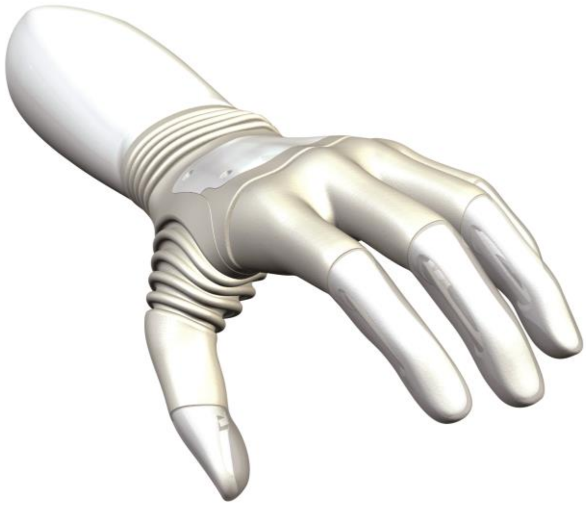
Upper extremity prosthesis for adults



Clinical Study Summaries

This document summarizes clinical studies conducted with upper extremity prosthesis for adults (Michelangelo hand, myoelectric vs. body powered prostheses, myoelectric vs. myoelectric prostheses, targeted muscle reinnervation (TMR) and training with upper extremity prostheses). The included studies were identified by a literature search made on PubMed and within the journals Der Orthopäde, JPO Journal of Prosthetics and Orthotics, Orthopädie-Technik and Technology & Innovation.

ottobock.

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Michelangelo Hand – Overview Table

The summaries are organized in three levels depending on the detail of information. The overview table (Level 1) lists all the relevant publications dealing with a particular product (topic) as well as researched categories (e.g. level walking, safety, activities, etc.). Summaries of all the literature dealing with a specific topic can be found in the document(s) above the overview table (Level 2).

For those interested to learn more about individual studies, a summary of the study can be obtained by clicking on the relevant author/reference (Level 3).

The studies presented in the table below are summarized here (Level 2):
Michelangelo Hand – literature summary

Reference		Category								Prosthesis
		Body Functions		Activity			Participation	Others		
Author	Year	Mechanics	Pain	Grip patterns / Force	Manual dexterity	ADL	Satisfaction / QoL	Training	Technical aspects	
Kyberd	2017			x						Michelangelo hand vs i-Limb, bebionic and Motion Control hands
Luchetti	2015				x		x			Michelangelo hand vs different myoelectric prostheses
Pröbsting	2015					x				Michelangelo hand vs different myoelectric prostheses
Cutti	2012	x				x				Michelangelo hand vs Digital twin hand
Belter	2011								x	Michelangelo hand, Vincent hand, iLimb hand, iLimb Pulse, Bebionic hand
Total Number: 5		1	0	1	1	2	1	0	1	

Myoelectric vs Body-Powered Upper Extremity Prostheses

The summaries are organized in three levels depending on the detail of information. The overview table (Level 1) lists all the relevant publications dealing with a particular product (topic) as well as researched categories (e.g. level walking, safety, activities, etc). Summaries of all the literature dealing with a specific topic can be found in the document(s) above the overview table (Level 2).

For those interested to learn more about individual studies, a summary of the study can be obtained by clicking on the relevant author/reference (Level 3).

The studies presented in the table below are summarized here (Level 2):
Myoelectric vs body-powered upper extremity prostheses – Do amputees need both of them?

Reference		Category								Prosthesis
		Body Functions		Activity		Participation	Others			
Author	Year	Mechanics	Pain	Grip patterns Force	Manual dexterity	ADL	Satisfaction QoL	Training	Technical aspects	
Johansen	2016						x			myoelectric, body-powered, passive prostheses
Carey	2015		x			x	x	x	x	myoelectric, body-powered prostheses
Razak	2014						x			biomechatronics wrist prosthesis, body-powered prosthesis
Ostlie	2012					x	x			myoelectric, body-powered, passive prostheses
Kooijmana	2000		x							myoelectric, body-powered, passive prostheses
Millstein	1986					x	x			myoelectric, body-powered prostheses
Stain	1983				x	x				myoelectric (Ottobock 6V), body-powered prosthesis
Northmore-Ball	1980					x	x			myoelectric, body-powered prostheses
Total: 8		0	2	0	1	5	6	1	1	

Myoelectric vs Myoelectric Upper Extremity Prostheses – Overview Table

The summaries are organized in three levels depending on the detail of information. The overview table (Level 1) lists all the relevant publications dealing with a particular product (topic) as well as researched categories (e.g. level walking, safety, activities, etc.). Summaries of all the literature dealing with a specific topic can be found in the document(s) above the overview table (Level 2).

For those interested to learn more about individual studies, a summary of the study can be obtained by clicking on the relevant author/reference (Level 3).

The studies presented in the table below are summarized here (Level 2):
Compensatory movements when using myoelectric prostheses
Phantom and residual limb pain

Reference		Category								Prosthesis
		Body Functions		Activity			Participation	Others		
Author	Year	Mechanics	Pain	Grip patterns Force	Manual dexterity	ADL	Satisfaction QoL	Training	Technical aspects	
Major	**2014**	x								Myoelectric prostheses
Bertels	**2012**	x								MovoShoulder Swing with DynamicArm and System Electric Hand vs no prosthesis
van der Niet	**2010**			x		x	x			DMC plus hand vs iLIMB
Bertels	**2009**	x								Transcarpal-Hand with and without Transcarpal Myowrist
Lotze	**1999**		x				x			Myoelectric, passive prosthesis
Total number : 5		3	1	1	0	1	2	0	0	

Targeted Muscle Reinnervation (TMR) - Overview Table

The summaries are organized in three levels depending on the detail of information. The overview table (Level 1) lists all the relevant publications dealing with a particular product (topic) as well as researched categories (e.g. level walking, safety, activities, etc). Summaries of all the literature dealing with a specific topic can be found in the document(s) above the overview table (Level 2).

For those interested to learn more about individual studies, a summary of the study can be obtained by clicking on the relevant author/reference (Level 3).

The studies presented in the table below are summarized here (Level 2):
TMR – literature summary

Reference		Category								Prosthesis
		Body Functions		Activity			Participation	Others		
Author	Year	Mechanics	Pain	Grip patterns Force	Manual dexterity	ADL	Satisfaction QoL	Training	Technical aspects	
Chees-borough	2015		x		x	x				Pattern Recognition control prosthesis
Souza	2014		x			x				Myoelectric prosthesis
Chees-borough	2014		x							Not fitted
Miller	2008				x	x				Externally powered vs Myoelectric prosthesis
Kuiken	2004				x	x	x			Body-powered vs Myoelectric prosthesis
Total number: 5		0	3	0	3	4	1	0	0	

Training with upper extremity prostheses – Overview Table

The summaries are organized in three levels depending on the detail of information. The overview table (Level 1) lists all the relevant publications dealing with a particular product (topic) as well as researched categories (e.g. level walking, safety, activities, etc). Summaries of all the literature dealing with a specific topic can be found in the document(s) above the overview table (Level 2).

For those interested to learn more about individual studies, a summary of the study can be obtained by clicking on the relevant author/reference (Level 3).

The studies presented in the table below are summarized here (Level 2):
Evidence-based training aspects for myoelectric prostheses

Reference		Category								Prosthesis	Target Group
		Body Functions		Activity			Participation	Others			
Author	Year	Mechanics	Pain	Grip patterns Force	Manual dexterity	ADL	Satisfaction QoL	Training	Technical aspects		
Ortiz-Catalan	**2016**		**X**							Machine learning, augment reality and gaming	Amputees
Bouwsema	**2014**							**X**		Myoelectric simulator - MyoHand VariPlus Speed	Able-bodied participants
Bouwsema	**2014**							**X**		Myoelectric simulator - MyoHand VariPlus Speed	Able-bodied participants
Romkema	**2013**							**X**		PAULA software connected to MyoBoy	Able-bodied participants
Bouwsema	**2012**	**X**		**X**						Dynamic Mode Control hands, Digital hands, Motion control	Amputees
Bouwsema	**2010**							**X**		Virtual hand – PAULA, Myoelectric simulator, Table-top hand	Able-bodied participants
Bouwsema	**2010**	**X**								Mechanical elbow, Digital Twin hands	Amputees
Bouwsema	**2008**							**X**		Body-powered and Myoelectric simulator	Able-bodied participants
Total Number: 8		**2**	**1**	**1**	**0**	**0**	**0**	**5**	**0**		

2 Summaries of categories

On the following pages you find summaries of specific questions researched in several studies. At the end of each summary you will find a list of reference studies contributing to the content of the particular summary.

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Michelangelo Hand – Literature Summary

Major Findings

With Michelangelo Hand compared to different myoelectric prostheses (Sensor hand speed; Myohand VariPlus Speed; Motion Control Hand; DMC plus Myo-hand):

→ **Higher manual dexterity is achieved (score of Box and Block Test increased by 20.8%)**
→ **Perceived ease of use to perform ADLs increased by 35%.**
→ **Hand is more actively used at home and the latteral grip is preffered in 77% of activities.**
→ **Hand was used to actively grasp an object in more bimanual activities and it was 31% easier to perform the activities**

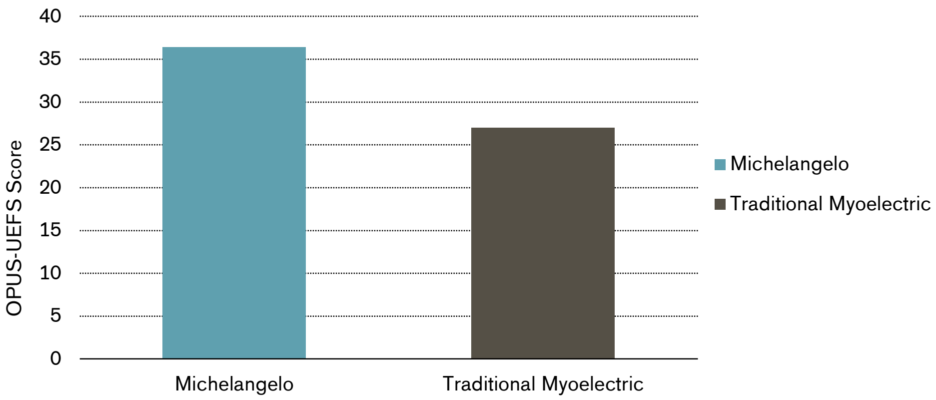
With Michelangelo Hand compared to Digital Twin Hand:

→ **Michelangelo hand reduces compensatory movements**
→ **Patient is more satisfied with Michelangelo hand**

With Michelangelo Hand compared to different myoelectric prostheses (Vincent hand; iLimb hand; iLimb Pulse; Bebionic hand; Bebionic hand v2):

→ **Michelangelo hand is the lightest and has the highest grip force**
→ **Michelangelo advantage is in the low number of actuators with transmissions that allow all functional grasping postures**
→ **Michelangelo hand presented significantly higher overall SHAP scores compared to iLimb and bebionic hand.**

Perceived Ease of Performing Activities of Daily Living



Perceived ease to perform 23 activities of daily living was measured with OPUS-UEFS questionnaire. Total OPUS-UEFS score was 35% higher with Michelangelo prostheses, meaning that tasks were easier to conduct with Michelangelo hand. (*Pröbsting et al., 2014*).

Clinical Relevance

Reporting frequency of prosthesis use in performing activities of daily life can provide information about prosthesis usefulness, satisfaction with the prosthesis and level of prosthetic skills.

Technical aspects of myoelectric prosthesis provide good insights of mechanical design and performance specifications. Best technical combination would achieve high functionality, durability and adequate cosmetic appearance of the prosthesis as well as affordability.

Summary

Manual dexterity is the ability to make coordinated hand and finger movements to grasp and manipulate objects. The study by Luchetti et al., 2015 showed that the manual dexterity of Michelangelo hand is significantly improved when compared to single grip myoelectric hands (measured by standard tests: Box and Blocks test (B&B)showed 23%, Minnesota Manual Dexterity Test (MMDT) 15% and the Southampton Hand Assessment Procedure (SHAP) HAP 11% of improvement). Additionally, Michelangelo hand is more used actively at home, especially its lateral grip which is preferred grip pattern in 77% of activities.

Michelangelo prosthesis significantly reduces perceived difficulty of activities of daily living and improves function as compared to regular single grip myoelectric hands. Amputees use Michelangelo more often in bimanual tasks and to actively grasp an object than with standard myoprosthesis (*Pröbsting et al., 2014*).

Michelangelo hand is closing the gap between prosthetic and the sound side by reducing compensatory motion and bringing more natural movement to the patient. In addition, Michelangelo hand´s pleasant appearance brings more satisfaction to the users (*Cutti et al., 2012*).

A grip force of 68N is minimally required for human hand to carry out ADLs (*Heckathorne et al., 1992*), while prosthetic hands need a minimum grip force of 45 N for practical use (*Vinet et al., 1995*). The Michelangelo hand has the highest grip force in comparison to other myoelectric prosthesis (opposition grip force – 70N vs 34N the highest in other myoelectric; lateral grip force – 60N vs 20 the highest in other myoelectric) (*Belter et al., 2011*).

Kyberd (2017) compared the i-Limb, bebionic and Michelangelo hands to a single degree-of-freedom hand (sDOF) (Motion Control) using a splint over his hand to simulate an amputation. The sDOF hand presented the highest SHAP scores from all tested hands; within the myoelectric hands, the Michelangelo hand presented the highest overall performance score followed by bebionic and iLimb. Both the sDOF and the Michelangelo hand presented significantly higher SHAP scores when using the power grip compared to the bebionic and iLimb hands.

References

Kyberd, PJ., JPO 2017; Vol. 29, pp. 103-111. Assessment of functionality of multifunction prosthetic hands.

Luchetti et al., Journal of Rehabilitation Research & Development 2015; 52(2):605-618. Impact of Michelangelo prosthetic hand: Findings from a crossover longitudinal study

Pröbsting et al., JPO 2015; Vol 27, Num 2, p 46 Ease of Activities of Daily Living with Conventional and Multigrip Myoelectric Hands

Cutt et al., Grasping the Future: Advances in Powered Upper Limb Prosthetics; 59-77, 2012 The Psychosocial and Biomechanical Assessment of Amputees Fitted with Commercial Multi-grip Prosthetic Hands – Case Study: Michelangelo hand

Belter et al., Journal of Rehabilitation Research & Development; 2011 10:0188: Mechanical design and performance specifications of anthropomorphic prosthetic hands: A review

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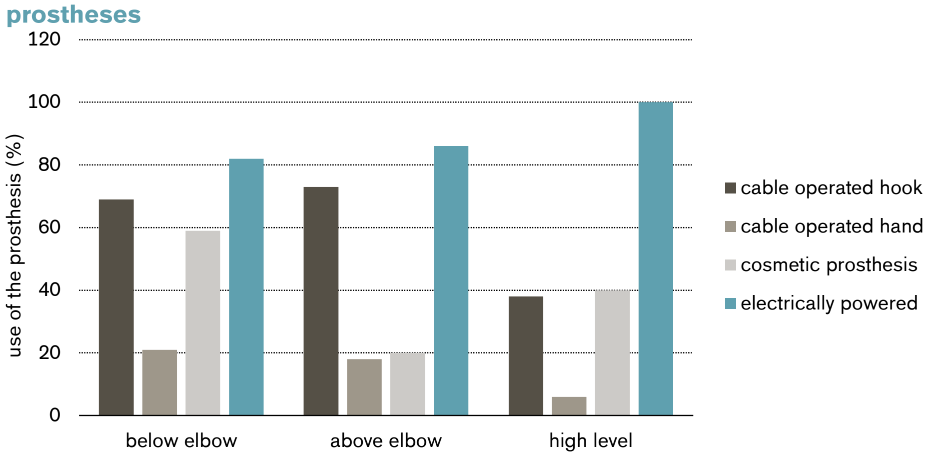
Myoelectric vs body-powered prostheses Do amputees need both of them?

Major Findings

Myoelectric compared to body-powered prosthesis:

→ The most preferred prostheses are myoelectric prosthesis.
→ The majority of amputees used more than one prosthesis for their functional needs and should be fitted with more than one type of prosthesis.
→ The rejection rate is similar with myoelectric (mean 23%) and body-powered (mean 26%) prostheses.
→ Myoelectric prosthesis offers to a user higher range of motion (RoM).
→ Myoelectric prosthesis could reduce phantom limb pain.
→ Body-powered prostheses are more robust and durable.
→ Less training is needed to learn how to use body-powered prosthesis.

Acceptance of body-powered and ellectrically powered prostheses



Amputees reported that myoelectric prosthesis is the most preferred type of prosthesis, followed by the cable operated hook, cosmetic and cable operated hand. Acceptance rate for myoelectric prosthesis was 82% for below elbow, 86% for above elbow and 100% for high level amputations. Acceptance rate for cable operated hook was 69% for below elbow, 73% for above elbow and 38% for high level amputations (Millstein et al., 1986).

Clinical Relevance

The prosthetic options to fit upper limb loss are passive (cosmetic) and active prosthesis (body-powered or myoelectric). The role of the prosthetic hand is not limited just to the restoration of the physical and functional movements, but it also plays a role in body gesture and posture, social life and communication. Oftentimes more than one prosthesis is needed to fulfil patients´ needs.

Summary

A body-powered prosthesis usually employs a harness and cables and a variety of terminal devices (hooks, hands) that can be attached. The advantages of body-powered prosthesis include (*Stain, et al., 1983; Millstein et al., 1986; Craig, et al., 2011*):

- Low cost
- More robust
- More durable
- Less intensive training needed to learn how to control it

- Used for jobs that require heavy lifting objects, where materials handled are dirty, greasy or sharp
- Used in hot, humid weather conditions
- Users report perceived sensory feedback
- Preferred for home use (e.g. washing)
- Preferred for heavier and more vigorous sports activities

Myoelectric technology uses electromyographic (EMG) signal from the voluntary activity in the stump muscles to operate the terminal device. The advantages of myoelectric prosthesis include (*Stain, et al., 1983; Millstein et al., 1986; Craig, et al., 2011;*)

- Increased comfort
- Control of the prosthesis is more natural
- The give a greater range of motion to the user
- User needs less compensatory motion to execute ADLs
- Bring more cosmetic acceptance
- Used for office related jobs, supervisory work or in contact with general public
- Preferred for home use (e.g. eating)
- Preferred for car driving
- Preferred for light sports activities
- Extensive use could reduce phantom limb pain

References

Carey et al., Journal of Rehabilitation Research & Development 2015; 52(3):247-262. Differences in myoelectric and body-powered upper-limb prostheses: Systematic literature review

Stain et al., Archives of Physical Medicine and Rehabilitation; Vol 64, 1983 Functional Comparison of Upper Extremity Amputees Using Myoelectric and Conventional Prosthesis

Millstein et al., Prosthetics and Orthotics International; Vol 10, 27-34, 1986. Prosthetic use in adult upper limb amputees: a comparison of the body powered and electrically powered prostheses

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Compensatory movements when using myoelectric prosthesis

Major Findings

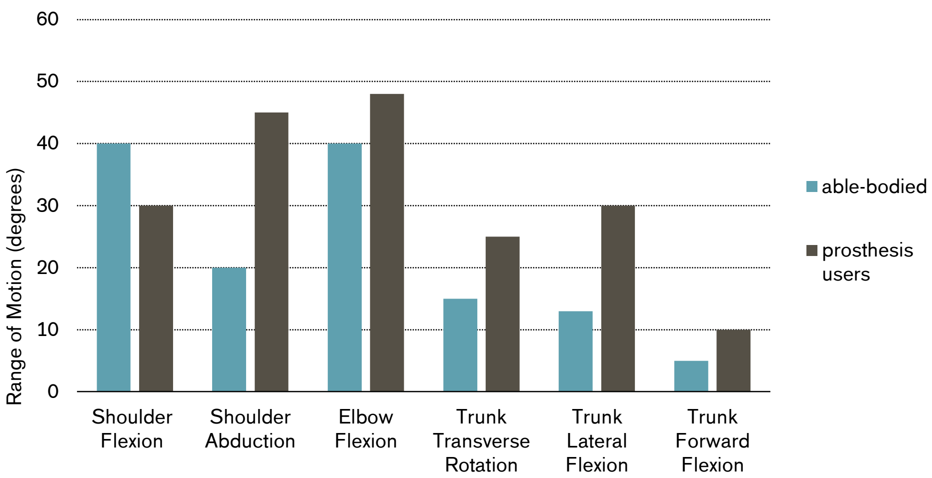
Compensatory movements with and without MovoShoulder Swing (with Dynamic-Arm and System Electric Hand):

→ **Compensatory movements during walking in shoulder, elbow and knee are reduced when using a free swinging shoulder joint**
→ **Swinging of the sound arm in shoulder joint is 23% reduced**
→ **Swinging of the sound arm in elbow joint is 13% reduced**
→ **Unphysiological loading of the knee joint on amputated side is 12% decreased**

Compensatory movements in myoelectric prosthesis users compared to able-bodied controls:

→ **Shoulder and trunk movements are common compensatory motions in prosthesis users.**
→ **Increased variability in movement suggests that prosthesis users do not stick to a defined motor strategy.**
→ **Kinematic repeatability may increase with prosthesis experience.**

Average range of motion for carton poring task



Upper body range of motion (RoM) was analysed on able-bodied controls and myoelectric transradial prosthesis users during execution of carton pouring task (lifting a carton, located at midline of the body, and emptying the liquid contents into a jar on the contralateral side with minimal spilling). Results indicate that prosthesis users demonstrate a significant increase in shoulder abduction, trunk transverse rotation, trunk lateral flexion and trunk forward flexion RoM (*Major et al., 2014*).

Clinical Relevance

The upper limb amputation leads to the loss of the voluntary degrees of freedom (DoF). Unfortunately current upper limb prosthesis cannot restore all DoFs. Lack of DOFs, such as controllable wrist rotation or elbow flexion, forces the individual to use compensatory motor strategies to accomplish unilateral functional tasks such as reach and grasp. Clinically, these strategies most prominently involve using the trunk or proximal residual limb to achieve the necessary motion.

Summary

Prosthetic users demonstrated a significant increase in shoulder abduction, trunk transverse rotation, trunk lateral flexion, and trunk forward flexion RoM when executing carton pouring, lifting and transferring tasks. Some prosthesis users were unable to routinely execute food cutting and page turning tasks. More experienced prosthetic users showed repeatability of upper body kinematics when conducting tasks. Due to this, transradial prosthesis users may benefit from training that enables optimization of body movement to facilitate execution of ADLs (*Major et al., 2014*).

Amputees with shoulder disarticulation can benefit from a functional myoelectric prosthesis with a free swinging shoulder joint. MovoShoulder Swing prosthesis decreased swing of the sound arm in shoulder and in elbow joint by 23% and 13%, respectively. It also improved the gait characteristics by reducing the unphysiological loading of the knee joint on amputated side for 12% (*Bertels et al., 2012*).

References

Year	Author	Journal	Title
2012	Bertels	Prosthetics and Orthotics International; 36(2) 165–172	Biomechanical influences of shoulder disarticulation prosthesis during standing and level walking
2014	Major	Journal of Neuro Engineering and Rehabilitation, 11:132	Comparison of range-of-motion and variability in upper body movements between transradial prosthesis users and able-bodied controls when executing goal-oriented tasks

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Phantom and residual limb pain

Major Findings

Prosthesis use and phantom and residual limb pain in upper limb amputees:

- → **The prevalence of phantom pain was 51%, of phantom sensations 76% and of residual limb pain 49% in subjects with acquired amputation (amputation not due to congenital malformation).**
- → **Phantom pain was not reported in the congenital group.**
- → **Phantom pain did not affect prosthesis use or functional ability.**
- → **Phantom sensations and residual limb pain could lead to phantom pain.**

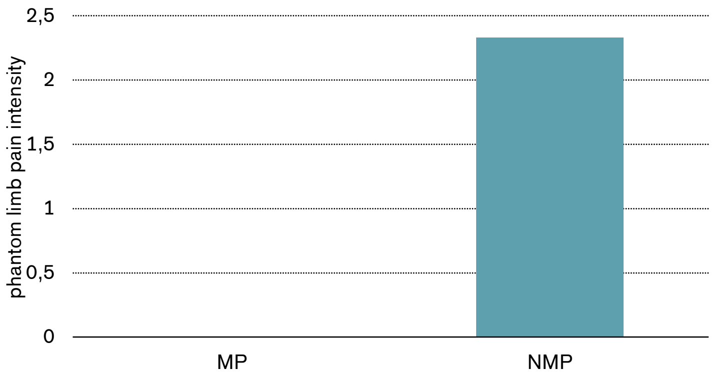
Prosthesis use and phantom and residual limb pain in upper limb amputees fitted with myoelectric prosthesis:

- → **Enhanced use of a myoelectric prosthesis was associated with reduced phantom limb pain and reduced cortical reorganization.**
- → **Phantom limb or residual limb pain was never reported as a reason for discontinuation of prosthesis use.**

With machine learning, augmented reality and gaming compared to traditional treatment for phantom limb pain:

- → **Pain intensity was decreased by 51%.**
- → **Pain duration was reduced by 47%.**
- → **All patients experienced reduction in quality of pain.**
- → **Pain-related disturbances of sleep and activities of daily living were reduced on average by 61% and 43%, respectively.**
- → **Pain sensations, such as stabbing and tiring–exhausting, were significantly less prevalent after treatment.**
- → **Improvements remained 6 months after treatment.**

Average phantom limb pain intensity



The first group (MP) of patients reported extensive wearing time (>8 h/day) and usage (>50 on a visual analogue scale (VAS) ranging from 0–100% usage of prosthesis in daily living, homemaking and work outside home).) for their myoelectric prosthesis. The second group (NMP) had either no prosthesis, or a passive prosthesis, or a myoelectric prosthesis that was poorly used (<8 h/day and/or < 50 VAS). Phantom limb pain intensity measurement was based on the MPI Pain Intensity Scale (range, 0–6). The MP group showed an average phantom limb pain intensity of 0 ± 0, whereas the NMP group reported an intensity of 2.33 ± 1.53 (*Lotze et al., 1999*).

Clinical Relevance

Phantom and residual limb pain after upper limb amputation are common problems. The determinants are still poorly understood, as is the impact of phantom or residual limb pain experience on prosthesis use.

Summary

Phantom pain was only reported in the group of patients that acquired an amputation during their life and not in patients who were born with upper limb deficiencies.

In the group with acquired amputation, the prevalence of phantom pain was 51%, of phantom sensations 76% and of residual limb pain 49%. Interestingly, pain in the limb before the amputation was experienced by 14% of subjects. Residual limb pain or pressing a specific place on the residual limb triggered phantom pain in 50% and in 28% of amputees, respectively (*Kooijmana et al., 2000*).

The phantom pain did not influence prosthesis use since the prosthesis was used for more than 8 h per day by 72% of amputees (*Kooijmana et al., 2000*) and did not lead to the rejection of the prosthesis (*Lotze et al., 1999*).

Frequent and extensive use of a myoelectric prosthesis could decrease cortical reorganization and, consequently, phantom limb pain. Amputees that used myoelectric prostheses more than 8h per day reported reduction in phantom pain over time (*Lotze et al., 1999*). These findings were recently supported by a study where machine learning, augmented reality and gaming showed promising results in the treatment of phantom limb pain compared to traditional treatment, such as mirror therapy (*Ortiz-Catalan et al., 2016*). With machine learning, augmented reality and gaming, all patients experienced reduction in quality of pain (pain sensations, such as stabbing and tiring–exhausting), pain intensity was decreased by 51% and pain duration by 47%. Pain sensations, such as stabbing and tiring–exhausting, were significantly less prevalent after treatment. Pain-related disturbances of sleep and activities of daily living were reduced on average by 61% and 43%, respectively. Importantly, improvements remained consistent 6 months after therapy, which was duration of the study.

References

Kooijman CM, Dijkstra PU, Geertzen JH, Elzinga A, van der Schans CP. Phantom pain and phantom sensations in upper limb amputees: an epidemiological study. Pain. 2000 Jul;87(1):33-41. PubMed PMID: 10863043.

Lotze M, Grodd W, Birbaumer N, Erb M, Huse E, Flor H. Does use of a myoelectric prosthesis prevent cortical reorganization and phantom limb pain? Nat Neurosci. 1999 Jun;2(6):501-2. PubMed PMID: 10448212.

Ortiz-Catalan M, Guðmundsdóttir RA, Kristoffersen MB, Zepeda-Echavarria A, Caine-Winterberger K, Kulbacka-Ortiz K, Widehammar C, Eriksson K, Stockselius A, Ragnö C, Pihlar Z, Burger H, Hermansson L. Phantom motor execution facilitated by machine learning and augmented reality as treatment for phantom limb pain: a single group, clinical trial in patients with chronic intractable phantom limb pain. Lancet. 2016 Dec 10;388(10062):2885-2894. doi: 10.1016/S0140-6736(16)31598-7. PubMed PMID: 27916234.

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Targeted Muscle Reinnervation (TMR) – Literature Summary

Major Findings

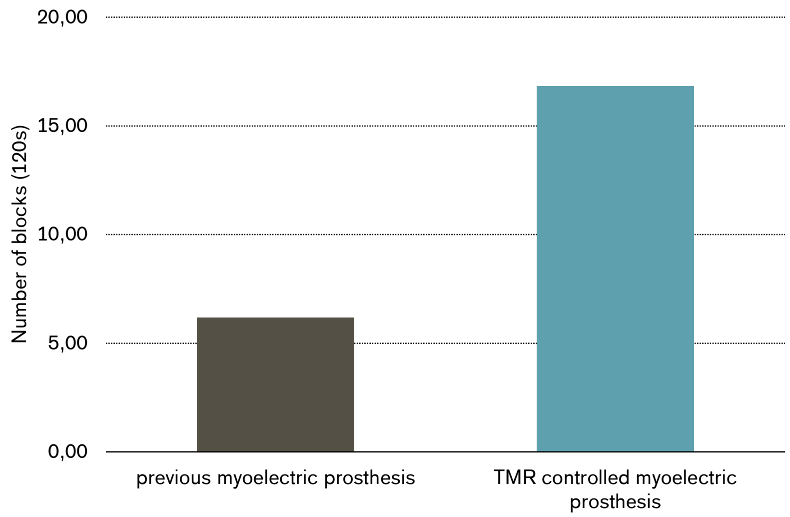
The effect of Targeted Muscle Reinnervation (TMR) on the use of myoelectric prostheses in upper-extremity amputees:

- → **88% of patients who underwent TMR surgery were able to operate a myoelectric prosthesis.**
- → **The performance with myoelectric prostheses assessed with the Box and Bocks and Clothespin Tests was increased by two to six times.**
- → **The speed measured in the Clothespin Test with myoelectric prostheses during task execution was increased by 26%.**
- → **Myoelectric prostheses were easier to use and felt more natural.**

The effect of Targeted Muscle Reinnervation (TMR) on residual limb neuroma pain in upper-extremity amputees:

- → **None of the patients who underwent TMR demonstrated evidence of new neuroma pain after the procedure.**
- → **93% of patients who presented with preoperative neuroma pain experienced complete relief of pain.**

Box and Blocks test



Performance with the pre-surgical myoelectric device and the TMR controlled myoelectric prosthesis was compared with a modified Box and Blocks test (patients were standing instead of sitting while duration of the test was 120s instead of 60s). With the new prosthesis patients showed marked improvement (on average 177%) (Miller et al., 2008)

Clinical Relevance

Achieving a high level of function with prosthetic limbs remains challenging, especially for higher upper extremity amputation levels, where the disability is greatest. Targeted muscle reinnervation (TMR) is a new technique that employs a series of novel nerve transfers to enable better control of upper limb prostheses mostly for above elbow amputees. Recent experience has suggested that TMR may also inhibit symptomatic neuroma pain formation.

Summary

Targeted muscle reinnervation may be considered in the acute trauma setting to prepare patients for myoelectric prosthesis fitting and to prevent neuroma pain. This procedure has been performed successfully on people with shoulder disarticulation and transhumeral level amputation. Performance and task execution speed with myoelectric prostheses after TMR surgery has increased on average 177% (Miller et al., 2008) and 26% (Kuiken et al., 2004), respectively, as compared to pre-surgical myoelectric prostheses. Patients reported that it was easier, faster and felt more natural to use the myoelectric prosthesis after TMR surgery (Kuiken et al., 2004, Miller et al., 2008; Cheesborough et al., 2015). Perceived ease in performing activities of daily living with the myoelectric prosthesis after TMR was reported for: eating, drinking from a bottle, cooking, cleaning, housework, yard work, and home maintenance (Miller et al., 2008; Cheesborough et al., 2015). In respect to pain relief, the TMR procedure brought complete relief of neuroma pain in 93% of patients, while none of the patients demonstrated evidence of new neuroma pain after the procedure (Souza et al., 2014).

References

Cheesborough, J., Smith, L., Kuiken, T., & Dumanian, G. (2015). Targeted Muscle Reinnervation and Advanced Prosthetic Arms. Seminars in Plastic Surgery, 29(01), 62–72. doi:10.1055/s-0035-1544166

Kuiken, T., Dumanian, G., Lipschutz, R. D., Miller, L. A., & Stubblefield, K. A. (2004). The use of targeted muscle reinnervation for improved myoelectric prosthesis control in a bilateral shoulder disarticulation amputee. Prosthetics and Orthotics International, 28, 245–253.

Miller, L. A., Stubblefield, K. A., Lipschutz, R. D., Lock, B. A., & Kuiken, T. (2008). Improved Myoelectric Prosthesis Control Using Targeted Reinnervation Surgery: A Case Series. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 16(1), 46–50. doi:10.1109/TNSRE.2007.911817

Souza, J. M., Cheesborough, J. E., Ko, J. H., Cho, M. S., Kuiken, T. A., & Dumanian, G. A. (2014). Targeted Muscle Reinnervation: A Novel Approach to Postamputation Neuroma Pain. Clinical Orthopaedics and Related Research®, 472(10), 2984–2990. doi:10.1007/s11999-014-3528-7

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Evidence-based training aspects for myoelectric prosthesis

Major Findings

Pre-prosthetic training:

→ **The pre-prosthetic training should start immediately after the amputation when the client is medically stable.**

→ **Train the stump musculature.**

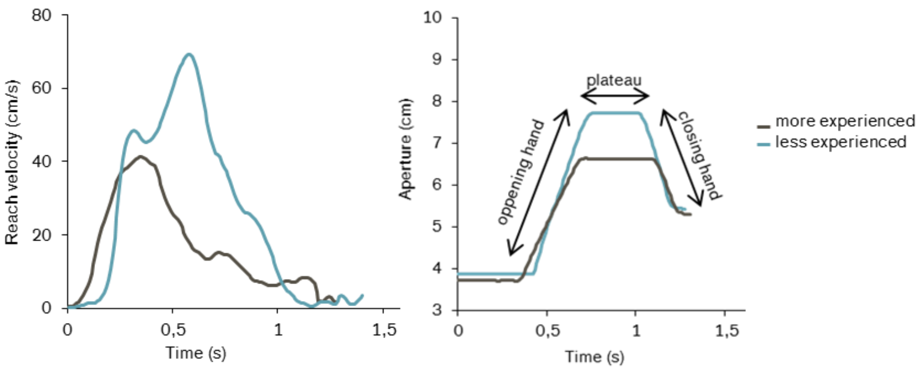
Prosthetic training:

→ **Focus on timing between hand opening and hand closing, pay attention to simultaneously end reach and start grasp.**

→ **Learn how to grasp an object first by handing it over from the unaffected hand to the prosthetic hand (indirect grasping), then proceed with tasks where an object is grasped directly with the prosthetic hand. Finally do fixating tasks (buttoning and unbuttoning, tying the shoelaces).**

→ **Oral feedback should be always provided for motor learning tasks; for cognitive tasks it should be keep to the minimum.**

Reaching and grasping an object



In the following figure the reach (left) and the grasp (right) of an object performed by experienced (gray) and less experienced (blue) prosthetic users are shown. More experienced user need less time to reach the object and plateau phase (time between opening and closing the hand when grasping an object) is shorter (Bouwsema et al., 2012).

Clinical Relevance

Twenty to forty percent of the people with an arm amputation do not use any prosthesis in daily living. To increase the use of prosthesis it is important to have a good training, with skills learned in the clinic that can be applied at home after the rehabilitation. Rehabilitation centres often use protocols which are based on clinical experiences (best clinical practice). Up to now the most efficient way of training is still not known, and the demand for a scientifically based training is becoming larger.

Summary

<u>The pre-prosthetic training:</u>

The pre-prosthetic training should start immediately after the amputation when the amputee is medically stable. The goal is to prepare the patient for use of the prosthesis and ultimately to increase its acceptance.

1. Training advice - Train the stump musculature: Training can be executed in several ways, such as training with a practice hand, a prosthetic simulator, or virtual on a screen. For the overall performance it does not matter in which of these ways are used for training. An example of a commercially available virtual system is the Prosthetics Assistant of Upper Limb Architecture® (PAULA) of Otto Bock, in combination with the MyoBoy®.

Result - Training the stump musculature will result in a good independent control of the myoelectric signals and will accelerate the learning process.

The prosthetic training:

1. Training advice – Reduce the plateau phase: Focus on timing between hand opening and hand closing, pay attention to simultaneously end reach and start grasp.

Result - Movements with the prosthesis will be faster and more fluent with shorter plateau phase.

2. Training advice – Train grasping an object: It is important to start with ***indirect grasping***. By handing over an object from the unaffected hand to the prosthetic hand, the client can retrieve information on the properties of the object, such as compressibility. In addition, the object can be positioned and grasped more easily with the prosthetic hand.
Proceed to ***direct grasping*** with the prosthetic hand. Besides the correct closing, the user needs to pay close attention to the correct positioning of the prosthetic hand with regards to the object as well.
Finally do ***fixating*** tasks (buttoning and unbuttoning, tying the shoelaces…).
Train with objects of different textures, compressibility and stiffness. Practice grasping objects without pressing them, and train varying degrees of compression.

Result – General positioning and gross motor control are learned quickly, but fine control such as grip force requires more time. A good control of grip force is needed in everyday life in order to handle objects correctly without breaking an object.

3. Training advice – Always provide feedback for motor learning: visual feedback on screen, auditory feedback with sounds, vibrotactile feedback, or verbal feedback.
Provide a feedback on the end result of the movement: Specify how an object is compressed rather than to indicate that the hand squeezed too hard. The emphasis is on the object (environment) rather than the body itself.
For cognitive tasks keep feedback to the minimum: In a virtual game the described training aspects can be applied easily. Here giving less feedback is more beneficial since it gives a patient opportunity to learn while performing a task.

Result – Patient will be more motivated and confident.

4. Training advice – The user should decrease gaze behaviour: Train basic control signals, reaching, and grasping with the prosthesis by looking at a fixed point in the peripheral field of view instead of directly looking at the hand. Train without visual information by letting the client look away during the exercise.

Result – The majority of sensory information such as proprioception and tactile information relevant to object manipulation is lost in prosthesis use. Only visual information is still available. Therefore prosthesis users rather look at the prosthetic hand, then in object to be grasped or manipulated, while performing actions.
The less a prosthetic hand is looked at, the better the overall performance of the prosthesis user. At the start of the rehabilitation, a patient is expected to look a lot at the hand, and the amount of time will reduce when the user gains more proficient control over the prosthesis.

References

Bouwsema H, van der Sluis CK, Bongers RM. Effect of feedback during virtual training of grip force control with a myoelectric prosthesis. PLoS One. 2014 May 27;9(5):e98301. doi: 10.1371/journal.pone.0098301. PubMed PMID: 24865570; PubMed Central PMCID: PMC4035328.

Bouwsema H, van der Sluis CK, Bongers RM. Changes in performance over time while learning to use a myoelectric prosthesis. J Neuroeng Rehabil. 2014 Feb 25;11:16. doi: 10.1186/1743-0003-11-16. PubMed PMID: 24568148; PubMed Central PMCID: PMC3944783.

Bouwsema H, Kyberd PJ, Hill W, van der Sluis CK, Bongers RM. Determining skill level in myoelectric prosthesis use with multiple outcome measures. J Rehabil Res Dev. 2012;49(9):1331-48. PubMed PMID: 23408215.

Bouwsema H, van der Sluis CK, Bongers RM. Learning to control opening and closing a myoelectric hand. Arch Phys Med Rehabil. 2010 Sep;91(9):1442-6. doi: 10.1016/j.apmr.2010.06.025. PubMed PMID: 20801265.

Bouwsema H, van der Sluis CK, Bongers RM. Movement characteristics of upperextremity prostheses during basic goal-directed tasks. Clin Biomech (Bristol,Avon). 2010 Jul;25(6):523-9. doi: 10.1016/j.clinbiomech.2010.02.011. PubMed PMID: 20362374.

Bouwsema H, van der Sluis CK, Bongers RM. The role of order of practice in learning to handle an upper-limb prosthesis. Arch Phys Med Rehabil. 2008 Sep;89(9):1759-64. doi: 10.1016/j.apmr.2007.12.046. PubMed PMID: 18675393.

Romkema S, Bongers RM, van der Sluis CK. Intermanual transfer in training with an upper-limb myoelectric prosthesis simulator: a mechanistic, randomized, pretest-posttest study. Phys Ther. 2013 Jan;93(1):22-31. doi: 10.2522/ptj.20120058. PubMed PMID: 22976445.

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3 Summaries of individual studies

On the following pages you find summaries of studies that researched Helix 3D hip joint system. You find detailed information about the study design, methods applied, results and major findings of the study. At the end of each summary you also can read the original study authors' conclusions.

Table of contents

Reference

Kyberd, PJ

Department of Engineering Science, University of Greenwich, Chatham Maritime, United Kingdom.

Assessment of Functionality of Multifunction Prosthetic Hands

Journal of Prosthetics and Orthotics, 2017, vol. 29, pp. 103-111.

Products

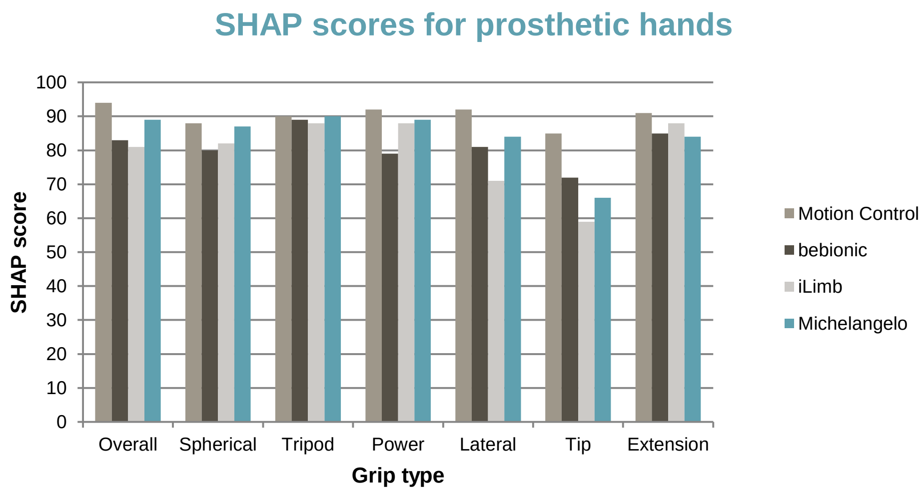
Michelangelo Hand

Major Findings

With Michelangelo Hand (Ottobock) compared to i-Limb (Touch Bionics), bebionic (Steeper) and Motion Control Hand (Motion Control).

→ **The Motion Control Hand had the highest overall performance score (94)**
Within multifunctional hands,
- → the Michelangelo Hand had the highest overall performance score (89), followed by the bebionic (83) and iLimb hand (81).

→ **The Motion Control and Michelangelo hands had significantly higher scores than the iLimb and bebionic hands when using a Power grip.**



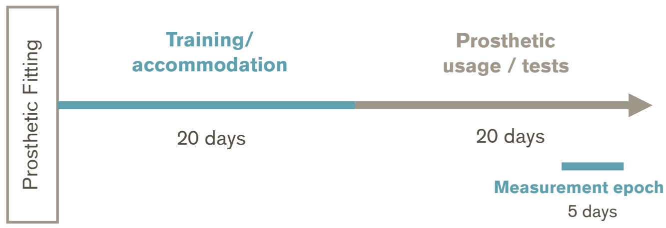
The column chart provides a comparison of the Southampton Hand Assessment Procedure (SHAP) scores of the three multifunction hands and the single degree of freedom (sDoF, Motion Control) hand (results taken from a previous publication from the same author). Overall score, Power grip score and lateral score for Michelangelo hand and Motion control were significantly better than bebionic hand and iLimb. The Motion Control score for Tip grip was significantly better than all other hands.

Population

Subjects:	1 abled bodied subject
Previous prosthesis:	none
Previous prosthetic experience:	none
Amputation causes:	no amputation
Mean age:	not reported
Mean time since amputation:	no amputation

Study Design

Not a clinical study, interventional, proof of concept design. Author was the single able bodied subject in the study.



Prosthetic fitting consisted of a splint over the left (non-dominant) forearm, used to hold the prosthesis over the dorsal surface of the arm, which was controlled by myoelectrode amplifiers/processors.

The training/accommodation phase (20 days long) consisted of the subject performing general activities with the prosthetic hands; considered successful if the subject could switch control to a different hand state on the first attempt on more than 90% of trials.

After the training, 20 additional days were divided into four 5-day epochs. The results reported in the publication are the mean of the last epoch (last 5 days).

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	**Grip patterns / force**	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	Training	Technical aspect

Category	Outcomes	Michelangelo hand compared to other prosthetic hands	Sig.*
Grip patterns / force	SHAP score	Motion Control overall score (94) significantly better than Michelangelo hand(89); Michelangelo hand overall score significantly better than both bebionic (83) and iLimb (81)	++
		Spherical grip: Motion control & Michelangelo hand score slightly higher than both iLimb & bebionic	0
		Tripod grip: No clear difference between hands	0
		Power grip: Motion Control & Michelangelo hand score significantly higher than both bebionic & iLimb	++
		Lateral grip: Motion Control > Michelangelo > bebionic > iLimb	++
		Tip grip: Motion control > bebionic > Michelangelo > iLimb	++
		Extension grip: Motion Control > iLimb > bebionic > Michelangelo	0

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion	"Using a validated procedure to measure hand function, the more complex multiarticulated hands were tested and they did not show improved functional performance compared with the simpler prosthetic designs. Each device requires more actions to trigger the different grips to respond to the range of objects and tasks. The factors that affect the Overall score include the control format and the design of the hand, as it was not possible to program each of the hands with the same control formats; thus it was not possible to separate the different factors. All three hands were more anthropomorphic in action and appearance than the earlier hands, but this did not result in greater function than the simpler fixed geometry hands." (Kyberd, 2017)

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Reference

Luchetti M., Cutti AG, Verni G, Sacchetti R, Rossi N.

Department of Psychology, University of Bologna, Italy.

Impact of Michelangelo prosthetic hand: Findings from a crossover longitudinal study

Journal of Rehabilitation Research & Development 2015; 52(2):605-618.

Products

Michelangelo hand vs Tridigit hands

Major Findings

With Michelangelo compared to conventional myoelectric prosthesis:

→ A higher functionality can be achieved

Score of Box and Block Test increased by 20.8%

Score of SHAP increased by 11.4%

Time needed to perform Minnesota Manual Dexterity Test decreased by 14.8%

→ ADL execution is easier

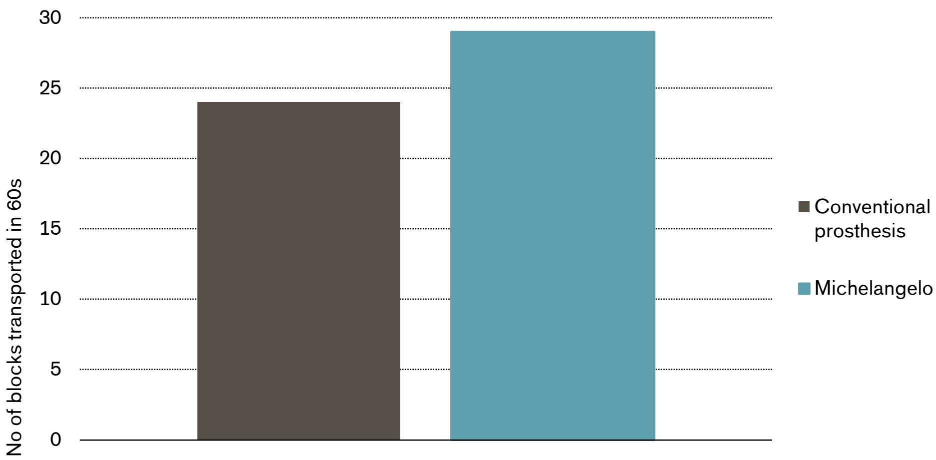
Reported by 84% of patients

→ Michelangelo hand is more actively used at home

Lateral grip preferred over opposition grip

→ Gesture and posture is more natural

Significant improvement in Box and Block Test



Box and Blocks is a manual dexterity test where number of blocks transported from one box to another in 60s is assessed. The users were able to transport 5 blocks more on average with Michelangelo hand. Four out of six participants (67%) had a sore above minimal clinically relevant detectable change (more than 6.5 blocks were transported with Michelangelo hand in 60s than with conventional myoelectric prosthesis).

Population

Subjects:	6 transradial amputees
Previous prosthesis:	tridigital myoelectric prosthesis
Amputation causes:	trauma
Mean age:	47 yrs (range: 35-65 yrs)
Mean time since amputation:	15 yrs (range: 4.5-48 yrs)

Study Design

Interventional pre- to post-test design:

The subjects were provided with 5 days of occupational therapy after they have been fitted with Michelangelo.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	Training	Technical aspect

Category	Outcomes	Results for Michelangelo vs Tridigit hands	Sig.*
Grip patterns / force	Activity monitoring data	After 3 months the median number of opening and closing cycles was 32,330. 83% of patients preferred the lateral grip (73% of cycles). After 6 months the median number of opening and closing cycles was 54,012 in total over six months. The lateral grip was preferred for 77% of cycles.	n.a.
Manual dexterity	Southampton Hand Assessment Procedure (SHAP)	The score for the SHAP was 11.4% higher with Michelangelo than with the conventional prosthesis. A higher score can be interpreted as a higher functionality.	+
	Box and Block Test (BBT)	**The number of blocks that was carried over a partition was increased by 20.8% suggesting higher hand functionality.** 67% of the patients increased the score over the minimal clinically relevant detectable change.	++
	Manual Dexterity Test (MMDT)	**The time for the test was decreased by 14.8% which also can be interpreted as a higher functionality.**	++
	Disabilities of the Arm, Shoulder, and Hand (DASH)	All patients showed high hand functionality (min DASH row score 26, range 0-100, lower score = higher functionality). No difference was observed between two hands.	0
Activities of daily living (ADL)	Orthotics and Prosthetics User Survey – Upper Extremity Functional Status (OPUS-UEFS)	84% of the patients reported an easier execution of ADLs.	+
Satisfaction and Quality of life (QoL)	Hospital Anxiety Depression Scale (HADS)	Despite the fact that questionnaires created to assess satisfaction and quality of life did not show statistical significant difference, interview transcripts emphasised that Michelangelo en-	0
	EuroQoL (Health-Related Quality of Life)		0

Category	Outcomes	Results for Michelangelo vs Tridigit hands	Sig.*
	Amputee Body Image Scale (ABIS)	hances functionality and brings more natural gesture and posture.	0
	Trinity Amputation and Prosthesis Experience Scales (TAPES) – Upper Limb Version		0
	Multidimensional Scale Perceived Social Support (MSPSS)		0
	Coping Inventory for Stressful Situations (CISS)		0
	Eysenck Personality Questionnaire Revisited – Short Form (SPQR-SF)		0

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"Amputation- and prosthetic-related factors, along with psychological factors (e.g., patient coping strategies, attitude, expectations) and social factors (i.e., support of family and friends, reactions of others), need to be screened in the prosthesis fitting process. The present study shows that the M is effective in improving the functional ability and in easing the social interaction of previous active users of a myoelectric prosthesis." (Luchetti et al. 2015)

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Reference

Pröbsting E, Kannenberg A, Conyers DW, Cutti AG, Miguelez JM, Shonhowd TP, Ryan TA

Otto Bock HealthCare GmbH, Gottingen.

Ease of Activities of Daily Living with Conventional and Multigrip Myoelectric Hands.

JPO 2015; Vol 27, Num 2, p 46

Products

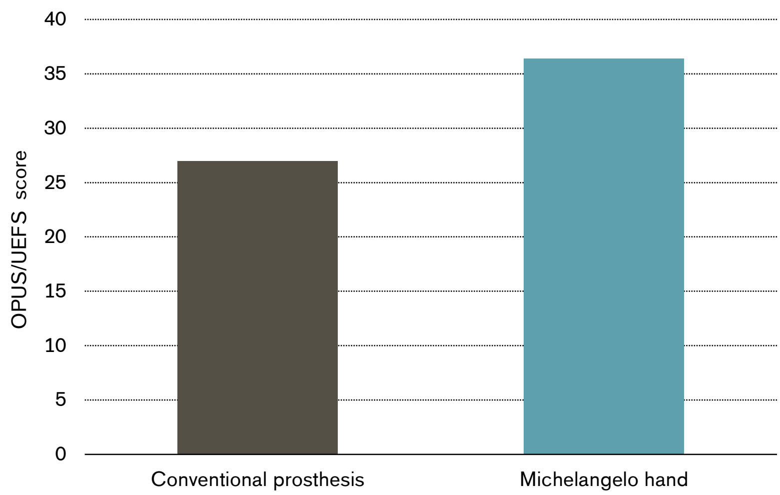
Michelangelo Hand vs previous myoelectric prostheses

Major Findings

With Michelangelo Hand compared to previous myoelectric prostheses:

- → **Perceived difficulty to perform tasks of daily living was decreased by 26%**
- → **Bimanual activities were easier to perform by 24%**
- → **Participants used the prosthesis to actively grasp an object in more bi-manual activities**

Perceived difficulty of activities of daily living



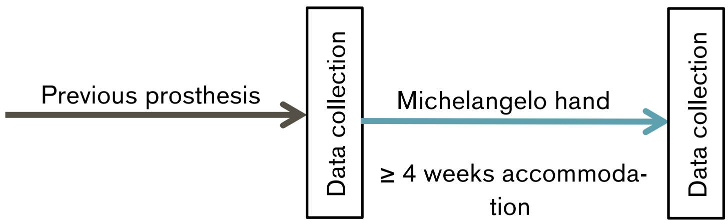
Perceived difficulty to perform 23 activities of daily living was measured with OPUS-UEFS questionnaire. Total OPUS-UEFS score was 26% higher with Michelangelo prostheses, meaning that tasks were easier to conduct with Michelangelo hand.

Population

Subjects:	16 subjects
Previous:	10 Sensor hand speed; 3 Myohand VariPlus Speed; 1 Motion Control Hand, 1 DMC plus Myohand, Elektrogreifer
Amputation causes:	8 traumas, 6 congenital deformities, 1 cancer and 1 sepsis
Mean age:	41 ± 14 years
Mean time since amputation:	12.8 ± 16.1 years

Study Design

Interventional, pre- to post-test design:



Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	**Activities of daily living (ADL)**	Satisfaction and Quality of life (QoL)	Training	Technical aspect

Category	Outcomes	Results for Michelangelo Hand vs previous myoelectric prostheses	Sig.*
Activities of daily living	Orthotics & Prosthetics User Survey – Upper Extremity Functional Status (OPUS-UEFS questionnaire)	**Perceived difficulty to perform tasks of daily living was decreased: Total OPUS-UEFS score was increased by 26% with Michelangelo prostheses.**	++
		5 activities of daily living (ADLs) were easier to perform with Michelangelo (wash face, put on socks, tie shoe laces, cut meat with knife and fork, carry laundry basket).	++
		Bimanual activities were easier to perform by 24%.	++
		Patients used Michelangelo in more activities than the conventional prosthetic hands.	++
	The Prosthetic Upper Extremity Functional Index (PUFI)	**Patients perceive to perform activities of daily life 15% easier.**	++
		Participants used prosthesis to actively grasp an object in more bimanual activities.	++

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"In conclusion, with the use of the Michelangelo hand, many ADLs were perceived to be easier to perform, resulting in a more active use of the prosthetic hand and a trend to reduce the primarily passive use of the prosthesis. Further research with performance-based outcome measures is encouraged to corroborate these self-reported findings." (Proebsting et al. 2015)

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Reference

Cutti A, Parel I, Luchetti M, Gruppioni E, Rossi N, Verni G
I.N.A.I.L. Centro Protesi – Vigorso di Budrio, Bologna

The Psychosocial and Biomechanical Assessment of Amputees Fitted with Commercial Multi-grip Prosthetic Hands – Case Study: Michelangelo hand

Grasping the Future: Advances in Powered Upper Limb Prosthetics, 2012, 59-77

Products

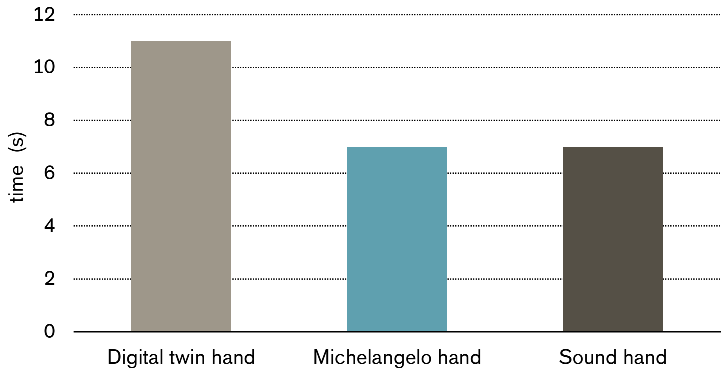
Michelangelo hand vs Digital twin hand

Major Findings

With Michelangelo hand compared to Digital twin hand:

→ Michelangelo hand reduces compensatory movements
→ Michelangelo hand gives more natural gesture and posture
→ Patient is more satisfied with Michelangelo hand

Disk task performance test with Michelangelo and Digital twin hand



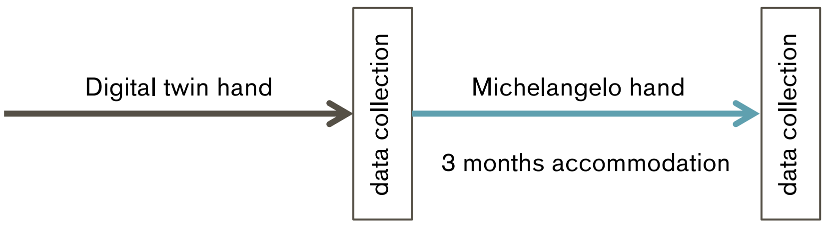
In disk task participant is moving the disk, positioned in front of the prosthetic hand, over the table. The participant moves disk over the table from the prosthetics hand to the sound hand, then in front of the participant and backwards. Michelangelo hand took same amount of time to perform disk task as sound hand (7s). Digital twin hand needed much more time to complete the same task (11s).

Population

Subjects:	male, unilateral transradial amputee, dominant side
Previous:	Digital Twin hand (Otto Bock)
Amputation causes:	trauma
Mean age:	50 years
Mean time since amputation:	30 years

Study Design

Case report



Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	**Satisfaction and Quality of life (QoL)**	Training	Technical aspect

Category	Outcomes	Results for Michelangelo hand vs Digital twin hand	Sig.*
Mechanics	Biomechanical analyses	Elbow flexion restriction was present with both prosthesis	0
		Michelangelo hand gave more natural approach to the object. With Digital Twin hand the patient approaches the object in adduction and with a relevant posterior tilting. With the sound and the Michelangelo hand, the patient approaches the object in abduction and almost without relying on scapula tilting.	+
		Michelangelo hand reduced compensatory movements	+
		Michelangelo hand was faster when performing some activities of daily life (moving the disk and jar).	+
Satisfaction	Questionnaire	Patient was more satisfied with Michelangelo than with previous prosthesis	+

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"Results highlighted an increased satisfaction with the new multi-grip hand and, remarkably, the new prosthesis triggered a higher level of embodiment, with a mind changing in the use the previous hand as well. Thanks to pleasant appearance and functional features of Michelangelo, the patient started to assume more natural gestures and postures also with the traditional myoelectric hand, reporting this different way of thinking the prosthesis as "a fundamental step for an amputee". Regarding the biomechanical assessment, the shoulder biomechanics was positively influenced by the availability of the lateral grip and by the overall hand shape, which allowed the patient to approach cylindrical and coin-shaped objects in a more natural way, limiting the shoulder compensatory movements." (Cutti et al. 2012)

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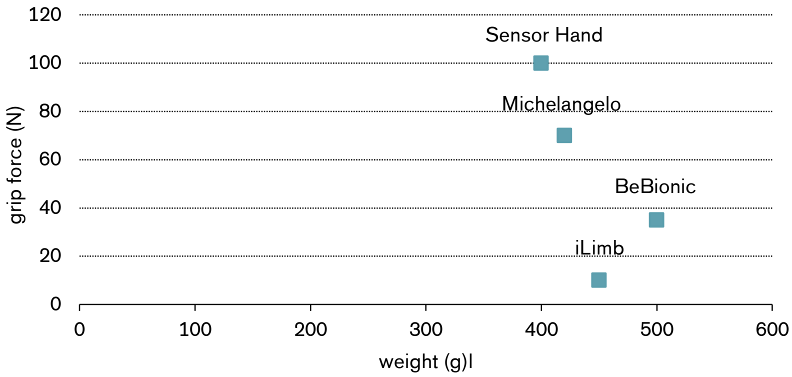
Reference	Belter JT, Segil JL, Dollar AM, Weir RF Yale University, Department of Mechanical Engineering and Materials Science, New Haven # Mechanical design and performance specifications of anthropomorphic prosthetic hands: A review Journal of Rehabilitation Research & Development 2011; 10:0188
Products	**Michelangelo hand** (Otto Bock) **Vincent hand** (Vincent Systems) **iLimb hand** (Touch Bionics) **iLimb Pulse** (Touch Bionics) **Bebionic hand** (RSL Steeper) **Bebionic hand v2** (RSL Steeper)
Major Findings	→ **Michelangelo hand has the highest grip force in group of multi-articulating hands** → **Michelangelo advantage is in the low number of actuators with transmissions that allow all functional grasping postures**

Distribution of hand weight compared with amount of grip force of the hand in grasp configuration



Population	Subjects:	no subject (technical comparison)
Study Design	Compare various prostheses in technical aspects	

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	Training	**Technical aspect**

Category	Outcomes	Results for **Michelangelo hand** (Otto Bock) **Vincent hand** (Vincent Systems) **iLimb hand** (Touch Bionics) **iLimb Pulse** (Touch Bionics) **Bebionic hand** (RSL Steeper) **Bebionic hand v2** (RSL Steeper)	Sig.*
Technical aspects	Thumb design and kinematics (authors suggestions)	Weight of the prosthesis (including mechanism, glove, electronics, etc.) should be below 500 g. Michelangelo´s weight is 420g, while all other prosthesis are heavier. Therefore only Michelangelo is fulfilling this criterion.	+
		Simple and robust finger kinematic designs are preferred. All listed prostheses are fulfilling this criterion.	0
		Powered adduction of the thumb. All listed prostheses are fulfilling this criterion.	0
		The use of brushless motors instead of brushed motors. All listed prostheses are fulfilling this criterion.	0
		A maximum pinch force at the finger tip of 65 N during palmar prehension. Fulfilled only with Michelangelo.	+
		230°/s should be achieved by a high-performing prosthesis, while 115°/s is a minimal acceptable speed.	n.a.
		Compliance in the mechanical design of a prosthetic hand can be achieved in various ways.	n.a.

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"The rules of thumb listed here focus on the mechanical design criteria that the authors are confident in prescribing as a universal opinion, and therefore not all mechanical design criteria discussed earlier in this study are addressed. However, the list provides a thorough foundation upon which mechanical designers of prosthetic hands can reference." (Belter et al. 2011)

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Reference

Johansen H, Østlie K, Andersen L, Rand-Hendriksen S.

TRS National Resource Centre for Rare Disorders, Sunnaas Rehabilitation Hospital, Nesodden , Norway,

Health-related quality of life in adults with congenital unilateral upper limb deficiency in Norway. A cross-sectional study

Disabil Rehabil. 2016 Nov;38(23):2305-14.

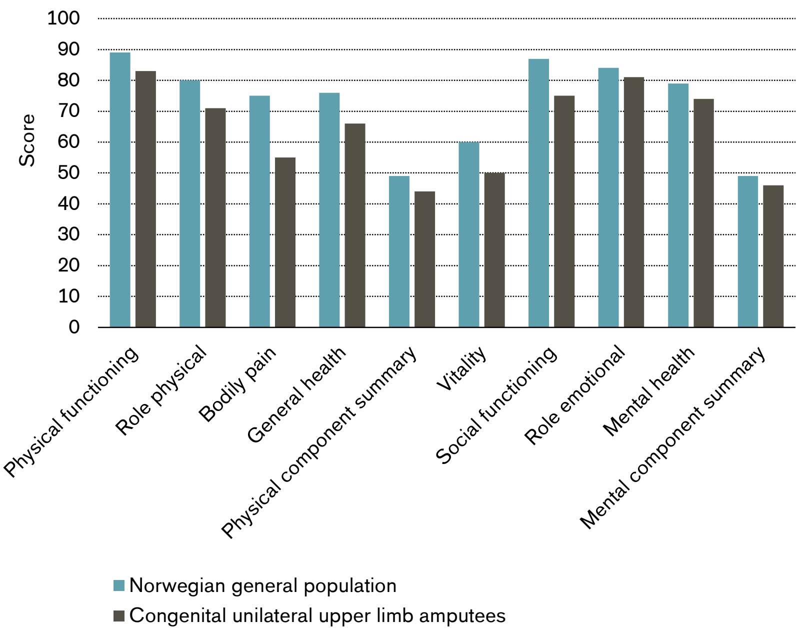
Study Population

Adults with upper limb congenital deficiency vs. able-bodied controls

Major Findings

The adults with upper limb congenital deficiency showed:
→ 11% reduced physical health compared to able-bodied controls.
→ 13% increased bodily pain compared to able-bodied controls.

SF-36 mean score for adults with unilateral congenital upper limb deficiency and able-bodied norms



→ Strain and overuse problems due to strenuous compensatory techniques may first appear in adulthood.

All four physical subscales (physical functioning, role physical, bodily pain, and general health) as well as physical component summary, and two of four mental subscales (vitality and social functioning) were statistically lower in adults with upper limb congenital deficiency compared to able-bodied controls ($p<0.05$). The highest impact was observed in bodily pain category.

Population

Subjects:	77 adults with congenital unilateral limb deficiency
Previous prosthesis:	not reported
Amputation causes:	77 congenital malformations
Mean age:	42.7 years
Mean time since first fitting:	not reported

Study Design

Observational, cross-sectional study

The objective of this questionnaire-based study was to compare health related quality of life of adults with congenital unilateral upper limb deficiency with age and gender matched control group from Norwegian population.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	**Satisfaction and Quality of life (QoL)**	Training	Technical aspect

Category	Outcomes	Results for adults with upper limb congenital deficiency vs. able-bodied controls	Sig.*
Satisfaction and Quality of life (QoL)	SF-36	**All four physical scales (physical functioning, role physical, bodily pain, and general health), as well as physical component summary, were statistically lower in adults with compared to normative data.**	--
		Two of four mental scales (vitality and social functioning) were lower in adults with upper limb congenital deficiency compared to able-bodied controls.	--
		Lower health related quality of life was associated with parenthood, living with a partner, comorbidity and chronic pain.	-
		Higher health related quality of life was found in those who reported being students or working.	+

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"In this study of Norwegian adults with unilateral upper limb deficiency most of them had left sided, transverse, below elbow deficiency. A significant fraction of the total study population showed reduced health related quality of life in most subscales, mostly in the physical health domain, when compared to the general population. The effect of the unilateral upper limb deficiency to the health related quality of life seemed to be mediated mainly by changes on occupational status, occurrence of comorbidity and pain. Professionals who meet adults with unilateral upper limb deficiency must be aware of reduced the health related quality of life, especially in physical health domain. Individual adaptive measures that may prevent pain and loss of function (grip-improving devices, adapted environment, adapted physical exercise, pain management programs) should be implemented early and might prevent reduced health related quality of life." (*Johansen et al. 2016*).

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Reference

Carey SL, Lura DJ, Highsmith MJ.

Department of Mechanical Engineering, University of South Florida, Tampa, FL.

Differences in myoelectric and body-powered upper-limb prostheses: Systematic literature review

Journal of Rehabilitation Research & Development 2015; 52(3):247-262.

Products

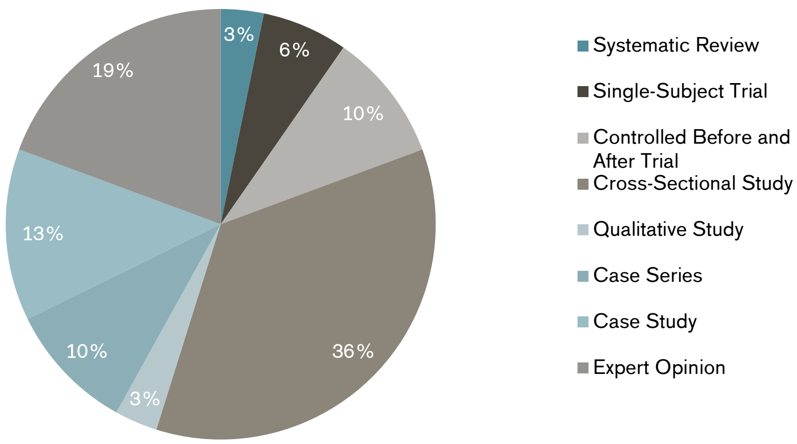
Myoelectric vs body-powered prostheses

Major Findings

→ Advantages of myoelectric prostheses
- preferred for office related jobs
- preferred in contact with general public
- cosmetic acceptance
- more comfortable
- may reduce affect phantom limb pain when intensively used

→ Advantages of body-powered prostheses
- preferred for heavy jobs
- more robust and durable
- less maintenance needed
- less training time needed
- perceived sensory feedback

Studies included for analysis



Population

Subjects:	1 - 1,216 adults per study (median: 12 subjects)
Previous prostheses:	not mentioned
Amputation causes:	not mentioned
Mean age:	43.3 yrs
Mean time since amputation:	not mentioned

Study Design

Systematic Review:

Studies retrieved from database search and additional resources n=462 → Studies for detailed review n=44 → Studies included n=31

Exclusion after screening for inclusion and exclusion criteria (n=418)

Exclusion due to content and quality (n=13)

Included publications:	Systematic Review (1), Single-Subject Trial (2), Controlled Before and After Trial (3), Cross-Sectional Study (11), Qualitative Study (1), Case Series (3), Case Study (4), Expert Opinion (6)
Quality assessment:	Internal validity was low in 19 studies, moderate in 5 studies and high in 1 study; external validity was low in 5 studies, moderate in 8 studies and high in 12 studies; overall quality was rated as low in 18 studies, moderate in 11 studies and high in 2 studies. The included publication spanned the years from 1993 to 2013, with the majority of publication occurring in 2012.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	Training	Technical aspect

Category	Empirical Evidence Statements	Supporting publications	Level of confidence
Pain	Myoprosthetic use decreases cortical reorganization which leads to reduction of phantom-limb pain.	2	Low
Activities of daily living (ADL)	Depending on functional needs, control scheme familiarity and preference body-powered prostheses or myoelectric prostheses are advantageous. Myoelectric prosthesis are preferred for office related jobs, supervisory work or contact with general public, while body powered prosthesis are mostly used in jobs that required heavy lifting objects, materials handled were dirty, greasy or sharp.	10	Moderate
Satisfaction and Quality of life (QoL)	Compared with myoelectric prostheses, body-powered prostheses are more durable, require less adjustment, are easier to clean and function with less sensitivity to fit.	3	Low
	Body-powered prostheses provide more sensory feedback than myoelectric prostheses.	3	Low
	Cosmesis is improved with myoelectric prostheses compared to body-powered prostheses.	4	Low
	Proportion of rejections is same with myoelectric	3	Insufficient

Category	Empirical Evidence Statements	Supporting publications	Level of confidence
	(mean 23%) and body-powered (mean 26%) prostheses.		
Training	Compared with myoelectric prostheses, body-powered prostheses require shorter training time.	3	Low
	Intuitive prosthetic control may require use of multiple control strategies. It should require less visual attention and ability to make coordinated motions of both joints. These should be evaluated for each prosthesis user.	8	Moderate
	Prosthetic rehabilitation plan addressing EMG site selection, controls and task training could improve function and long-term success of myoelectric prosthesis users.	2	Low
Technical aspects	Improvements in body-powered prosthetic operation should be made within harness and cabling systems.	3	Low
	Roll-on sleeve improves suspension and increases range of motion.	1	Low

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"This report is a systematic review of publications related to upper-limb prostheses with the goal of identifying evidence comparing currently available MYO and BP prosthetic devices. Eleven EESs were generated addressing the areas of interest: control, function, feedback, cosmesis, and rejection. Conflicting evidence has been found in terms of the relative functional performance of BP and MYO prostheses. Several specific domains have been established that show advantages of each type of prosthesis. Activity-specific passive and BP prostheses can provide significant advantages to prostheses users and are typically lower cost than alternatives. BP prostheses have been shown to have advantages in durability; training time; and frequency of adjustment, maintenance, and feedback. Some evidence demonstrated BP prosthetic control can be improved by optimizing harness and cabling systems. MYO prostheses have been shown to provide a cosmetic advantage, are more accepted for light-intensity work, and may positively affect phantom limb pain when used actively. MYO prostheses can be improved with more advanced control methods; however, there is little evidence of these methods transitioning into larger controlled studies and further into clinical practice.

Outside of surveys, there is little evidence addressing the functional capabilities of prostheses users and fewer studies making a direct comparison of prostheses in a controlled setting. A few standardized tests to directly evaluate prostheses function were found in multiple studies. Currently, evidence is insufficient to conclude that either the current generation of a MYO or a BP prosthesis provides a significant general advantage. Selection of a prosthesis should be made based on a patient's individual needs with regard to domains where differences have been identified. A patient's personal preferences, prosthetic experience, and functional needs are all important factors to consider. This work demonstrates that there is a lack of empirical evidence regarding functional differences in upper-limb prostheses." (Carey et al. 2015)."

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Reference

Razak A, Osman A, Kamyab M, Abas W, Gholizadeh H
Department of Biomedical Engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur

Satisfaction and Problems Experienced with Wrist Movements

American Journal of Physical Medicine & Rehabilitation 2014;93:437Y444

Products

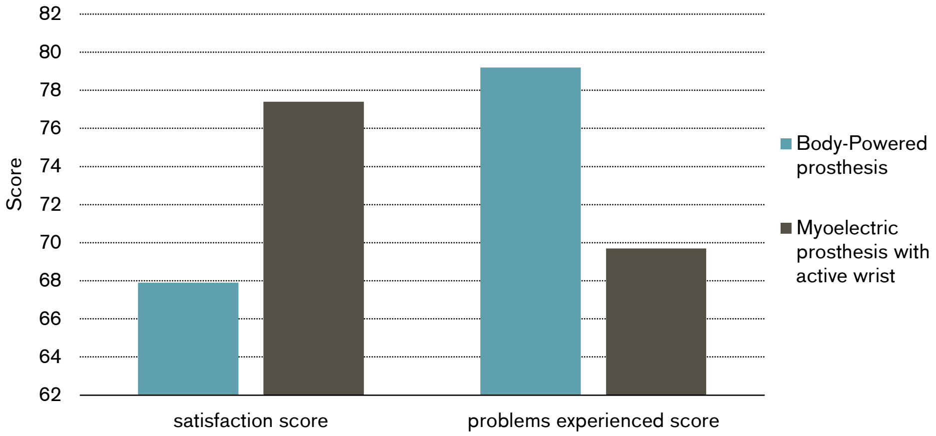
Myoelectric prosthesis with active wrist vs Body-powered prosthesis

Major Findings

With myoelectric prosthesis with active wrist compared to body-powered prosthesis:

→ **Users were satisfied with the active wrist**
→ **The overall satisfaction score was 12% higher for the myoelectric prosthesis with active wrist than for body-powered prosthesis system.**
→ **The overall scores for problems experienced with the myoelectric prosthesis with active wrist were 13% lower than for body-powered prosthesis system.**

Satisfaction and problems experienced scores with myolecetric prosthesis with active wrist and body powered prosthesis



Population

Subjects:	15 persons with transradial amputation
Previous:	body-powered prostheses
Amputation causes:	trauma
Mean age:	45.38 ± 11.25
Mean time since amputation:	n.a.

Study Design

Retrospective study

Participants were already fitted with myoelectric prosthesis with active wrist and the subjects were asked to recall their experiences with body-powered prosthesis.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	**Satisfaction and Quality of life (QoL)**	Training	Technical aspect

Category	Outcomes	Results for myoelectric prosthesis with active wrist vs body-powered prosthesis	Sig.*
Satisfaction	Questionnaire (self-designed)	The overall satisfaction score was 12% higher for the myoelectric prosthesis with active wrist than for body-powered prosthesis system.	+
		The level of the subjects' satisfaction was higher for the myoelectric prosthesis with active wrist in terms of: - **pronation and supination,** - **flexion and extension** - **in ability to open a door**.	++
		Abilities to pick up, place and hold the cup were lower with myoelectric prosthesis with active wrist.	--
		No differences were observed in terms of sweating, wounds, irritation, socket, smell, sound, and durability.	0
		Fewer difficulties were observed with the myoelectric socket system in terms of pain.	+
		The overall scores for problems experienced with the myoelectric prosthesis with active wrist were 13% lower than for body-powered prosthesis system.	+

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"Overall, this study revealed that most of the participants with transradial amputation were more satisfied with the biomechatronics wrist prosthesis than the common body-powered prosthesis. Some users prefer the body-powered prosthesis depending on the task they are doing. Further study should focus on comparing both prostheses while doing other daily life activities such as fishing, driving, and many more. The study of kinematics approach also needs to be considered for all parts of the upper limb while doing the task." (Razak et al. 2014)

↑ Back to overview table

Reference

Østlie K, Lesjø IM, Franklin RJ, Garfelt B, Skjeldal OH, Magnus P

Innlandet Hospital Trust, Department of Physical Medicine and Rehabilitation, Ottestad

Prosthesis use in adult acquired major upper-limb amputees: patterns of wear, prosthetic skills and the actual use of prostheses in activities of daily life

Disability and Rehabilitation: Assistive Technology 2012;7(6):479-93

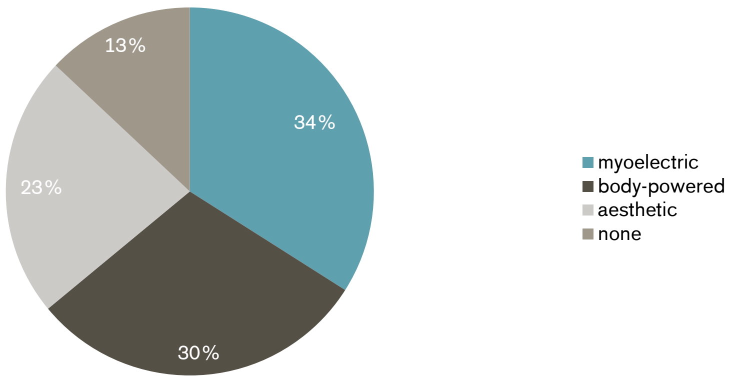
Products

Myoelectric vs Body-powered vs Cosmetic prostheses

Major Claims Prosthetic use in adult amputees:

→ 80.8% amputees wear prostheses
→ 90.3% consider their most worn prosthesis to be useful
→ Most prevalent prosthesis among adult amputees is myoelectric
→ Prostheses are used in only ½ activities of daily living
→ Increased actual use was associated with sufficient prosthetic training

The most worn prosthesis



Population

Subjects:	181 upper limb amputees (71% forearm/wrist, 29% elbow/upper arm)
Previous:	average of 2,5 prosthesis per a patient, mostly combination of myoelectric and body-powered
Amputation causes:	not listed
Mean age:	54.7 years
Mean time since amputation:	28.6 years

Study Design

Cross-sectional study

The purpose of this study was to describe prosthesis wear and perceived prosthetic usefulness as well to describe prosthetic skills and actual use of prosthesis in activities of daily life (ADL).

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	**Activities of daily living (ADL)**	**Satisfaction and Quality of life (QoL)**	Training	Technical aspect

Category	Outcomes	Results for Myoelectric vs Body-powered vs Cosmetic prostheses	Sig.*
Activities of daily living	Clinical testing and interviews (n=50 patients)	Myoelectric prosthesis is used more than other prosthesis in ADL.	+
		With myoelectric prosthesis it is easier to perform bimanual tasks	+
		Bilateral amputees tend to use their prosthesis more than unilateral amputees (in ⅔ of ADL).	+
		Higher scores for "housework", "shopping" and "desk procedures" with myoelectric prostheses.	+
		Lower scores for myoelectric prostheses for "cooking and washing", "eating", "communication".	-
		Compensatory movements in myoelectric prosthetic users involved shoulder, shoulder girdle or torso.	n.a.
Satisfaction	Questionnaire (self-designed) (n=181 patients)	Average prosthesis wearing time is 4h per day.	n.a.
		82% amputees are satisfied with their prosthesis.	n.a
		Cosmetic prostheses were most useful for improving appearance.	-
		Myoelectric and body powered prostheses were more useful for ADL than cosmetics prostheses.	+
		44% amputees needed adjustment of the prosthesis less than once a year; 22% more than 4 times a year	n.a.
		65% amputees received a prosthetic training (only 44% of them rated a training as important for their prosthetic use)	n.a.

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"Prosthesis wear was found in 80.8% with each prosthesis wearing upper limb amputees (ULA) possessing an average of 2.5 prostheses at survey. The majority wore their most worn prosthesis for >8 hours a day. Our findings suggest that major ULAs choose to wear the prosthetic type(s) that best meet their functional needs and that these preferences are extremely individualised. In the process of fitting an ULA with a new prosthesis, type-specific usefulness profiles as those provided in our study may give a valuable contribution to an informed decision. The prosthesis-wearing amputees in our sample were mainly satisfied with their prostheses, reported their prostheses as useful and showed good prosthetic skills in ADL tasks – but did not use their prostheses for more than about half of the ADL tasks carried out in everyday life. Our findings suggest that in unilateral ULAs, individualised and targeted prosthetic training may increase optimal, active prosthesis use in ADL and that the effect of sufficient prosthetic training on the Actual Use Index (AUI) may be mediated by a decrease in one-handed task performance. Individualised prosthetic training should probably be mandatory at every prosthetic fitting and extra prosthetic training should probably be offered when the functional needs of the amputee change. Furthermore, our findings suggest that fitting the amputee with myoelectric rather than passive prostheses may increase prosthesis use in ADL, regardless of amputation level. Prosthetic skills did not affect every day prosthesis use in our material." (Østlie et al. 2012)

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Reference

Kooijmana C, Dijkstra P, Geertzena J, Elzingad A, van der Schans C

Department of Rehabilitation, University Hospital Groningen, The Netherlands

Phantom pain and phantom sensations in upper limb amputees: an epidemiological study

Pain 87 (2000) 33-41.Published by Elsevier Science.

Products

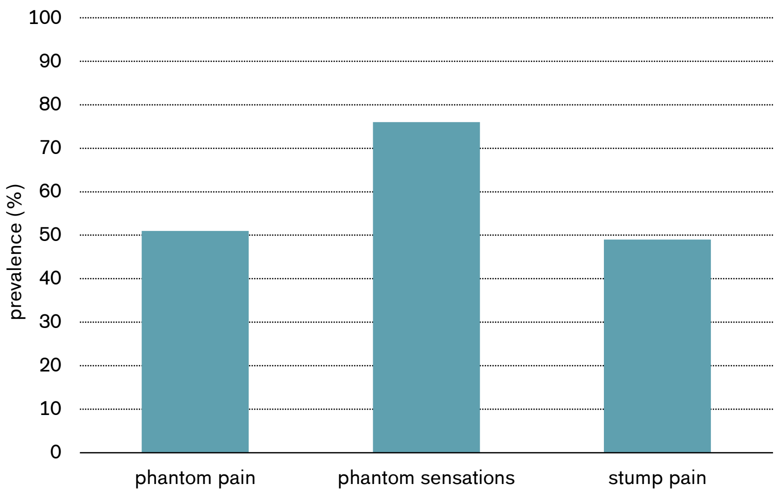
Myoelectric, body-powered, cosmetic prostheses

Major Findings

With phantom pain and phantom sensations in upper limb amputees:

- → **The prevalence of phantom pain was 51%, phantom sensations 76% and stump pain 49% in the subjects with acquired amputation.**
- → **Phantom pain was not reported in congenital group.**
- → **Phantom pain did not affect prosthetic usage or functional ability.**
- → **Phantom sensations and stump pain could lead to phantom pain.**

Prevalence in the group with acquired amputation



Population

Subjects:	99 upper limb amputees
Prosthesis:	myoelectric, body-powered, cosmetic prostheses
Amputation causes:	56 accident, 27 congenital malformations, 11 cancer, 2 vascular disease, 2 infection,
Median age:	congenital group – 30.5 years; acquired group - 44.2 years
Median time since amputation:	19.1 years

Study Design

Retrospective study
This study retrospectively evaluated the pre-amputation pain and frequencies of phantom sensations, phantom pain, and stump pain post-amputation. Additionally, the study reviewed the types of medical treatments received for phantom pain and/or stump pain as well as self-medication and prosthetic use. The median follow-up time was 19.1 years.

Results

Body Function		Activity			Participation	Others	
Mechanics	**Pain**	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	Training	Technical aspect

Category	Outcomes	Results for stump pain, phantom pain and sensation.	Sig.*
Pain	Questionnaire (self-designed)	Phantom pain was not reported in congenital group.	n.a.
		The prevalence of phantom pain in acquired group of amputees was 51%, of phantom sensations 76% and of stump pain 49%.	n.a.
		Pain before amputation was experienced by 14% of subjects that acquired amputation during their life.	n.a.
		Medical treatment was given to 4 subjects (transcutaneous electrical nerve stimulation, medication injections), two responded.	n.a.
		Medical treatment for stump pain was given to 5 subjects of which four subjects underwent an operation and one subject received massage. In three subjects the operation was effective.	n.a.
		In 20 subjects a spot was present which upon touching provoked phantom pain and stump pain.	n.a.
		The arm prosthesis was used for more than 8 h per day by 72% of amputees.	n.a.
		Phantom sensations associated with phantom pain: • Itching 25% • Movement 38% • Abnormal shape 9% • Abnormal position 22% • Something touching 7% • Warmth 11% • Cold 40% • Electric sensations 42%	n.a.
		The relative risk of experiencing phantom pain when having stump pain is about twice as high compared with those not experiencing stump pain.	n.a.
		Phantom pain was present in 97% of subjects experiencing phantom sensations.	n.a.

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"In conclusion, phantom pain after upper limb amputation is a common problem. The determinants are still poorly understood." (Kooijmana et al. 2000)

↑ Back to overview table

Reference

Millstein S, Heger H, Hunter G

Amputee Clinics, Ontario Workers´ Compensation Board, Ontario, Canada

Prosthetic use in adult upper limb amputees: a comparison of the body powered and electrically powered prostheses

Prosthetics and Orthotics International, 1986, 10, 27-34

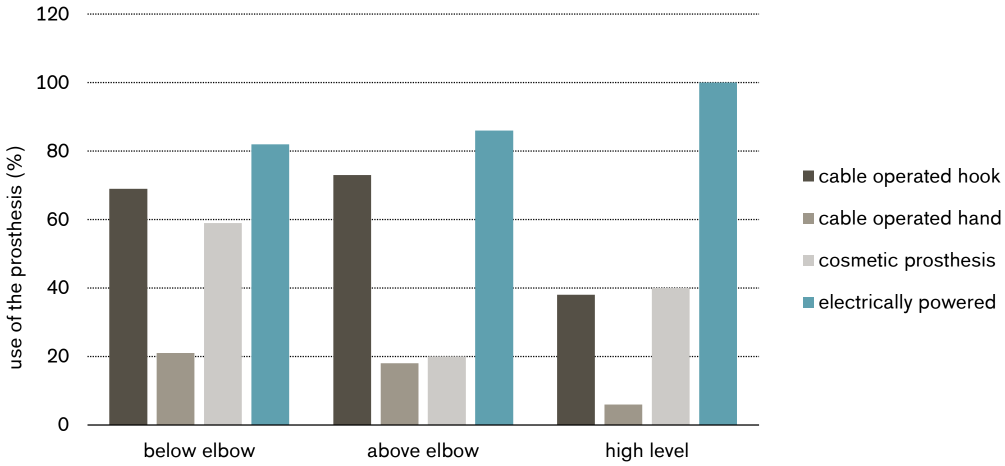
Products

Electrically vs body powered prostheses

Major Findings

- → **The most preferred prosthesis was electrically powered prosthesis.**
- → **The cable operated hook was the second most favoured prosthesis.**
- → **82% of below-elbow patients fitted with electrically powered prosthesis reported using it.**
- → **69% of below-elbow patients fitted with body powered prosthesis reported using it.**
- → **The majority of amputees used more than one prosthesis for their functional needs suggesting that it is necessary to fit amputees with more than one type of prosthesis.**

Acceptance of body-powered and electrically powered prostheses



Amputees reported that electrically powered prosthesis is the most preferred one, followed by the cable operated hook, cosmetic and cable operated hand. Acceptance rate for electrically powered prosthesis was 82% at below elbow, 86% at above elbow and 100% at high level amputation.

Population

Subjects:	314 upper limb amputees
Prosthesis type:	cable operated hook, cable operated hand, cosmetic prosthesis, electrically powered
Amputation causes:	work related accident
Mean age:	49 years
Mean time since amputation:	15 years.

Study Design	Retrospective study: The period between amputation and follow-up ranged from 1 to 49 years with a mean of 15 years. Evaluation after the follow-up period included the questionnaire and the review of patients´ records.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	Training	Technical aspect

Category	Outcomes	Results for electrically vs body powered prostheses	Sig.*
Activities of daily living	Questionnaire (self-designed)	The electrically powered prosthesis was used 8h each day through the week. The cable operated hook was used for an average 8h each work day and 7h on weekend day. The cable operated hand was used for an average 5h each day and cosmetic hand was worn on average 4h per week day.	+
		Work use: Amputees who used electrically powered prosthesis primarily had jobs that involved office work, supervisory work or contact with general public. Amputees who used cable operated prostheses had jobs that required lifting heavy objects and handling objects that were dirty, greasy or sharp.	+ -
		Sports use: Both electrically and body powered prostheses were used for variety of sports.	0
		Social use: Electrically powered prosthesis was more acceptable in the social sphere than the cable operated hook.	+
		Home use: Electrically powered prosthesis was used most often for eating, holding objects and occasionally driving a car.	+
Satisfaction	Questionnaire (self-designed)	Complete or useful acceptance of an upper prosthesis was reported in 89% of below-elbow amputees, 76% of above-elbow amputees and 60% of high level amputees.	n.a
		Amputees reported that electrically powered prosthesis is the most preferred one, followed by the cable operated hook.	+
		Acceptance rate for <u>cable operated hook</u> was 69% for below elbow, 73% for above elbow and 38% for high level amputation. Acceptance rate for <u>cable operated hand</u> was 21% for below elbow, 18% for above elbow and 6% for high level amputation.	+

Category	Outcomes	Results for electrically vs body powered prostheses	Sig.*
		Acceptance rate for cosmetic prosthesis was 59% for below elbow, 20% for above elbow and 40% for high level amputation. Acceptance rate for electrically powered was 82% for below elbow, 86% for above elbow and 100% for high level amputation.	

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"The findings of the review of 314 upper limb amputees confirm that complete or useful acceptance of and upper limb prosthesis was reported in 89% of below-elbow, 76% of above-elbow and 60% of high level amputees. Prostheses are well used and essential to the amputees' personal and employment activities. Most upper limb amputees should be fitted with both a body powered and electrically powered prosthesis to meet their various functional requirements. The benefits of these prostheses far outweigh their costs. The cable operated hook s well accepted and used by the majority of amputees for heavy work and precision tasks at work and at home. It provides good sight of grasped objects is not easily damaged and is easy to clean. The cable operated hand and cosmetic prosthesis are used by a small number of amputees primarily for cosmesis at social occasions. In spite of the high initial cost and continued maintenance and repair, improvement in comfort, cosmesis and comfort and function have led to good levels of acceptance of the electrically powered prosthesis. For high level amputees, it provides better function, superior pinch force and requires less energy expenditure than the body powered prosthesis." (Millstein et al. 1986)

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Reference

Stain R, Walley M

Departments of Physiology and Occupational Therapy, University of Alberta, Edmonton, Canada

Functional Comparison of Upper Extremity Amputees Using Myoelectric and Conventional Prosthesis

Archives of Physical Medicine and Rehabilitation Vol 64, June 1983.

Products

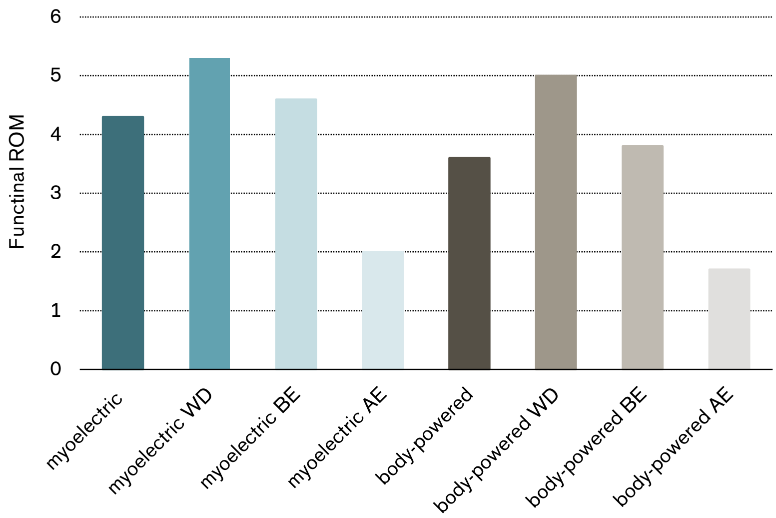
Myoelectric (Ottobock 6V) vs body-powered prosthesis

Major Findings

With myoelectric compared to body-powered prosthesis:

→ Myoelectric prosthesis provides to the user higher range of motion.
→ Task execution was faster with body-powered prosthesis, but with more compensatory movements.
→ 60% of amputees preferred myoelectric prosthesis.

Functional Range of Motion (RoM) for patients tested with myoelectric and body-powered prosthesis



The myoelectric amputees scored higher on average in test of functional range of motion (RoM) than body-powered amputees (4.3 compared to 3.6, dark blue and grey bars). A score of 4 means that the amputee could open his terminal device (hook or myoelectric hand) in 4 of the 5 positions tested (above shoulder level, at the mouth, behind the neck, far in front of the body, behind the back). Amputees fitted with body-powered prosthesis were unable to open the hook behind the back and the neck, because the cable became slack in these positions. (WD – wrist disarticulation, BE – below elbow, AE – above elbow)

Population

Subjects:	34 upper limb amputees
Products:	16 body-powered prostheses;
	20 myoelectric prostheses (Ottobock 6V)
Amputation causes:	60% traumatic causes, 40% congenital malformation
Mean age:	body-powered group: 40 ± 17 years
	myoelectric group: 27 ± 14 years

Mean time since amputation:	body-powered group: 12.2 ± 12.9 years myoelectric group: 1.4 ± 1.5 years

Study Design

Observational study

Amputees were tested on standardised series of tasks using their myoelectric hand, conventional prosthesis and their normal hand. Questionnaires were also administered.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	**Manual dexterity**	**Activities of daily living (ADL)**	Satisfaction and Quality of life (QoL)	Training	Technical aspect

Category	Outcomes	Results for myoelectric vs body-powered prosthesis	Sig.*
Manual dexterity	Functional Range of Motion (RoM): • above shoulder level, • at the mouth, • behind the neck, • far in front of the body, behind the back	**The myoelectric amputees scored higher on average in test of functional range of motion (RoM) than body-powered amputees (4.3 compared to 3.6).**	**++**
		Amputees fitted with body-powered prosthesis were unable to open the hook behind the back and the neck, because the cable became slack in these positions.	+
	Tasks: • Pick up small objects • Simulated feeding • Stacking checkers • Picking up pegs • Picking up and rotating heavy objects • Strength of cylindrical grasp • Box and Block test • Endurance	Amputees performing tasks with myoelectric prosthesis took about twice as long as those with a conventional prosthesis, and nearly 5 times as long as when performing tasks with their normal arm.	-
		Although amputees were able to accomplish the task faster with the body-powered than with myoelectric prosthesis, they had to use extreme body movements such as rotating their trunk to rotate heavy objects, because of harnessing.	+
Activities of daily living	Questionnaire	The average scores on the ADL questionnaire were not different for myoelectric and conventional prosthesis users.	0
		Body-powered prosthesis was worn for a longer period of time (14h per day on average) than myoelectric prosthesis (9.6h per day on average).	**--**
		60% preferred to use myoelectric prosthesis compared to body-powered, which they had been fitted previously.	+

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"Amputees who had been fitted only with a conventional prosthesis and used their prosthesis regularly, tended to wear the prosthesis more hours per day (14 hours) than amputees fitted with a myoelectric hand (9.6 hours), some of whom continued to use a conventional prosthesis for some jobs. However, the amputees with myoelectric prostheses had a greater functional range of motion (RoM) than those with a conventional prosthesis and many regular wearers of myoelectric prosthesis had long since rejected a conventional prosthesis. Amputees took about 2.5 times as long to complete the tasks tested with a conventional prosthesis and about five times as long with myoelectric prosthesis than with their normal hand. Despite the slower function, more than 60% of below-elbow amputees accepted the myoelectric prosthesis, which they had all been fitted with previously. Others preferred to continue using a conventional prosthesis to which they become accustomed (13%) or no prosthesis (26%). The combination of function, RoM, and cosmetic appearance of myoelectric prosthesis is preferred by most below-elbow amputees, despite its slower performance at present time." (Stain et al. 1983)

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Reference

Northmore-Ball M, Heger H, Hunter G

Addenbrooke´s hospital, Hills Road, Cambridge, England

The below-elbow myoelectric prosthesis

The Journal of Bone and Join Surgery, VOL. 62-B No.3, 1980

Products

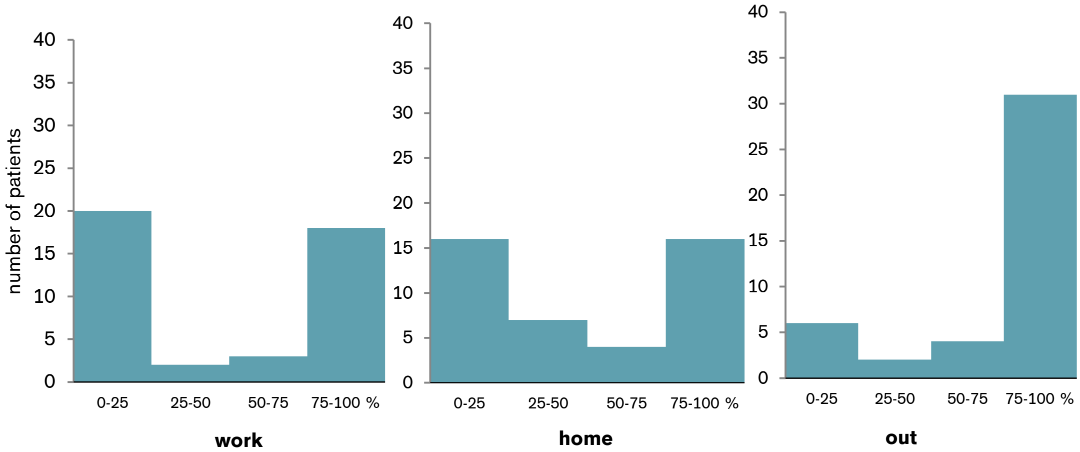
Myoelectric prosthesis, body-powered prosthesis

Major Findings

With myoelectric prosthesis:

- → **Nearly 50% of the patient used myoelectric prosthesis all the time at work**
- → **The myoelectric users that mostly benefited from prosthesis had office jobs**
- → **No patient had completely rejected the myoelectric prosthesis**

Use of myoelectric prosthesis



Histogram shows use of myoelectric prosthesis at work, home and during social time. Myoelectric prosthesis was worn almost all time at work by 42%, at home by 38% and when going out by 72% of patients.

Population

Subjects:	one bilateral, 42 unilateral transradial amputees
Previous prosthesis:	body-powered
Amputation causes:	n.a.
Mean age:	36 years
Mean time since amputation:	n.a.

Study Design

Retrospective study:

The study aimed to get reliable information about actual use of standard, prosthesis that the patients were fitted with myoelectric prosthesis. Each patient all possessed both a myoelectric prosthesis and a standard artificial limb.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	**Activities of daily living (ADL)**	**Satisfaction and Quality of life (QoL)**	Training	Technical aspect

Category	Outcomes	Results for myoelectric prosthesis	Sig.*
Activities of daily living	Questionnaire (self-designed)	Myoelectric prosthesis was worn almost all time at work by 42%, all time at home by 38% and all time when going out by 72% of patients.	+
		Patients who used the myoelectric hand predominantly at work tended to have office jobs (quality control inspector, chemist, student, computer programmer…).	+
		Type of jobs, where patients used myoelectric prosthesis less than 25% of their working time, were industrial jobs (machine operator, metal worker, factory worker…).	-
Satisfaction	Questionnaire (self-designed)	Common reason for not using myoelectric prosthesis at work (65%) was fear of damaging either the prosthesis itself or its glove.	-
		Myoelectric prosthesis had a functional use at work, but in the public its value tended to be more cosmetic and passive.	+
		Patients felt that myoelectric prosthesis gives them more sensory feedback than body-powered prosthesis.	+
		Patients felt that myoelectric prosthesis was more like a part of them than a body-powered prosthesis.	+

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"The place of myoelectric prosthesis in below-elbow amputees has been reviewed, Forty-three patients were seen and all possessed both a myoelectric prosthesis and a standard artificial limb. Nearly half the patients used the never device almost all the time at work and many of these wore it for the majority of their working hours. Its use at work was mainly related to the patient's type of job and here in turn there was concern about damaging the device. It is suggested that acceptance would be further increased if greater attention were paid to the durability of the arm and its glove." (Northmore-Ball et al., 1980)

↑ Back to overview table

Reference

Major M, Stine R, Heckathorne C, FatoneS and Gard S

Northwestern University Prosthetics-Orthotics Center, Northwestern University Feinberg School of Medicine, Chicago, USA

Comparison of range-of-motion and variability in upper body movements between transradial prosthesis users and able-bodied controls when executing goal-oriented tasks

Journal of NeuroEngineering and Rehabilitation 2014, 11:132.

Products

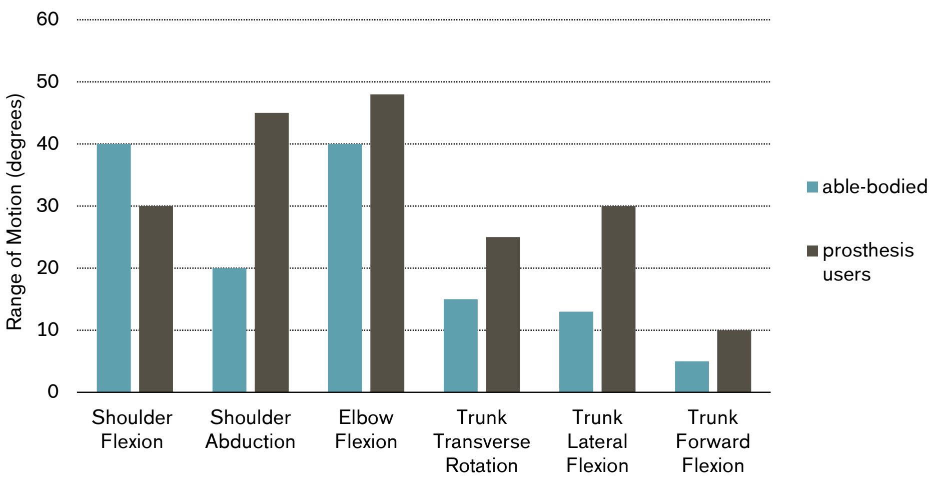
Myoelectric prosthesis

Major Findings

With myoelectric prosthesis users compared to able-bodied controls:

→ **Shoulder and trunk movements are common compensatory motions in prosthesis users.**
→ **Increased variability in movement suggests that prosthesis users do not stick to a defined motor strategy.**
→ **Kinematic repeatability may increase with prosthesis experience.**

Average range of motion for carton poring task



Upper body range of motion (RoM) was analysed on able-bodied controls and myoelectric transradial prosthesis users during execution of carton pouring task (lifting a carton, located at midline of the body, and emptying the liquid contents into a jar on the contralateral side with minimal spilling). Results indicate that prosthesis users demonstrate a significant increase in shoulder abduction, trunk transverse rotation, trunk lateral flexion and trunk forward flexion than able-bodied subjects.

Population

Subjects:	6 able-bodied controls 7 myoelectric transradial prosthesis users
Prosthesis:	System Electric Hand, MyoHand VariPlus Speed Hand, Transcarpal Hand, Motion Control Hand, i-Limb Ultra Revolution, i-Limb Ultra and i-Limb Hand
Amputation causes:	4 traumatic, 3 congenital
Mean age:	able-bodied individuals - 35 ± 11 year prosthetic users - 49 ± 18 years
Mean time since amputation:	9.5 ± 11.0 years

Study Design	Observational study: Participants were requested to execute five goal-oriented tasks while seated (carton poring, page turning, food cutting, lifting and transferring weighted object, lifting and transferring tray). Able-bodied controls and prosthesis users performed these tasks using their non-dominant and prosthetic limb, respectively.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	Training	Technical aspect

Category	Outcomes	Results for myoelectric prosthesis users compared to able-bodied controls:	Sig.*
Mechanics	Goal orientated tasks: • carton poring • page turning • food cutting • lifting and transferring weighted object • lifting and transferring tray	The majority of prosthesis users were unable to routinely execute food cutting and page turning tasks.	n.a.
		Prosthesis users demonstrated a significant increase in shoulder abduction, trunk transverse rotation, trunk lateral flexion, and trunk forward flexion RoM when executing carton pouring, lifting and transferring tasks.	--
		No difference in shoulder and elbow flexion/extension RoM was observed.	0
		Kinematic variability was high for prosthetic users.	--
		Kinematic repeatability was low for prosthetic users.	--

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion	"Transradial prosthesis users utilize shoulder abduction and trunk movement as compensatory motions to execute goal-oriented tasks, and the majority of these motions are accompanied by increased kinematic variability when compared to able-bodied controls. The average repeatability of upper body kinematics was positively associated with prosthesis experience. As these dynamics may be necessary to compensate for the absence of active distal DoFs (degrees of freedom) in the prosthetic arm, transradial prosthesis users may benefit from dedicated training that: 1) encourages optimization of these dynamics to facilitate execution of ADLs, and 2) fosters adaptable but reliable motor strategies." (Major et al. 2014)

↑ Back to overview table

Reference

Bertels T, Schmalz T, Ludwig E

Otto Bock HealthCare GmbH, Goettingen

Biomechanical influences of shoulder disarticulation prosthesis during standing and level walking

Prosthetics and Orthotics International 2012; 36(2) 165–172

Products

MovoShoulder Swing with DynamicArm and System Electric Hand vs no prosthesis

Major Findings

MovoShoulder Swing with DynamicArm and System Electric Hand:

- → **Compensatory movements during walking in shoulder, elbow and knee are reduced when using a free swinging shoulder joint**
- → **Swinging of the sound arm in shoulder joint is 23% reduced**
- → **Swinging of the sound arm in elbow joint is 13% reduced**
- → **Unphysiological loading of the knee joint on amputated side is 12% decreased**

Mean range of contralateral shoulder motion during walking with or without prosthesis

The prosthesis (MovoShoulder Swing, DynamicArm and System Electric Hand) reduced the pronounced unphysiological swing of the sound arm (segment angle of sound side decreased from 33° without the prosthesis to 25.5° with prosthesis).

Population

Subjects:	8 patients with unilateral shoulder disarticulation and 6 able-bodied subjects
Amputation causes:	6 traumas, 1 cancer and 1 sepsis
Mean age:	44 ± 13 years
Mean time since amputation:	14 ± 9 years

Study Design

Observational (non-interventional) study:

Aim of this study was to observe the impact of functional arm prosthesis on body posture and gait of shoulder disarticulation patients and compare it with able-bodied individuals.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	Training	Technical aspect

Category	Outcomes	Results for MovoShoulder Swing with DynamicArm and System Electric Hand vs no prosthesis	Sig.*
Mechanics	Gait analyses (kinematic)	Walking speed between amputees and able bodied participants was similar.	0
		Intensive swinging of the sound arm in shoulder and elbow joint is drastically reduced with MovoShoulder Swing and DynamicArm.	++
		Shoulder backward rotation is reduced with the use of prosthesis.	++
		Unphysiological loading of the knee joint decreases with free swing in the shoulder joint enabled by the prosthesis.	++

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"From the biomechanical point of view, unilateral shoulder disarticulation patients benefit greatly from modern prosthetic systems as described in this paper. This study shows that the patient's body posture is significantly improved by using a prosthesis. Compensatory movements, such as abnormal swinging of the contralateral arm, are reduced. In addition, unphysiological loading of the knee joint decreases if the prosthetic shoulder joint freely swings in the sagittal plane." (Bertels et al. 2012)

↑ Back to overview table

Reference	van der Niet O, Reinders-Messelink H, Bongers R, Bouwsma H, van der Sluis C Department of Rehabilitation, University Medical Center Groningen, Groningen

The i-LIMB hand and the DMC plus hand compared: A case report

Prosthetics and Orthotics International, June 2010; 34(2): 216–220

Products

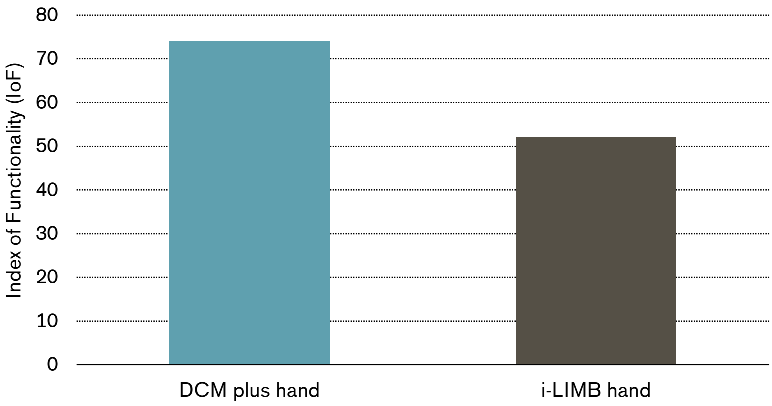
DMC plus hand vs iLIMB

Major Findings

With DMC plus hand compared to i-LIMB (Touch Bionics):

- → **Grip strength is higher for DMC plus hand than for i-LIMB hand in all 5 positions measured.**
- → **Index of Functionality (SHAP score) was 30% higher for DMC hand.**
- → **The DCM plus hand offers more power and robustness, when compared to i-LIMB.**

Index of Functionality (IoF) for DCM plus hand and i-LIMB



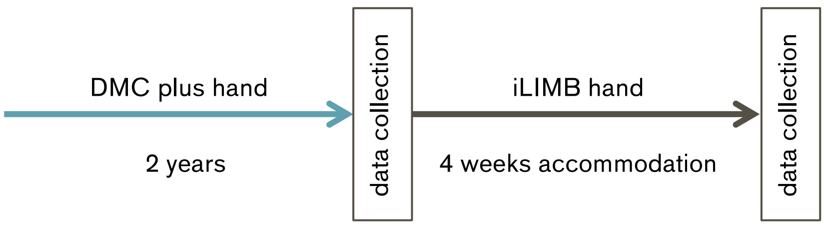
Index of Functionality (IoF) was calculated after Southampton Hand Assessment Procedure (SHAP) test was performed with DCM plus and i-LIMB hand. IoF is a number that provides an overall assessment of hand function.

Population

Subjects:	1 unilateral wrist disarticulation of dominant left side
Previous:	Dynamic Mode Control hand (DMC plus hand)
Amputation causes:	trauma
Mean age:	45 years
Mean time since amputation:	4 years

Study Design

Case report:



Patient was fitted with DMC plus hand and a passive wrist rotator for two years. Afterwards patient received an i-LIMB hand with a rigid wrist and had 4 weeks of accommodation period. A series of tests were performed with both prosthetic hands.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	**Grip patterns / force**	Manual dexterity	**Activities of daily living (ADL)**	**Satisfaction and Quality of life (QoL)**	Training	Technical aspect

Category	Outcomes	Results for DMC plus hand vs iLIMB	Sig.*
Grip patterns /force	Grip and pinch strength (dynamometer and a pinch meter)	Grip strength is higher for DMC plus hand than for i-LIMB hand in all 5 positions measured.	+
		Lateral and tip pinch strength were not applicable for DMC plus hand.	-
		Strength of tripod pinch was higher with DMC plus hand than with i-LIMB hand.	+
	Southampton Hand Assessment Procedure (SHAP)	SHAP score with the DMC plus hand was higher than the score with the i-LIMB.	+
	Visual analogue scale (VAS)	DMC plus hand was less reliable in holding objects.	-
		DMC plus hand was valued for its strength.	+
		DMC hand was valued for its robustness.	+
Activities of daily living	Assessment of Capacity for Myoelectric Control (ACMS)	The Capacity of Myoelectric Control is well above average for both devices: 2.6 logits for the i-LIMB hand and 2.47 logits for the DMC plus hand.	0
Satisfaction	Trinity Amputation and Prosthesis Experience Scales (TAPES)	The patient was less satisfied with DMC plus hand.	-
	Orthotics and Prosthetics Users' Survey (OPUS)	The OPUS functional status was similar for both prosthesis (29 for the i-LIMB hand and 30 for the DMC plus hand, respectively).	0

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"In this case report we could not establish a clear functional advantage of the i-LIMB compared to the DMC-hand. The i-LIMB hand has a higher reliability when holding objects but has less strength and robustness. Thus, dependent on the users' needs, patients should opt for an i-LIMB hand or a more conventional DMC plus hand. Moreover, future innovations of prosthetic hands should take the limitations of the i-LIMB hand into account." (van der Niet et al. 2010)

↑ Back to overview table

Reference	Bertels T, Schmalz T, Ludwigs E Otto Bock HealthCare GmbH, Goettingen

Objectifying the Functional Advantages of Prosthetic Wrist Flexion

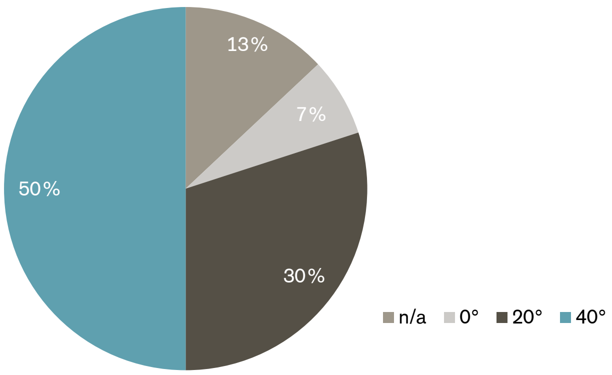
Journal of Prosthetics & Orthotics 2009; Vol 21, Num 2

Products — **Transcarpal-Hand with and without Transcarpal Myowrist**

Major Findings

→ Wrist flexion of 40° is preferred by 50% of the patients.
→ Active wrist reduces compensatory movements of shoulder

Users´ flexion angle preference



Population

Subjects:	6 transradial amputees
Previous:	not specified
Amputation causes:	3 traumas and 3 congenital deficiencies
Mean age:	39 ± 21 years
Mean time since amputation:	23 ± 15 years

Study Design

Pilot study

Study was designed to compare benefits of wrist motion at 20° and 40° in flexion and extension with the locked wrist (0° in flexion and extension).

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	Training	Technical aspect

Category	**Outcomes**	**Results for Transcarpal-Hand with and without Transcarpal Myowrist**	**Sig.***
Mechanics	Motion analyses of wrist, elbow and shoulder	The compensatory movements with wrist flexion were drastically reduced while performing ADL.	+
		With wrist flexion, anteversion (being tilted further forward than normal) of a shoulder was decreased for 35°.	+

Category	Outcomes	Results for Transcarpal-Hand with and without Transcarpal Myowrist	Sig.*
		With wrist flexion, shoulder tilting is reduced by 7°.	+
		Wrist flexion of 40° is preferred by 50% of the patients.	+

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"In the present pilot study, motion patterns typically performed in the patients' daily life were selected. The results of motion analysis show that compensatory movements may be reduced by wrist flexion in most of the cases. This is noted considerably by kinematic characteristics of the shoulder joint on the prosthetic side. Even if only slight differences of few degrees were measured, the patients perceived an optimization of the motion pattern. Reduced compensatory movements support more physiological loading of the unaffected joints of the locomotor system. The more natural subjective impression is an important psychological aspect for the prosthetic user."

↑ Back to overview table

Reference	Lotze M, Grodd W, Birbaumer N, Erb M, Huse E and Flor H

Department of Neuroradiology, University of Tübingen, Germany

Does use of a myoelectric prosthesis prevent cortical reorganization and phantom limb pain?

Nature Neuroscience, volume 2 no 6, June 1999

Products

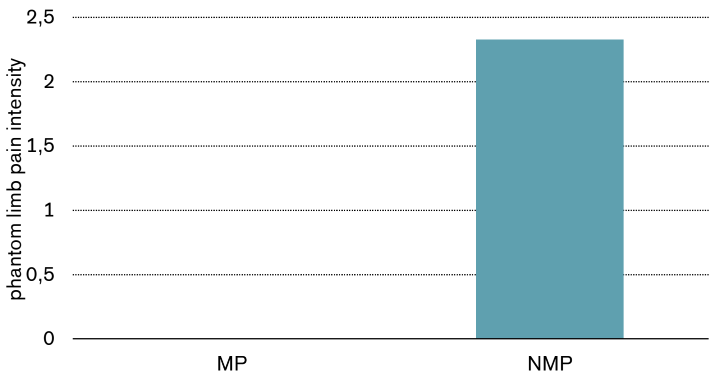
Myoelectric prosthesis, cosmetic prosthesis

Major Findings

Prosthetic use and phantom limb pain in upper limb amputees:

→ **Enhanced use of a myoelectric prosthesis was associated with reduced phantom limb pain and reduced cortical reorganization.**
→ **Phantom limb or stump pain was never given as a reason for discontinuation of prosthetic use.**

Average phantom limb pain intensity



First group (MP) had patients with a myoelectric prosthesis who reported extensive wearing time (>8 h/day) and usage (>50 on a visual analogue scale (VAS) ranging from 0–100). The second group (NMP) had either no prosthesis or a cosmetic prosthesis or myoelectric prostheses was poorly used (<8 h/day and/or < 50 VAS). Phantom limb pain intensity measurement was based on the MPI Pain Intensity Scale (range, 0–6). The MP group showed an average phantom limb pain intensity of 0 ± 0 8no pain), whereas the NMP group reported an intensity of 2.33 ± 1.53.

Population

Subjects:	9 upper limb amputees; 10 control, healthy participants
Previous:	2 myoelectric prosthesis, 3 cosmetic prosthesis, 4 no prosthesis
Amputation causes:	not listed
Mean age:	49 ± 18 years
Mean time since amputation:	22 ± 19 years

Study Design

Observational study

Nine unilateral upper-limb amputees and 10 control participants were examined with functional magnetic resonance imaging (fMRI) of the brain while they moved the lip. Location and amount of cortex devoted to each part of the body is known and described. Cortical reorganization was assessed by comparing the location and the extent of the cortical representation during the lip movements in comparison to hand location in healthy and upper limb amputated participants.

Results

Body Function		Activity			Participation	Others	
Mechanics	**Pain**	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	**Satisfaction and Quality of life (QoL)**	Training	Technical aspect

Category	Outcomes	Results for amputees with and without phantom pain	Sig.*
Pain	functional Magnetic Resonance Imaging (fMRI) of brain	**In amputees with phantom limb pain, cortical area of activation during lip movement was displaced towards the hand area (by 10.67 ± 7.33 mm in somatosensory cortex and 5.84 ± 3.57 mm in motor cortex). In pain free amputees, area of activation during lip movement was symmetrical.**	++
		Cortical area of activation during lip movement was more symmetrical in group of extensive prosthetic users (myoelectric prosthesis used >8 h/day - MP group) than in the group of amputees that poorly used their prostheses (no prosthesis or a cosmetic prosthesis or myoelectric prostheses used <8 h/day – NMP group)	++
	Pain Intensity Scale (range, 0–6)	**The MP group showed an average phantom limb pain intensity of 0 ± 0, whereas the NMP group reported an intensity of 2.33 ± 1.53.**	++
		Reduction in phantom limb pain over time was significantly positively correlated with extensive myoelectric prosthesis use.	++
Satisfaction	Satisfaction with the prosthesis	Reasons given for discontinuation (typically in the first months after amputation) were preference for the intact arm and/or impracticability of the prosthesis, but never phantom limb or stump pain.	n.a.

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"This study showed that frequent and extensive use of a myoelectric prosthesis is correlated negatively with cortical reorganization and phantom limb pain and positively with the reduction in phantom limb pain over time. This suggests that the ongoing stimulation, muscular training of the stump and visual feedback from the prosthesis might have a beneficial effect on both cortical reorganization and phantom limb pain. The converse that increased phantom limb pain might have motivated patients to decrease prosthesis use, is unlikely because no patient reported increased phantom limb pain with prosthesis use or gave stump or phantom limb pain as reason for discontinuing prosthesis use. Our data are in accordance with animal experiments suggesting that behaviourally relevant tactile stimulation expands the cortical representation of the stimulated body region. Our data strongly suggest that extended use of a myoelectric prosthesis might reduce both cortical reorganization and phantom limb pain, a still relatively treatment-resistant disorder." (Lotzke et al. 1999)

↑ Back to overview table

Reference

Cheesborough J, Smith L, Kuiken T, Dumanian G

Neural Division of Plastic and Reconstructive Surgery, Northwestern University, Chicago, Illinois

Targeted Muscle Reinnervation and Advanced Prosthetic Arms

Semin Plast Surg 2015;29:62–72.

Products

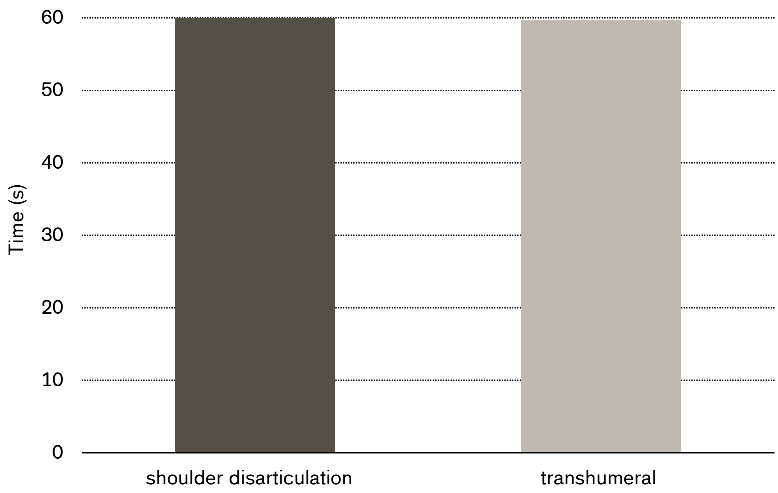
Targeted Muscle Reinnervation and Coapt Pattern Recognition control myoelectric prosthesis

Major Findings

The effect of Targeted Muscle Reinnervation (TMR) and Coapt pattern recognition control on myoelectric prosthetic use:

→ **Similar functional performance of the shoulder disarticulation and the transhumeral side of a bilateral amputee, despite poorer expectation for the higher-level amputation side**

Clothespin Relocation Test



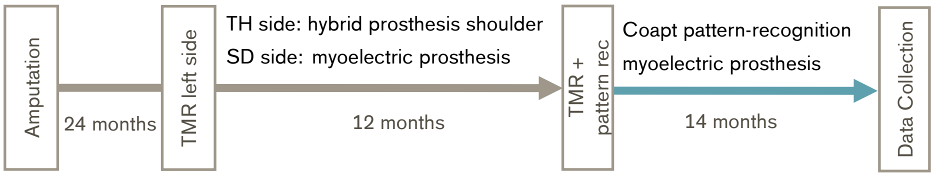
During functional tests such as the clothespin relocation test the patient demonstrated similar performance between his left - shoulder disarticulation (60.6 ± 11.5s) and right - transhumeral sides (59.7 ± 10.6s), despite the difference in amputation level. The results suggest the intuitiveness of control with TMR and pattern recognition control, as higher-level amputation would otherwise be expected to provide poorer performance in functional tasks.

Population

Subjects:	one male bilateral amputee (left shoulder disarticulation and right transhumeral amputation)
Amputation etiology:	trauma
Age at amputation:	43 years
Age at TMR	45 years
Previous prosthesis:	hybrid prosthesis on his transhumeral side, which included a passive (non-moving) elbow and a myoelectric hook; myoelectric prosthesis after TMR surgery on his shoulder disarticulation side
Intervention prosthesis:	bilateral fitting with Coapt pattern-recognition myoelectric prostheses

Study Design

Case report:



A 43 year old male sustained a severe electrical burn injury and required a left side amputation at the shoulder disarticulation level and a right side amputation at the transhumeral level. Two years after the injury, the TMR surgery was first performed on the patient's left side and four months later on his right side. The patient was initially fitted with a hybrid prosthesis on his transhumeral side and with a myoelectric prosthesis on his shoulder disarticulation side. After one year of prosthetic use, the patient was bilaterally fitted with Coapt pattern-recognition myoelectric prostheses as intervention devices.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	Training	Technical aspect

Category	**Outcomes**	**Results for pattern recognition myoelectric prosthetic use after TMR:**	**Sig.***
Pain	Self-reported	Five months after the TMR surgery, the patient reported complete resolution of his neuroma pain bilaterally. Some occasional phantom limb pain was reported.	n.a.
Manual dexterity	Box and Blocks	Similar performance of the left (11.0 ± 1.5blocks) and right (14.3 ± 0.3blocks) side with pattern recognition prosthesis, despite the difference in amputation level.	n.a.
	Clothespin Relocation Task	Similar performance of the left (60.6 ± 11.5s) and right (59.7 ± 10.6s) side with pattern recognition prosthesis, despite the difference in amputation level.	n.a.
Activities of daily living (ADL)	Self-reported	Many tasks were easier to perform with the pattern recognition controlled myoelectric prosthesis after TMR: eating with a fork, drinking from a water bottle, carrying a laundry basket, yard work, as well as placing, retrieving and replacing items from a refrigerator.	n.a.

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"Targeted muscle reinnervation combined with existing and emerging prosthetic technology allows for intuitive control of myoelectric prostheses for amputees at multiple levels. For complex amputees, such as the patient presented in the case example, a strategic and orderly approach to care is essential, understanding that each patient will present unique challenges." (Cheesborough et al., 2015)

↑ Back to overview table

Reference

Souza J, Cheesborough J, Ko J, Cho M, Kuiken T, Dumanian G

Division of Plastic Surgery, Northwestern Feinberg School of Medicine; Chicago

Targeted Muscle Reinnervation: A Novel Approach to Postamputation Neuroma Pain

Clin Orthop Relat Res (2014) 472:2984–2990.

Products

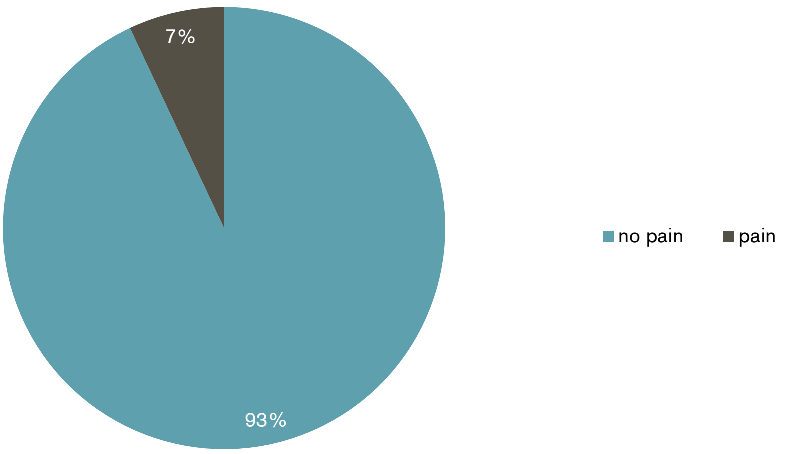
Myoelectric prosthesis in combination with Targeted Muscle Reinnervation

Major Findings

The effect of Target Muscle Reinnervation (TMR) on residual limb neuroma pain in upper-extremity amputees:

- → **None of the patients who underwent TMR demonstrated evidence of new neuroma pain after the procedure**
- → **93% of patients who presented with preoperative neuroma pain experienced complete relief of pain after TMR**
- → **88% of patients were able to operate a TMR-controlled myoelectric prosthesis**

% patients who had a pain relief after TMR



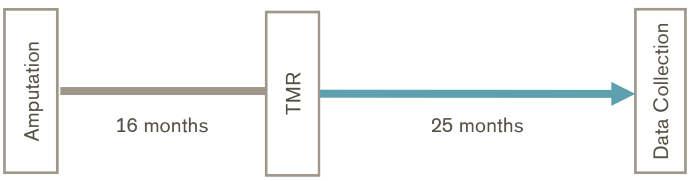
Of the 15 patients presenting with neuroma pain before TMR, 14 experienced complete resolution of pain in the transferred nerves.

Population

Subjects:	16 transhumeral and 10 shoulder disarticulation amputees
Amputation etiologies:	all trauma
Mean age at TMR:	32.8 ± 11.7 years
Mean time since TMR:	16.5 ± 14.6 months

Study Design

Retrospective study:



A retrospective medical record review of all 26 patients treated with TMR from 2002 to 2012 was conducted. The mean time between amputation and TMR surgery was 16 months. Mean follow-up was 25 months (range, 6–124 months).

Results

Body Function		Activity			Participation	Others	
Mechanics	**Pain**	Grip patterns / force	Manual dexterity	**Activities of daily living (ADL)**	Satisfaction and Quality of life (QoL)	Training	Technical aspect

Category	Outcomes	Results for TMR:	Sig.*
Pain	Neuroma pain	Of the 15 patients with neuroma pain after amputation, 14 (93%) experienced complete resolution of pain in the transferred nerves. However, one patient experienced substantial increase in pain.	n.a.
		None of the 11 patients who underwent TMR and did not have preoperative evidence of post-amputation neuroma pain developed neuroma pain after the procedure.	n.a.
Activities of daily living (ADL)	Prosthetic use	23 of the 26 patients (88%) were successfully fit with a TMR myoelectric prosthesis. In one patient the fitting failed due to persistent residual limb pain; a second patient was found to have a brachial plexopathy intraoperatively that prevented successful reinnervation; a third patient was not fit due to financial challenges. These three patients were still able to wear a non-TMR prosthesis.	n.a.

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"None of the 26 patients who underwent TMR demonstrated evidence of new neuroma pain after the procedure, and all but one of the 15 patients who presented with preoperative neuroma pain experienced complete relief of pain in the distribution of the transferred nerves. TMR offers a novel and potentially more effective therapy for the management of neuroma pain after limb amputation." (Souza et al., 2014)

↑ Back to overview table

Reference	Cheesborough J, Souza J, Dumanian G, Bueno R

Northwestern Feinberg School of Medicine and Neural Engineering Center for Artificial Limbs

Targeted muscle reinnervation in the initial management of traumatic upper extremity amputation injury

HAND (2014) 9:253–257.

Products

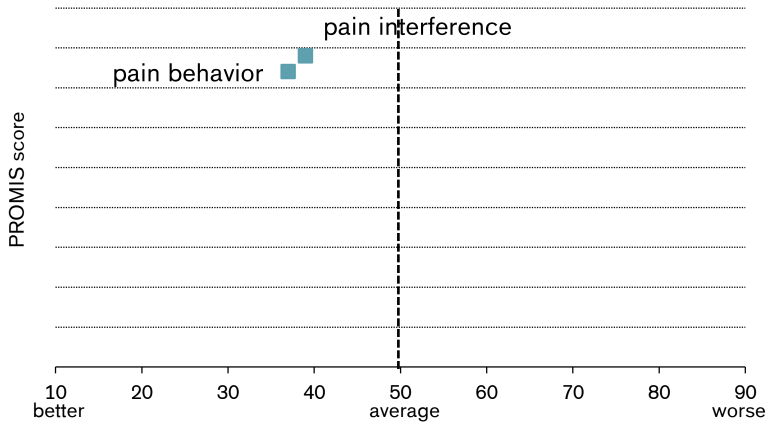
Myoelectric prosthesis in combination with Targeted Muscle Reinnervation

Major Findings

The effect of Targeted Muscle Reinnervation (TMR) on neuroma pain in an amputee with traumatic shoulder disarticulation:

→ **The patient exhibited no evidence of neuroma pain on clinical exam eight months postoperatively.**
→ **Patient was able to use a myoelectric prosthesis**

Pain behavior and pain interference in shoulder dissarticulation amputee



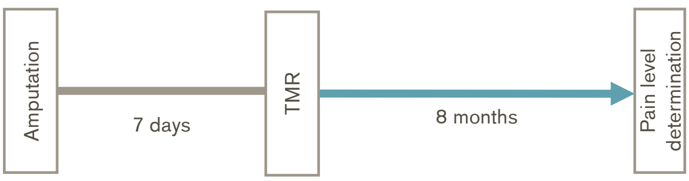
This figure demonstrates the patient's PROMIS score results for pain behavior and pain interference. The square is the estimated score. A score of 50 is average for the US general population, and most people will fall between 40 and 60. The estimated pain behavior score indicates that the patient's pain behavior is very low, within the 10^{th} percentile for the general population. The pain interference score reveals that the patient falls in the lowest 1% of the general population.

Population

Subjects:	one (gender) (unilateral?) shoulder disarticulation amputee
Amputation causes:	trauma
Age at TMR:	54 years
Follow up time:	8 months

Study Design

Case report:



One week after the initial traumatic amputation the TMR procedure was conducted to prevent painful neuroma pain and allow for myoelectric prosthetic use in the future. Eight months after TMR surgery pain level was measured.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	Training	Technical aspect

Category	**Outcomes**	**Results for TMR:**	**Sig.***
Pain	Neuroma pain	Eight months following the procedure, the patient demonstrates no neuroma pain on clinical exam.	n.a.
	Phantom sensations and phantom pain	The patient reports phantom sensations, but no phantom pain.	n.a.
	Patient Reported Outcome Measurement Information System (PROMIS)	The patient reports minimal pain-related behavior (37 on PROMIS score) or pain interference (39 on PROMIS score).	n.a.

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"Targeted muscle reinnervation may be considered in the acute trauma setting to prevent neuroma pain and to prepare patients for myoelectric prostheses in the future." (Cheesborough et al., 2014)

↑ Back to overview table

Reference

Miller L, Stubblefield K, Lipschutz R, Lock B, Kuiken T

Neural Engineering Center for Artificial Limbs, Rehabilitation Institute of Chicago, Chicago, Illinois

Improved Myoelectric Prosthesis Control Using Targeted Reinnervation Surgery: A Case Series

IEEE Trans Neural Syst Rehabil Eng. 2008 February; 16(1): 46–50.

Products

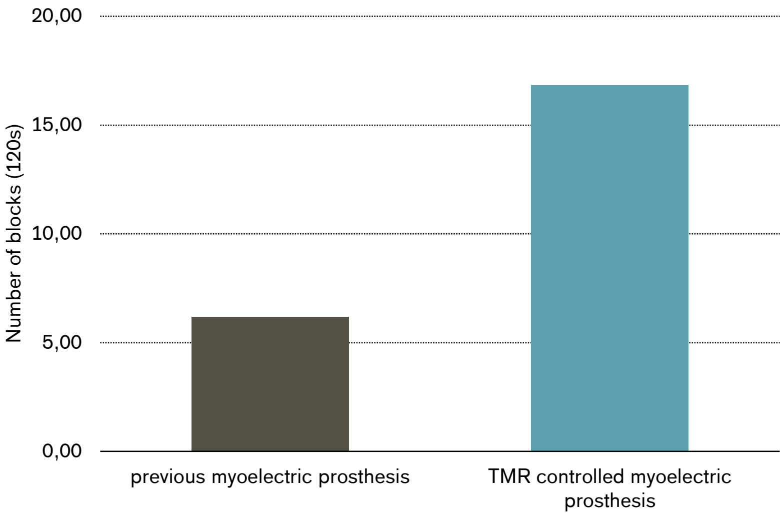
Myoelectric prosthesis in combination with Targeted Muscle Reinnervation

Major Findings

The effect of Targeted Muscle Reinnervation (TMR) on the control of myoelectric upper limb prostheses:

→ **The performance in timed tests (Box and Block and Clothespin Test) has increased by two to six times.**
→ **All subjects reported that the prosthesis was easier to operate.**

Box and Blocks test



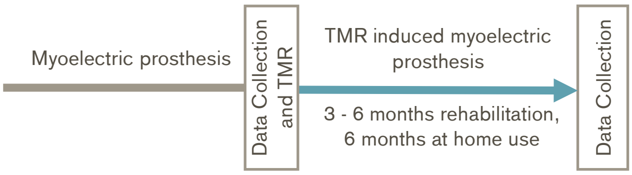
Performance of the pre-surgical myoelectric device and the TMR controlled myoelectric prosthesis was compared with a modified Box and Blocks test (patients were standing instead of sitting while the duration of the test was increased to 120s instead of 60s). With the new prosthesis patients showed marked improvement (on average 177%)

Population

Subjects:	3 shoulder disarticulation and 3 transhumeral amputees
Amputation etiology:	Not reported
Mean age:	Not reported
Mean age at TMR:	Not reported
Previous prosthesis:	myoelectric prostheses (type not reported)
Intervention prosthesis:	TMR in combination with Boston Digital arm, Otto Bock electric wrist rotator and an electric terminal device (hook or hand)

Study Design

Case series:



Manual dexterity was tested before TMR surgery with the previous myoelectric prosthesis. Three to six months of rehabilitation and occupational therapy were needed after the TMR procedure to enable extensive device use. Functional testing with the new myoelectric prosthesis was performed after 6 months of home use.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	**Manual dexterity**	**Activities of daily living (ADL)**	Satisfaction and Quality of life (QoL)	Training	Technical aspect

Category	Outcomes	Results for myoelectric prosthetic use after TMR:	Sig.*
Manual dexterity	Modified Box and Blocks Test (in standing position, duration 120s)	All subjects demonstrated marked improvement with the myoelectric prosthesis and TMR. Number of blocks moved increased on average by 177 % (mean number of 6.17 boxes with pre-surgical fitting vs 16.50 boxes with post-TMR fitting).	n.a.
	Clothespin Relocation Task	All subjects demonstrated improvement ranging from 31% to 55% with an average difference of 45% reduction in time with the TMR controlled myoelectric device compared to previous prosthesis (mean time needed with pre-surgical fitting 85.8s vs mean 57.5 s needed with post-TMR fitting).	n.a.
Activities of daily living (ADL)	Assessment of Motor and Process Skills	80% and 60% of patients had a clinically relevant improvement in motor score and in process score, respectively (mean motor score increased from 0.92 to 1.72 on average, while process score improved from mean 1.02 vs mean 1.60).	n.a.
	Self-reported	Many tasks were easier to perform with the myoelectric prosthesis: cooking, cleaning, housework, yard work, and home maintenance.	n.a.

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"The targeted reinnervation technique makes possible the creation of new EMG control signals for the operation of complex prosthetic systems. With relatively little training, TMR patients showed an ability to control a prosthesis using the additional control signals added through the nerve transfers. These advancements have increased the incentive to develop more advanced artificial arms that will allow people with high level amputations, especially bilateral amputees, to improve their functional abilities and independence." (Miller et al., 2008)

↑ Back to overview table

Reference	Kuiken T, Dumanian G, Lipschutz R, Miller L, Stubblefield K

Rehabilitation Institute of Chicago and Department of PM&R at Feinberg School of Medicine, Northwestern University, Chicago, Illinois, USA

The use of targeted muscle reinnervation for improved myoelectric prosthesis control in a bilateral shoulder disarticulation amputee

Prosthetics and Orthotics International 2004, 28, 245-253.

Products

Myoelectric prosthesis in combination with Targeted Muscle Reinnervation

Major Findings

The effect of Targeted Muscle Reinnervation (TMR) on the control of a myoelectric upper limb prosthesis:

- → **Patients moved double amount of blocks during Box and Blocks test.**
- → **The speed assessed by Clothespin Relocation Task was increased 26%.**
- → **The patient was able to simultaneously control two degrees of freedom with proportional control.**
- → **Myoelectric prosthesis was easier to use and it felt more natural.**

Things patent **can do better** with the myoelectric prosthesis after TMR	New things patient **can only do** with the myoelectric prosthesis after TMR
take out garbage	feed himself
carry groceries	shave
pick-up yard	put socks on
vacuum clean	weed in garden
dust mop	water the yard
pick up toys	open small jar
put a hat on	use pair of handicap scissors
put on glasses	throw a ball
wash driveway	

The patient´s self-reported functional improvements with the myoelectric prosthesis after TMR procedure compared to the myoelectric prosthesis before TMR.

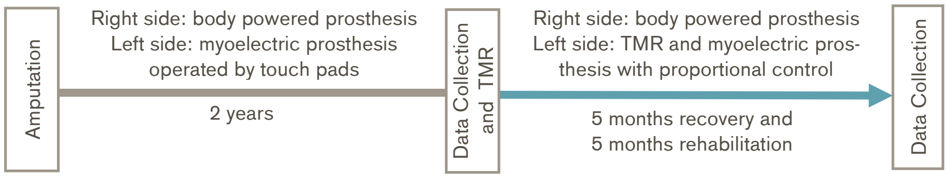
Population

Subject:	one male subject with bilateral amputation at the shoulder disarticulation level, TMR performed only on the left side
Amputation causes:	trauma
Age at amputation:	52 years
Age at TMR:	54 years
Previous prosthesis:	*Right side:* The body powered arm had a voluntary opening split hook (Homer 5XA), modified four-function wrist unit, internal locking elbow and LTI Collier manual locking shoulder joint. *Left side:* Greifer terminal device; a powered wrist rotator; a Boston digital arm and an LTI-Collier manual locking shoulder joint operated by a single mechanical chin switch.

Prosthesis fitted after TMR:	*Right side:* The body powered prosthesis was unchanged from the initial design with the exception of adding an electronic lock to the shoulder, operated by a single touch pad in the apex of the right socket *Left side:* Greifer terminal device; a powered wrist rotator; a Boston digital arm and an LTI-Collier manual locking shoulder joint operated by a single mechanical chin switch. An electronic lock was also added to the left shoulder joint, operated with a single touch pad in the apex of the left socket.

Study Design

Interventional case report:



The 54-year old man with bilateral shoulder disarticulation, previously fitted with a body powered prosthesis on the right side and a myoelectric prosthesis on the left side, underwent TMR. After rehabilitation, a myoelectric prosthesis with proportional control (enabled by the three most robust EMG signals) was fitted on the left side.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	**Manual dexterity**	**Activities of daily living (ADL)**	**Satisfaction and Quality of life (QoL)**	Training	Technical aspect

Category	Outcomes	Results for myoelectric prosthetic use before (operated with a single touch pad) and after TMR surgery (TMR induced proportional control):	Sig.*
Manual dexterity	Box and Blocks	The patient moved twice as many blocks following TMR.	n.a.
	Clothespin Relocation Task	The patient moved the clothes pins on average 26% faster after TMR.	n.a.
Activities of daily living (ADL)	Self-reported	The tasks that the patient reported to do better with the myoelectric prosthesis: take out garbage; carry groceries; pick-up yard; vacuum clean; dust mop; pick up toys; put a hat on; put on glasses; wash driveway	n.a.
		The tasks that the patient reported to be able to do with the myoelectric prosthesis and not with previous prosthesis: feed himself shave; put socks on; weed in garden; water the yard; open small jar; use pair of handicap scissors; throw a ball	n.a.
Satisfaction	Self-reported	The patient strongly preferred the myoelectric prosthesis with TMR induced proportional control.	n.a.

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion	"By anastomosing the residual peripheral nerves to the pectoralis major muscle in a shoulder disarticulation patient additional independent myoelectric control signals were developed. These additional control signals allowed simultaneous control of two degrees-of-freedom using just the EMG signals. In this patient, both objective testing and subjective impressions, demonstrated improvement in the speed and ease of use of the prosthesis. Sensory reinnervation of the chest with the nerve transfers occurred in areas where the subcutaneous fat was removed." (Kuiken et al., 2004)

↑ Back to overview table

Reference

Ortiz-Catalan M, Guðmundsdóttir R, Kristoffersen M, Zepeda-Echavarria A, Caine-Winterberger K, Kulbacka-Ortiz K, Widehammar C, Eriksson K, Stockselius A, Ragnö C, Pihlar Z, Burger H, Hermansson L.

Department of Signals and Systems, Chalmers University of Technology, Gothenburg, Sweden.

Phantom motor execution facilitated by machine learning and augmented reality as treatment for phantom limb pain: a single group, clinical trial in patients with chronic intractable phantom limb pain

Lancet 2016; 388: 2885–94.

Products

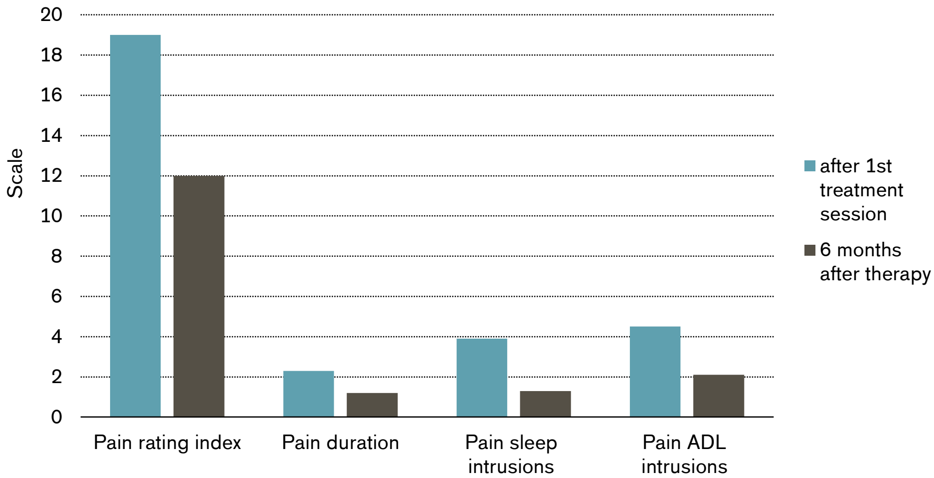
Machine learning, augmented reality and gaming vs. traditional treatment for phantom limb pain

Major Findings

With machine learning, augmented reality and gaming compared to traditional treatment for phantom limb pain:

→ **Pain intensity was decreased by 51%.**
→ **Pain duration was reduced by 47%.**
→ **All patients experienced reduction in quality of pain.**
→ **Pain sleep and activities of daily living intrusions were reduced on average by 61% and 43%, respectively.**
→ **Pain sensations, such as stabbing and tiring–exhausting, were significantly less prevalent after treatment.**
→ **Improvements remained 6 months after treatment.**

Perception of phantom limb pain intensity, duration, ADL and sleep pain intrusion



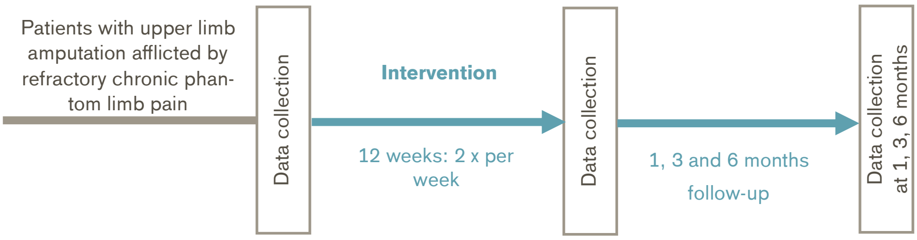
On the graph, the perception of phantom limb pain intensity, weight distribution, activities of daily living (ADL) and sleep pain intrusion are compared after the 1st treatment session and 6 months after therapy. The pain intensity (measured by pain rating index) was decreased by 51%, weight pain distribution by 47%, while pain sleep and activities of daily living intrusions were reduced on average by 61% and 43% respectively.

Population

Subjects:	14 (7 transhumeral, 2 of them bilateral; 7 transradial) patients with upper limb amputation afflicted by refractory chronic phantom limb pain
Previous prosthesis:	n.a.
Amputation causes:	12 trauma, 1 infection, 1 tumor
Mean age:	50.3 years (± 10.3 years)
Mean time since amputation:	10.4 years (± 11.1 years)

Study Design

Interventional pre- to post-test design:



All patients received an intervention twice per week except for one who had it daily. Each session lasted 2 h and consisted of (1) pain evaluation, (2) placement of the electrodes and marker, (3) practice motor execution in augmented reality, (4) gaming by racing car using phantom movements, and (5) matching random target postures of a virtual arm in virtual reality.

Results

Body Function		Activity			Participation	Others	
Mechanics	**Pain**	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	Training	Technical aspect

Category	**Outcomes**	**Results for machine learning, augmented reality and gaming vs. traditional treatment for phantom limb pain**	**Sig.***
Pain	Pain rating index	**Significant reduction of pain intensity by 51%.**	++
		All patients experienced reduction in quality of pain. Pain sensations, such as stabbing and tiring–exhausting, were significantly less prevalent after treatment.	++
		Reduction in pain intensity was maintained at all of follow-up visits. The average improvement measured at the last treatment session decreased by 2%, 6%, and 24% at 1, 3, and 6 month follow-ups, respectively.	++
	Numeric rating scale of phantom limb pain	**Significant reduction of pain intensity by 32%.**	++
		9 patients (64%) experienced reduction of pain intensity.	++
		Pain sleep and activities of daily living intrusions were reduced on average by 61 and 43%, respectively.	++
	Weighted pain distribution	**Significant reduction of pain duration by**	++

Category	Outcomes	Results for machine learning, augmented reality and gaming vs. traditional treatment for phantom limb pain	Sig.*
		47%.	
		12 patients (86%) experienced reduction of pain weight distribution.	**++**
	Pain medication	Intake of pain medication was reduced at last treatment in 2 of 4 patients.	+
		Intake of pain medication was reduced at last treatment in 2 of 4 patients.	+

*no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"We introduce a novel plasticity-based, non-invasive treatment for phantom limb pain, in which phantom motor execution is decoded via machine learning, while visualisation of the phantom is accomplished via augmented and virtual reality. These technological features overcome previous limitations of plasticity-based treatments, such as mirror therapy, while enhancing patient engagement via serious gaming. Reversal of cortical reorganisation and competitive plasticity are hypothesised to be the mechanisms of action of the approach presented here." (*Ortiz-Catalan et al. 2016*)

↑ Back to overview table

Reference	Bouwsema H, van der Sluis C, Bongers R University of Groningen, University Medical Center Groningen, Center forHuman Movement Sciences, Groningen # Changes in performance over time while learning to use a myoelectric prosthesis Journal of NeuroEngineering and Rehabilitation 2014, 11:16.

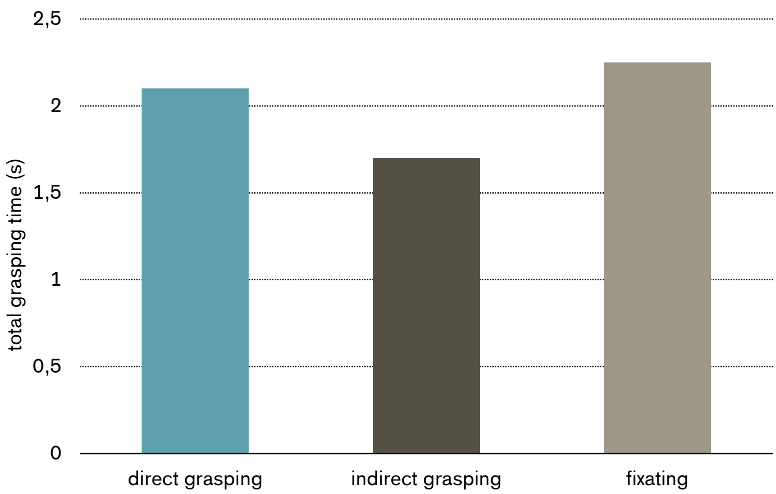
Products **Myoelectric simulator - MyoHand VariPlus Speed**

Major Findings

For different types of practice:

→ **A training program should spend more time on learning fine control aspects such as grip force control**
→ **Training should start with the indirect grasping tasks (handing over an object from the unaffected hand to the prosthetic hand)**
→ **Patients should train in a blocked repeated fashion**

Time needed to grasp a low resistance objects



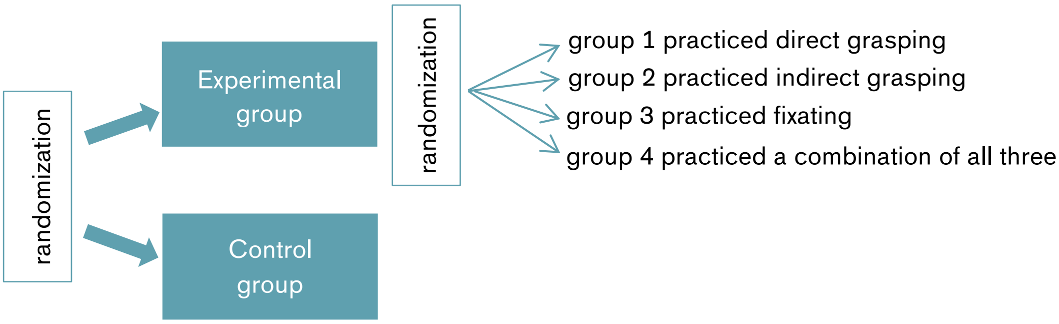
Participant needed the shortest amount of time to hand over an object from the unaffected hand to the prosthetic hand (indirect grasping) than to directly grasp an object or to fix it (e.g. unbutton and buttoning).

Population

Subjects:	62 healthy, able-bodied participants
Previous:	none
Amputation causes:	none
Mean age:	21 ± 2 years
Mean time since amputation:	none

Study Design

A randomized study:



Participants in the experimental condition, randomly assigned to one of four groups, practiced with a myoelectric simulator for five sessions in a two-week period. Group 1 practiced direct grasping, Group 2 practiced indirect grasping, Group 3 practiced fixating, and Group 4 practiced a combination of all three tasks. The Southampton Hand Assessment Procedure (SHAP) was assessed in a pretest, posttest, and two retention tests. Participants in the control condition performed SHAP two times, two weeks apart with no practice in between.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	**Training**	Technical aspect

Category	**Outcomes**	**Results for different types of practice**	**Sig.***
Training	Southampton Hand Assessment Procedure (SHAP)	The experimental groups improved more on SHAP than the control group.	++
	Compression during grasping	The indirect grasping group had the smallest object compression.	++
	Grasping time	The indirect grasping group had the smallest grasping time.	++

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"Learning processes were examined in participants that learned to use a prosthetic simulator in different goal directed tasks. Results showed that grasping force control took longer to learn than positioning of the prosthesis and that indirect grasping was beneficial for controlling the grip force. Practicing different tasks improved grasping control to the same level than training just grasping while the number of grasping trials in practice were less. Improvement in performance lasted even after a period of non-use. Suggestions for clinical practice are to focus specifically on grip force control of the hand, to start to train with an indirect grasping task, and to train in a blocked-repeated fashion." (Bouwsema et al. 2014)

↑ Back to overview table

Reference

Bouwsema H, van der Sluis C, Bongers R

University of Groningen, University Medical Center Groningen, Center for Human Movement Sciences, Groningen

Effect of Feedback during Virtual Training of Grip Force Control with a Myoelectric Prosthesis

PLoS ONE 9(5): e98301

Products

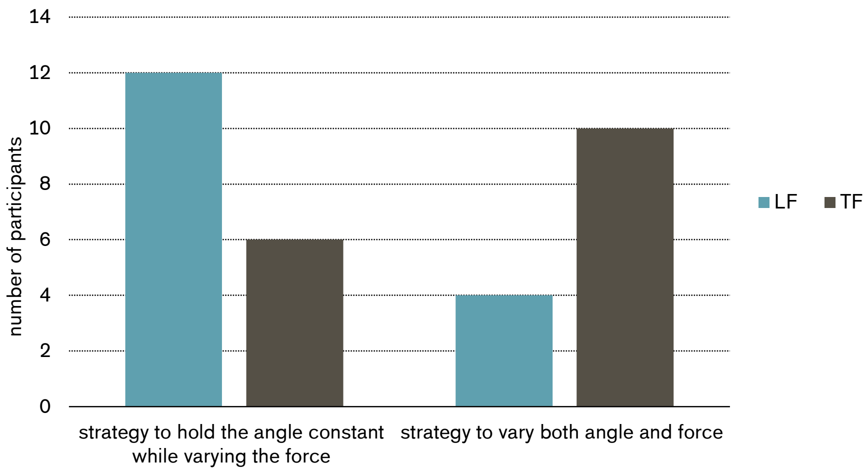
Myoelectric simulator - MyoHand VariPlus Speed

Major Findings

When different types of feedback were compared:

→ **Feedback during training is important**
→ **When performing cognitive tasks keep oral feedback to the minimum**

Strategy while performing virtual gaiming in groups feceiving less (LF) and more feedback (TF)



Able-bodied participants were provided with a prosthetic stimulator and asked to play a virtual ball throwing game. By grasping and controlling the handle with the prosthetic simulator, their task was to throw a ball with a certain angle and velocity into a target. One strategy was to hold the angle constant while varying the force (12 participants whom less oral feedback was given (LF) and 6 participants whom more feedback was given (TF)); the other strategy was to vary both angle and force (4 participants with LF and 10 participants with TF). Group which received fewer oral feedback had faster transfer of the learned skills into real life tasks.

Population

Subjects:	48 healthy, able-bodied participants
Previous:	none
Amputation causes:	none
Mean age:	21 ± 3 years
Mean time since amputation:	none

Study Design

A randomized study:

experimental group → randomization → feedback about the outcome (less information)
→ feedback about the outcome (more information)

control group → training that did not focus on force control

32able-bodied subjects were randomly assigned to either a group that received feedback about the outcome — the landing position of the ball (LF) — or feedback about the movement execution — the applied parameters angle and force, and the trajectory of the ball (TF). Thirty-two able-bodied participants trained grip force with a virtual ball-throwing game for five sessions in a two-week period, using a myoelectric simulator. Another sixteen able-bodied participants received training that did not focus on force control.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	**Training**	Technical aspect

Category	Outcomes	Results for different types of feedback	Sig.*
Training	Virtual training	Number of errors decreased over time	n.a.
	Influence of feedback on performance	No main effect of feedback was seen during training.	0
		The type of feedback provided during training influenced the transfer of the learned grip force control to the tests. Movement outcome (LF) enhanced transfer of the learned skill more than feedback on movement execution (TF).	+
	Grip force control	In experimental group transfer of learning occurred from this virtual training to a real life task.	+

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"Performance increased during virtual training of force control with a prosthetic simulator, reflected in a reduction in error. Using the TNC approach, variability was shown to decrease mainly as a result of the reduction of N-cost and a good covariation between the used force and angle during training. Grip force control improved only in the test-tasks that provided information on the performance. Starting the training with a task that required low force production decreased transfer of the learned grip force. Whereas feedback on movement execution was detrimental, feedback on the movement outcome enhanced transfer of the grip force to other tasks than trained." (Bouwsema et al. 2014)

↑ Back to overview table

Reference

Romkema S, Bongers R, van der Sluis C

Department of Rehabilitation Medicine, University Medical Center Groningen, University of Groningen

Intermanual Transfer in Training with an Upper-Limb Myoelectric Prosthesis Simulator: A Mechanistic, Randomized, Pretest-Posttest Study

Physical Therapy 2013; 93:22-31

Products

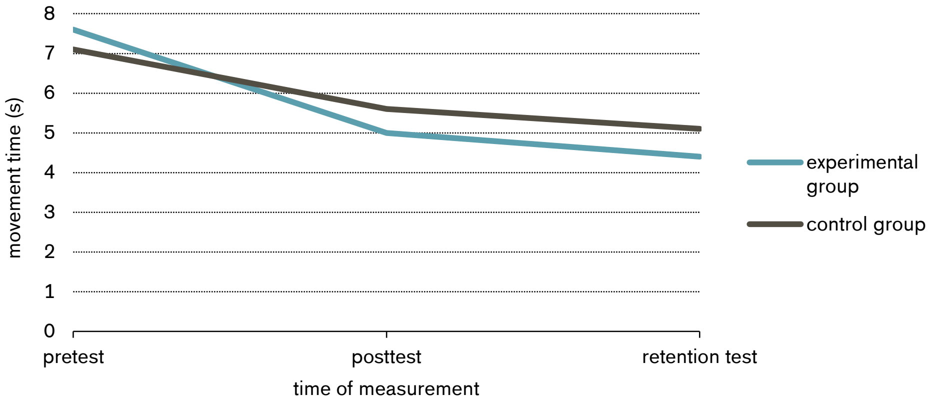
Prosthetics simulator – PAULA software connected to MyoBoy

Major Findings

Prosthesis´ control was compared between groups with and without previous training:

→ **Training with prosthesis simulator enables faster handling of the prosthesis**
→ **Intermanual transfer effects were present after training with a myoelectric prosthesis simulator**

Movement time for all tasks



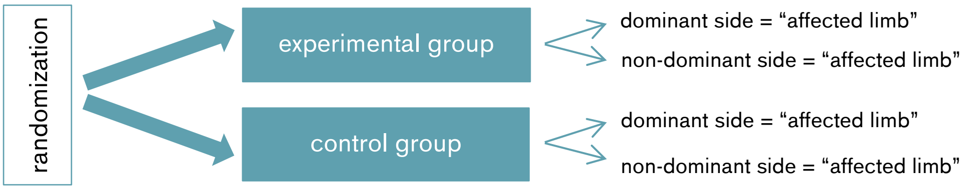
To determine the improvement in skill, a test was administered before (pretest), immediately after (posttest) and 6 days after training (retention test) for experimental group. The control group only performed the tests without training.

Population

Subjects:	48 healthy, abled bodied participants
Previous:	none
Amputation causes:	none
Mean age:	24.6
Mean time since amputation:	none

Study Design

A randomized study:



Experimental group performed the training with the unaffected arm, and tests were performed with the affected arm (the affected arm simulating an amputated limb). Half of the participants were tested with the dominant arm and half with the non-dominant arm.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	**Training**	Technical aspect

Category	Outcomes	Results for with and without previous training:	Sig.*
Training	Initiation time	Time from starting signal until start of the movement was not different between groups.	0
	Movement time	Time from beginning of the movement until competition of the task was shorter in experimental group.	++
	Force control	Maximal applied force on the object did not differ between groups.	0

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"Intermanual transfer effects were present after training with a myoelectric prosthesis simulator in individuals who were healthy. The initiation time did not show intermanual transfer effects, presumably because of the differences in training tasks and test tasks. The movement time showed intermanual transfer effects, whereas the force control did not. Finally, no laterality effects were found. These findings suggest that intermanual transfer might be of clinical relevance for people with an upper-limb amputation because intermanual transfer training would enable them to start prosthetic training shortly after the amputation." (Romkema et al. 2013)

↑ Back to overview table

Reference Bouwsema H, Kyberd P, Hill W, van der Sluis C, Bongers R

Center for Human Movement Sciences, University of Groningen, University Medical Center Groningen, Groningen

Determining skill level in myoelectric prosthesis use with multiple outcome measures

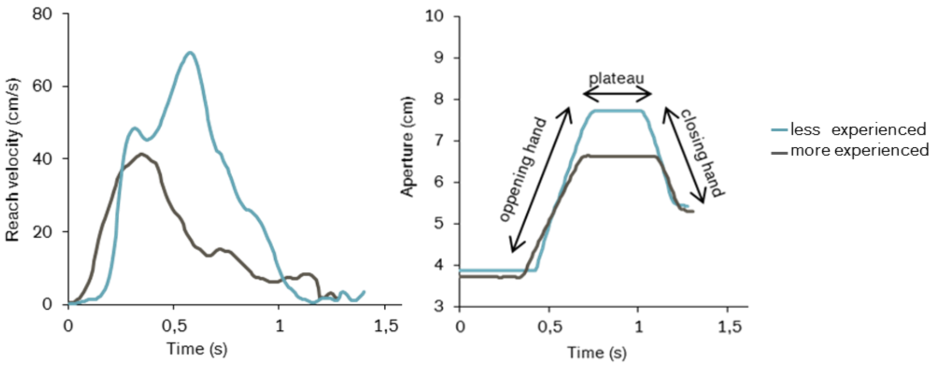
Journal of Rehabilitation Research & Development 2012; 49(9):1331–48

Products **Dynamic Mode Control hand, Digital hand, Motion control**

Major Findings

- → **Time is a key parameter when using an upper extremity prosthesis**
- → **Minimizing the time needed to reach and grasp an object should be a major goal of rehabilitation**
- → **More experienced prosthetic users are faster, have better grip force control and need less visual attention when using the hand**

Reaching and grasping an object



In the figure the reach (left) and the grasp (right) of an object performed by experienced (grey) and less experienced (blue) prosthetic users are shown. Grasp time and plateau phase were shorter for the forearm prostheses.

Population

Subjects:	6 unilateral transradial patients
Previous:	3 Dynamic Mode Control hands, 2 Digital hands, 1 Motion control
Amputation causes:	2 congenital deformities, 3 traumas, 1 illness
Mean age:	36 ± 18 years (range 19-59 years)
Mean time since amputation:	10 ± 8 years (range 1-19 years)

Study Design Observational (non-interventional) study:

To obtain more insight into how the skill level of an upper-limb myoelectric prosthesis user was composed, the study aimed to portray prosthetic handling at different levels of description, relate results of the clinical level to kinematic measures, and identify specific parameters in these measures that characterize the skill level of a prosthesis user. Six experienced transradial myoelectric prosthesis users performed a clinical test (Southampton Hand Assessment Procedure [SHAP]) and two grasping tasks. Kinematic measures were end point kinematics, joint angles, grasp force control, and gaze behaviour.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	**Grip patterns / force**	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	Training	Technical aspect

Category	Outcomes	Results for more and less experienced prosthetic users	Sig.*
Grip patterns /force	Southampton Hand Assessment Procedure (SHAP)	The highest scores were obtained in the spherical grip, whereas the participants scored the lowest on the tip grip. Patients who had better scores on SHAP showed overall better performance on kinematic measurements.	+
Mechanics	End point kinematics	More experienced prosthetics users are reaching the object faster with shorter plateau phase between reaching and grasping an object and they need less time to execute the task.	+
	Joint angles	The movement patterns were rather similar for all participants, except for the variation in the amount of shoulder abduction (more shoulder abduction was used to compensate for the lack of wrist movement in the prosthesis).	0
	Gaze behaviour	More experienced prosthetic users focus on the object most of the time during task execution. The less experienced ones focus on the object of interest only at the beginning of a task and on the prosthesis during the task execution.	+

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"In this study, we measured prosthesis use on different levels of description using clinical and kinematic measures. This study followed and extended the suggestion to combine several outcome measures, by not only measuring on a clinical, functional level, but also on more kinematic levels. The results provided a wide range of information. The clinical test (SHAP) was a good measure of skill level of the prosthesis user, whereas the fundamental measures provided deeper insight into the performance and skill level of the prosthesis users. Participants who scored higher on the SHAP showed less deviation in end point kinematic profiles from nondisabled movement patterns, with, among other factors, shorter movement times, higher peak velocities, and shorter plateau times in the aperture. Moreover, they showed better grip force control and less visual attention to the hand. The results show that time is a key parameter in prosthesis use and should be one of the main aspects of focus in rehabilitation. The insights provided by this study are useful in rehabilitation, because they allow therapists to specifically focus on certain parameters such as plateau time or visual control, which will hopefully result in the highest level of skill that can be achieved for that prosthesis user." (Bouwsema et al. 2012)

↑ Back to overview table

Reference	Bouwsema H, van der Sluis C, Bongers R

Center of Human Movement Sciences, University of Groningen, Groningen

Learning to Control Opening and Closing a Myoelectric Hand

American Congress of Rehabilitation Medicine 2010; 91:1442-6

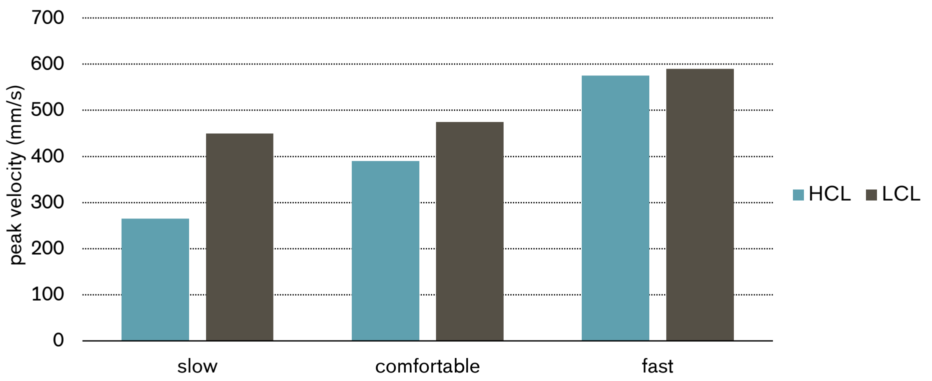
Products

Virtual hand – PAULA; Myoelectric simulator; Table-top hand (acts like Sensor Hand Speed)

Major Findings

→ **Prosthetic users differ in learning capacity which determines time needed to learn how to use myoelectric prosthesis.**
→ **Acquired control of a myoelectric hand is irrespective of the type of device used for training** (PAULA/ simulator/ table-top hand)
→ **PAULA software is as effective as tabletop hand and prosthetic simulator.**

Peak velocity after the training period



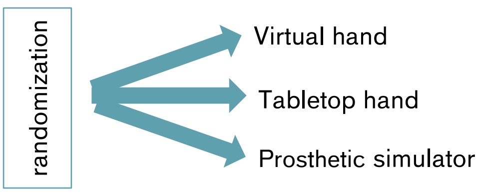
Graph shows peak velocities of opening and closing the hand reached in the post-test (after the training period) for the high capacity learners (HCL) and low capacity learners (LCL) plotted for each of the velocity conditions – slow, comfortable and fast. High-capacity learners could make a good distinction between the 3 different velocity conditions, whereas low-capacity learners could not make this distinction.

Population

Subjects:	34 able-bodied participants
Previous:	none
Amputation causes:	none
Mean age:	21 years
Mean time since amputation:	none

Study Design

A randomized study:



After entering into the study, the subjects were randomized into three groups based on type of the training they will receive. On the first day a pretest was conducted. Afterwards, the subject's control of the hand was trained on 3 consecutive days either by using virtual hand, tabletop hand or prosthetic simulator. After the last training session on the 3rd day, a posttest was administered to determine the level of skill after the training. The pretest and the posttest test were the same and consisted of 2 parts: the participant was asked to first provide a maximum myoelectric signal for at least 2 seconds (this was repeated 5 times) and, second, to open and close the hand to the maximal aperture on 3 different velocities at command. Participants were asked to control hand opening and closing at the slowest speed possible, at a comfortable speed, and at the highest speed possible. All velocities were executed 3 times in a random order. When the hand was not fully opened or closed, the participants were corrected and instructed again.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	**Training**	Technical aspect

Category	Outcomes	Results for training with PAULA vs simulator vs table-top hand:	Sig.*
Training	Peak and mean velocity	Both peak velocity and mean velocity showed the same main effects.	0
	Number of peaks	A large effect of the velocity conditions showed that in the slow condition the most peaks occurred, whereas in the fast condition the fewest number of peaks were shown.	0

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"In conclusion, learned control of a myoelectric hand does not depend on the type of training (with a virtual hand, an isolated hand, or a prosthetic simulator). Prosthetic users may differ in learning capacity, and this should be taken into account when choosing the appropriate type of control for each patient." (Bouwsema et al. 2010)

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Reference

Bouwsema H, van der Sluis C, Bongers R

Center for Human Movement Sciences, University of Groningen, Groningen

Movement characteristics of upper extremity prostheses during basic goal-directed tasks

Clinical Biomechanics 2010; 25: 523–529

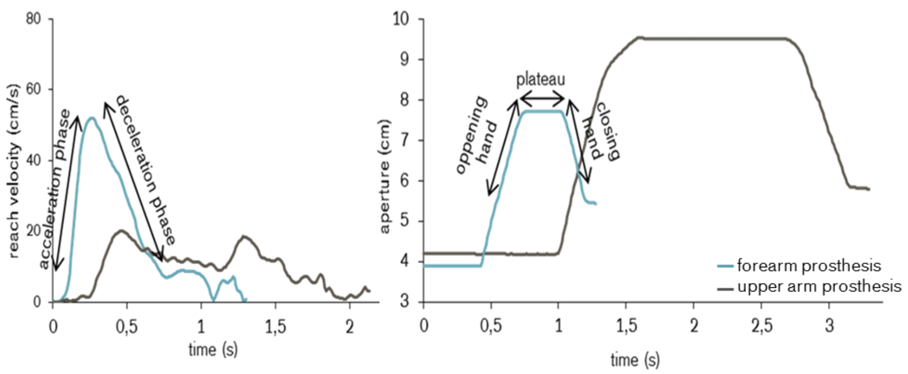
Products

Digital Twin hand

Major Findings

- → **Reaching and grasping of an object with the prosthesis is slower with a plateau phase than in able bodied persons.**
- → **The forearm amputees require less time to pick up an object than the upper arm amputees.**
- → **Training should focus on timing between hand opening and hand closing.**
- → **During training amputee should pay attention to simultaneous finish reaching and start grasping an object.**

Reaching and grasping movements for forearm and upper arm amputees:



The forearm prostheses required less time to execute the reach than the upper arm prostheses. Grasp time and plateau phase were shorter for the upper arm prostheses.

Population

Subjects:	3 forearm and 3 upper arm amputees
Previous:	forearm amputees used myoelectric prostheses with Digital Twin hands upper arm amputees used hybrid prostheses = mechanical elbow + myoelectric prostheses with Digital Twin hands
Amputation causes:	n.a.
Mean age:	45 ± 11 years
Mean time since amputation:	14 ± 12 years

Study Design

Observational (non-interventional) study:

Movements from six users of upper extremity prostheses were analysed, three participants with a hybrid upper arm prosthesis, and three participants with a myoelectric forearm prosthesis. Three tasks were investigated: direct grasping task – participants reached out for and grasped an object positioned on the table in front of them with their prosthetic hand; the indirect grasping task – participants handed an object over from their sound hand to the prosthetic hand; the pointing task – participants made horizontal back and forth movements between two vertical bars, with a stylus held in their prosthetic hand.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	Training	Technical aspect

Category	Outcomes	Results for movement characteristics of forearm and upper arm amputees	Sig.*
Mechanics	Grasping	**The forearm prosthetic users required less time to reach an object.**	++
		The forearm prosthetic user needed less time to grasp an object.	++
		The plateau phase (time between opening and closing the hand) is shorter for forearm prosthetic users.	0

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"By characterizing movements with upper extremity prostheses, specific deviations have been pinpointed between two types of prostheses and between prostheses and existing knowledge of able-bodied behaviour. Developments in technology and rehabilitation should focus on these issues to increase the use of prostheses, in particular on improving motor characteristics and the control of the elbow, and learning to coordinate the reach and the grasp component in prehension." (Bouwsema et al. 2010)

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Reference

Bouwsema H, van der Sluis C, Bongers R

Center of Human Movement Sciences, University of Groningen, Groningen

The Role of Order of Practice in Learning to Handle an Upper-Limb Prosthesis

Archives of Physical Medicine and Rehabilitation 2008; 89:1759-64

Products

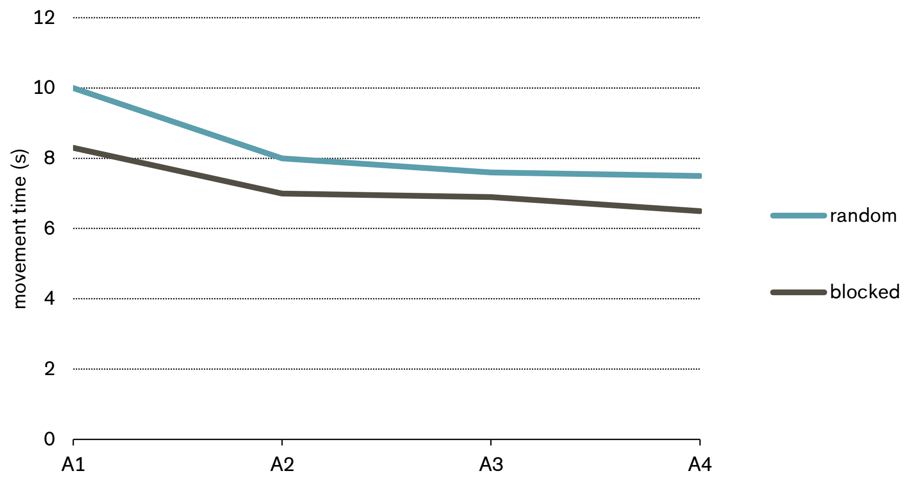
Body-powered and myoelectric simulator

Major Findings

Different orders of presentation of practice tasks:

→ Practicing in a blocked fashion leads to faster performance

Movement time in task performance

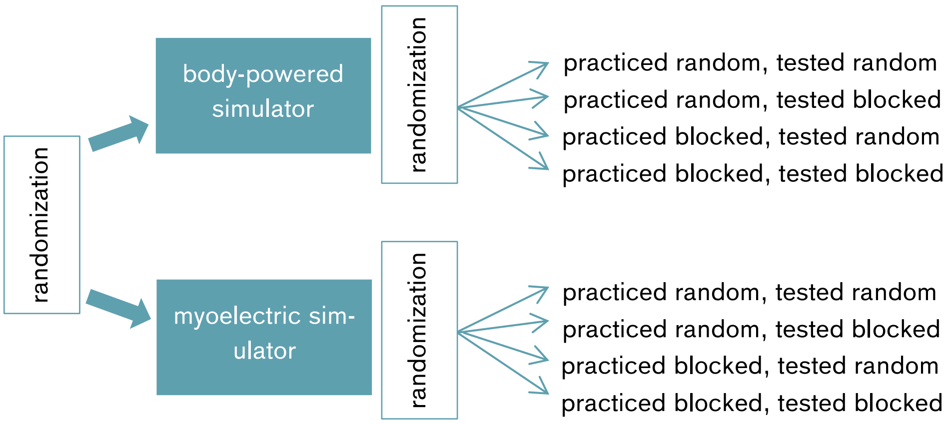


Movement time in seconds for each of the 2 groups (random – blue, blocked – grey) in the four blocks of acquisition phase (A1, A2, A3, A4). Blocked practicing involves trainings of all trials of 1 task before the next task is introduced. In the acquisition phase participants performed 3 tasks: direct grasping, indirect grasping, and fixating, each consisting of 20 trials.

Population

Subjects:	72 healthy, able-bodied participants
Previous:	none
Amputation causes:	none
Mean age:	21 ± 2 years
Mean time since amputation:	none

Study Design



On day 1, participants performed 3 tasks (direct grasping, indirect grasping, and fixating, each consisting of 20 trials) in the acquisition phase. The order of practice was either random or blocked. On the second day, a retention test and a transfer test were conducted to determine the effect of learning from the previous day. In 2 groups, the order was changed, from random to blocked and from blocked to random. The retention test consisted of 5 trials of each acquisition task, while in the transfer test, 5 trials of 3 new tasks had to be executed.

Results

Body Function		Activity			Participation	Others	
Mechanics	Pain	Grip patterns / force	Manual dexterity	Activities of daily living (ADL)	Satisfaction and Quality of life (QoL)	**Training**	Technical aspect

Category	Outcomes	Results for different orders of presentation of practice tasks:	Sig.*
Training	Initiation time	No difference between groups, between simulators, or among tasks.	0
	Movement time	Blocked groups performed faster than random groups.	+

* no difference (0), positive trend (+), negative trend (–), significant (++/––), not applicable (n.a.)

Author's Conclusion

"Performance in daily life with a prosthetic device is indifferent to the structure in which the training is set up. However, because practicing in a blocked fashion leads to faster performance, it might be suggested that patients practice at least a part of the training tasks in blocks." (Bouwsema et al. 2008)

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