, the question arises as to what training these patients should have. The multigrip hand can be operated either by the two-site electrode system used in conventional myoelectric hands, by other control methods such as force-sensitive resistors, switches, and linear transducers, or by a pattern recognition system with multiple electrodes.22 The pattern recognition system was originally developed for multifunction prostheses to control movements in the elbow, wrist, and hand.23,24 However, the weight, size, and especially the high cost of commercially available pattern recognition systems leave many users content with the two-site electrode system even for operating multigrip hands. For these users, the training to use conventional myoelectric hands and multigrip hands should thus be similar, apart from the training to switch between the additional functions in multigrip hands. The conventional training to learn how to operate a prosthesis and finally use it in daily life is often described in different phases: preprosthetic phase, integration phase, control training phase, and training in daily activities.4,6,9

To use a prosthesis in daily activities, the training needs to be performed in an everyday context.25 The theories behind learning and training for prosthesis use have been studied by a research group from the Center for Human Movement Sciences at the University of Groningen in the Netherlands.26 They have contributed with new insights into the learning process for prostheses control, but this research does not examine how people learn to use a prosthesis in actual daily life activities. A majority of their published research is focused on training in laboratory settings, often with able-bodied participants.27 How users of multigrip prostheses learn to integrate the new functionality into their daily lives, by contrast, is sparsely studied. Overall, there is very limited scientific evidence regarding the outcome of prosthetic rehabilitation and most guidance is based on clinical experience.8,9,28 Little is known about what methods are recommended for training with multigrip prosthetic hands and whether there is evidence for the efficiency of these methods. To refine the training for users of multigrip hand prostheses, it is important to synthesize current knowledge on training procedures, to identify gaps that might negatively affect prosthesis use. This review aims to critically examine the content of published sources for training of users with myoelectric multigrip hand prostheses.

**Methods**

To gain an overview of existing training instructions for users of multigrip myoelectric prosthetic hands, a scoping review according to Grant and Booth’s description29 was performed. It included a systematic search, review, and synthesis of documented multigrip myoelectric prosthesis training. The Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews Checklist was followed to guide the process.30,31 The aim was to include sources describing training methods for users of multigrip hands that had been peer-reviewed, were published as primary sources, and would be accessible to clinicians searching for a training method. An expert group consisting of three occupational therapists (the authors), each with 30–40 years of clinical experience, two from prosthetic rehabilitation and one from neurological rehabilitation, performed the review.

**Literature search**

Sources were searched from the databases PubMed, CINAHL, and the Allied and Complementary Medicine Database. Fitting of myoelectric prostheses with multigrip functions started in 2007 with the i-limb hand. Therefore, the search was limited to a period between January 2007 and February 2020. Training instructions for users of myoelectric prostheses are rarely available, and the designation for multigrip hands varies between advanced, multifunctional, and multiarticulated, among other terms, with no established generic term. The literature searches, therefore, covered all types of myoelectric prostheses to ensure that multigrip hands were included. With expert help from a research librarian, titles and abstracts were identified using the following 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 limb” OR “artificial arm” OR “artificial hand” OR “prosthesis” OR “prostheses” OR “prosthetic” OR “myoelectric” OR “myoelectric”. 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. Several of the research articles referred to user manuals from manufacturers for training instructions. Hence, in addition, a gray literature search was made among available published user manuals from manufacturers of commonly used multigrip prosthetic hands.31

**Inclusion and exclusion criteria**

Original English-language, peer-reviewed research articles describing training instructions for users of multigrip myoelectric prostheses, or a combination of multigrip myoelectric prostheses and other types of prostheses, were included. Articles focusing only on conventional myoelectric prostheses and body-powered or passive prostheses were excluded, as were articles concerning prototypes of multigrip prostheses not available on the market. Articles that did not describe any training with a prosthesis involved, in other words, those only describing signals training with prosthesis simulators or myo bands in a laboratory setting, were also excluded (Figure 1).

**Selection process**

The literature search resulted in 2,005 peer-reviewed articles and four user manuals from manufacturers. After duplicates were removed, 1,528 sources remained. After screening titles and abstracts, 88 articles and four user manuals remained, which were reviewed in full text. First, the three authors independently judged the same 20 sources for inclusion in the full-text review. The results were discussed, and disagreements on inclusion and data extraction were solved by consensus. The first author screened the remaining 72 sources in the same way. In total, 83 sources were excluded and nine remained for inclusion in the data synthesis (Figure 1).
Data synthesis

Based on the previously established phases of preprosthetic and prosthetic training, a data charting matrix was jointly developed by the authors to determine which variables to extract. All the authors then independently used this matrix as a guide to extract data describing multigrip training for the given type of prosthesis at each of the established training phases. They categorized the content of each phase present in the nine included sources, based on how clearly that phase was described. The content categories were, in order of descriptive level, 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; and Well-described—a procedure description that any instructor could follow to guide the training. Finally, the categorizations were discussed until consensus was reached.

Results

The full-text review resulted in the inclusion of five research articles and four user manuals from manufacturers describing myoelectric training with prostheses of various designs. See Table 1 for an overview of each source, the study design, participants, and prosthesis type.10,12,14,32-37 In the two case studies, the participants (one participant in the first study and two in the other study) had transradial amputations. In the case-control study, five participants with transradial amputations were matched with five participants with intact limbs. In the observational study, the 36 participants had either transradial or transhumeral amputations. Four of the sources were from Europe,10,12,14,35 four were North Americans,33,34,36,37 and one was from Oceania.32 Of the nine sources, only one mentioned all phases of training,36 and no source described all phases well. Table 2 presents an overview of which training phases each source
described and at what level of detail. The information given for each phase is synthesized below.

**Preprosthetic physical training**

Three of the nine sources stated that physical training is necessary to prepare the user to wear, tolerate, and use a prosthesis.\(^{12,14,36}\) They explained that training for a range of motion and strength helps to regain posture, coordination, and balance. The Michelangelo user manual recommended training in front of a mirror to prevent compensatory movements.\(^{12}\) The bebionic user manual included an illustrated program with examples of exercises for full body training with simple materials, such as blankets and plastic bottles.\(^{14}\) Johnson and Mansfield\(^{36}\) pointed out that, depending on the condition of the amputated limb, physical training may include edema and scar management, pain management such as desensitization, or, in the case of phantom limb pain, mirror therapy.

| Year, author | Country | Design | Participants | Prosthesis |
|--------------|---------|--------|--------------|------------|
| 2020, Touch Bionics by Össur\(^{10}\) | U.K. | User manual | N.A. | i-limb hand |
| 2020, Ottobock\(^{12}\) | Germany | User manual | N.A. | Michelangelo hand |
| 2020, Ottobock\(^{14}\) | Germany | User manual | N.A. | Bebionic hand |
| 2020, TASKA Prosthetics\(^{22}\) | New Zealand | User manual | N.A. | TASKA hand |
| 2018, Resnik\(^{33}\) | USA | Case study | 2 persons with upper limb amputation | i-limb hand |
| 2018, Resnik\(^{34}\) | USA | Observational study | 36 persons with upper limb amputation | DEKA arm |
| 2015, Roche\(^{35}\) | Austria | Case study | 1 person with upper limb amputation | Michelangelo hand |
| 2014, Johnson and Mansfield\(^{36}\) | USA | Method article | N.A. | Conventional/multigrip hand prostheses |
| 2009, Kuijken\(^{37}\) | USA | Case-control study | 5 persons with upper limb amputation | DEKA arm |

**Table 1. Overview of the included sources.**

| Source year, author | Prosthesis type | Preprosthetic training | Prosthetic training |
|---------------------|-----------------|-----------------------|---------------------|
| 2020, Touch Bionics by Össur\(^{10}\) | i-limb | — | — | Briefly described |
| 2020, Ottobock\(^{12}\) | Michelangelo | Briefly described | — | Well-described | Briefly described |
| 2020, Ottobock\(^{14}\) | Bebionic | Well-described | — | Well-described | Briefly described |
| 2020, TASKA by Fillauer\(^{22}\) | TASKA hand | — | — | Mentioned |
| 2018, Resnik\(^{33}\) | i-limb | — | Briefly described | Mentioned | Briefly described | Briefly described |
| 2018, Resnik\(^{34}\) | DEKA EMG-PR | — | Mentioned | Mentioned | Mentioned |
| 2015, Roche\(^{35}\) | Michelangelo | — | Briefly described | Mentioned | — |
| 2014, Johnson and Mansfield\(^{36}\) | Conv./multigrip | Briefly described | Well-described | Mentioned | Briefly described |
| 2009, Kuijken\(^{37}\) | DEKA EMG-PR | — | Mentioned | Mentioned | — |

**Table 2. Data synthesis: level of details in descriptions for each training phase.**

Abbreviations: Conv., conventional myoelectric prosthesis; DEKA EMG-PR, DEKA arm with EMG pattern recognition control; Multigrip, prosthesis with multiple grip functions. 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.
Preprosthetic signals training

Signals training was reported and well-described in the included research articles, whereas the user manuals did not mention this type of training. The articles explained that a myotester is often used for signals testing to identify muscle signals and to determine control sites before prosthesis fabrication. They generally noted that the myotester can also be used for training the patient to recognize and produce the signals, with or without feedback from virtual reality. Johnson and Mansfield recommended that the therapist should first show the patient how to activate the electrodes; then, the patient can start the training by using the intact hand or arm for activating the electrodes, to learn that relatively little force is needed. They explained that a high artificial strengthening of the muscles may hamper the patient's ability to control the grip at slow speed, and therefore, the goal is to keep the electrodes at a low-sensitivity setting if possible. They advised placing electrodes on a muscle belly using a band or a test socket. If the patient produces signals that are too weak, the electrodes can be relocated. They recommended a transparent test socket to facilitate the relocation of electrodes.

The articles about pattern recognition control systems reported that the signals training is commonly performed with feedback from virtual reality. They explained that the patient should practice different grip types by imagining the phantom limb performing the movement. The patient can perform the same movement with the intact limb to facilitate the imagined movement in the phantom limb. Resnik et al. advised that increased muscle force should be avoided, and at least 5 minutes of rest every 30 minutes should be incorporated into this signals training to avoid fatigue; if the muscle force is inconsistent, recalibration of the system is needed.

Integration training

This training phase was mentioned in two of the nine sources. Johnson and Mansfield mentioned a prosthesis wearing schedule, whereas Resnik et al. described how the therapist should pay attention to the patient's posture and positioning of the prosthesis to avoid compensatory movements.

Control training with a prosthesis

The training phase that was described by most sources and in most detail was control training with a prosthesis. Four of the sources recommended starting with training the patient to don and doff the prosthesis and then familiarizing the patient with the basic prosthesis functions, different grip functions, and grip patterns. Several sources described how the patient is taught how to open and close the hand, in a sitting position to start with, then supporting the prosthesis with a table and later in a standing position without support. The next step that they described is indirect and direct grasping, practiced with objects of various shapes and textures, holding the arm in different positions, and with and without visual feedback. The most thorough descriptions provided examples of training material for practicing control of both speed and grip force. The Michelangelo user manual recommended starting training with large, heavy, and solid objects that do not require adjustment of gripping force, before continuing with smaller, lighter, and softer objects. This training is often performed by means of repetitive drills. Two of the sources also described how to place the hand and elbow to avoid awkward positions. Various techniques can be used for switching between components such as hand, wrist, or elbow. Johnson and Mansfield described quick-slow signals and cocontraction, whereas the i-limb user manual described four different ways to switch grips: (1) hold open, (2) double impulse, (3) triple impulse, and (4) cocontraction. This manual also emphasized the importance of relaxing the muscles, stating that relaxing is as important as learning to open and close the prosthesis hand. Resnik et al. gave a good description of how to practice with a prosthesis controlled by pattern recognition, which is performed in the same way as the signals training without a prosthesis, as described above.

Activity performance training

Most of the sources included an element of activity performance training, but the level of detail was limited. The importance of training in activities that are familiar and meaningful for the prosthesis user was emphasized by two of the sources. Johnson and Mansfield described the training as bimanual tasks in daily activities, and they recommended progressing from simple to more complex activities, at home, at work, and in the community. The aim of activity performance training is to incorporate the prosthesis efficiently into daily activities using a natural motor pattern and preventing compensatory movements, according to two sources. In the bebionic manual, the therapist is instructed to encourage the prosthesis user to minimize the amount of visual attention paid to the prosthesis during the training of two-handed activities. Resnik et al. described activity performance training with examples of activities, details of what skills to practice, and instructions for performing the training. None of the nine sources presented guidance on how to practice multigrip functions or switch between grip functions in real-life daily activities.

Discussion

Overall, we found few sources in the literature that describe training to use a prosthetic hand. This review revealed that the training in published articles and manuals is not described sufficiently well to guide a clinician training users of multigrip hand prostheses. The four training phases (preprosthetic, integration, control training, and activity performance training) seem to be established in the literature and mentioned in most of the included sources. Although it has earlier been stressed that the habit of wearing a prosthesis is essential for future use and development of prosthetic control skills, still, the integration phase was hardly mentioned in the included sources. By contrast, activity performance training is mentioned or briefly described by almost all included sources, which may indicate that this part of the prosthetic rehabilitation is important. However, there are no detailed descriptions of how to perform this training.

The importance of training to use all new features of the prosthesis when switching to using a hand with multigrip functions was highlighted, as well as the benefits of using the full capabilities of the prosthesis for more ergonomic movement.
patterns with less compensatory movements. However, despite the fact that most users have a two-site control system, sources in this study have no detailed instructions on how to operate the different multigrip functions with two-site electromyographical control. Different hand positions are mentioned but not how to practice the use of them. Johnson and Mansfield merely recommended the manufacturers’ websites for more specific training instructions, but the descriptions in the user manuals vary. Most manuals had more detailed and illustrated instructions for the functions, whereas the TASKA hand manual only mentioned different grip functions with a few examples of activities where the functions may be used. Two of the manuals, bebionic and i-limb, described how to switch between different grip functions, but failed to describe how to practice this in real life. The research articles on prostheses controlled by pattern recognition gave more detailed instructions of the control training phase and highlighted the importance of starting to practice a few combinations of movements. However, they gave no information about the actual use of the grip types. If such incomplete training is offered to the patients, could this be the reason why they are not using the additional functions in their multigrip hand prostheses? The fact that our search identified only nine sources describing training methods may indicate that there is a need for further research with the purpose of describing training for users of these prostheses.

Overall, the sources that we found focused primarily on control training in laboratory settings without actual prosthetic use. Close to half of the 88 articles that we reviewed in full text had to be excluded on these grounds. The current research in control systems and advanced prosthetic technology seems to focus increasingly on preprosthetic control training and not the actual use of the prosthesis, despite the fact that the ability to activate the myoelectric control system into positions and grip types is no guarantee for prosthesis use in daily life. The patient needs to practice the use of the prosthesis in the context where it is intended to be used. Furthermore, a skilled user of a conventional prosthesis is not automatically a skilled user when switching to a multigrip hand. Practice is needed to master the new functions and make use of them in daily life. For example, the i-limb manual recommended 20–30 hours of occupational therapy when learning to use the new functions in the i-limb hand. Furthermore, Johnson and Mansfield mentioned the need for retraining when switching to a hand with multigrip functions. The question remains, what is the best way to retrain and develop new proficiency? Prosthetic rehabilitation has earlier been compared with proficiency in other areas. The learning process is described in the same way as the process of learning to drive a car. First, one needs to learn the various functions of the car (preprosthetic training), then adjust the seat position to one’s body shape and develop a sense of the car in relation to the environment (integration), then practice driving, first at a slow speed and with no traffic (control training with prosthesis), and practice driving in different contexts (activity performance training). Finally, the driving is “automated,” meaning that one no longer has to consciously think of what to do when driving; one simply drives (final goal in prosthesis use). Perhaps something like a “driving licence for prosthesis use” could be introduced in the form of a structured checklist for the therapist to work through when introducing a multigrip hand. Similar checklists are used for other assistive technologies, such as powered wheelchairs, with the requirement that all training phases must be checked and approved before training ends. Potentially, a well-described structured training method will enable the users to actually use their prosthesis more and make use of the various functions more often in their daily lives. Finally, there is a need for evidence of the efficacy of training methods, and detailed descriptions of each method would facilitate research when comparing different methods.

As suggested in the literature, preprosthetic training is only one phase in prosthetic rehabilitation and the result may not be directly transferable to patients using an actual prosthesis in daily life. However, some of the studies on preprosthetic training with able-bodied subjects have interesting findings that may be useful in the future development of training methods for prosthesis users. For example, preprosthetic electromyographical training with virtual feedback before amputation may be a good strategy and facilitate training with the prosthesis later. The grasping function can also be practiced in several steps, beginning with indirect grasping, where the subject places objects in the prosthetic hand with the sound hand, and moving on to direct grasping, where the subject grasps objects directly with the prosthetic hand. A study from 2014 on direct vs. indirect grasping by Bouwsema et al concluded that it is important to start the control training with indirect grasping. This is in line with the study from 1981 by Agnew et al and clinical recommendations, which suggests that indirect grasping is an element that should be included in training methods.

Limitations

There are several potential limitations in this study. First, the number of sources for review was very low—we found only nine sources that could be included. This could be related to either the review method or the subject under review. There are different definitions of a scoping review in the literature, and in this review, we followed the description by Grant and Booth. This definition is more stringent than some others and includes a systematic search. We chose this approach because our aim was to describe data from persistent published sources that can contribute to the evidence base as opposed to, for example, film clips. There is very limited scientific evidence regarding prosthetic training, and most descriptions are based on clinical judgement and expertise. This is reflected in the low number of sources. To strengthen the validity of this study and ensure that no important literature was missed, the search was performed together with a research librarian who had expertise in searching research literature. With this wide systematic search in three databases, covering technical, medical, and rehabilitation research in the period 2007–2020 and including follow-up of gray literature referenced in the research articles, we believe that we covered this field and found all relevant sources. In addition, the three authors independently read all nine included sources and discussed the synthesis of the data to reach a consensus, which strengthens the validity of the analysis.

Second, the quality of the information in the included sources is an interesting consideration that is generally examined in a review; however, in a scoping review, a quality assessment of included sources is not motivated. Nevertheless, the quality and the content of the sources affect the results. To be able to fulfill our purpose, we included both method articles and gray literature, which affects the level of evidence of the sources used in this review. However, none of
the nine included sources had evaluated the effect of the training methods that they described, which means that we have no information about how effective the training is. Therefore, the evidence for different training methods is something for future research to address.

Conclusions

In conclusion, published training instructions for users of myoelectric prostheses with multigrip functions are few and may not be detailed enough for the provision of sufficient training. They give limited guidance to clinicians, and their patients may thus not receive the extensive training that they need to be able to use their prostheses to their full potential. Further research is needed to establish the content and efficacy of various training methods.

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Supplemental material

There is no supplemental material in this article.

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