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The New Hero of Upper Limb Prosthetics

Erin Miskell
Augustana College, Rock Island Illinois

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Portrayed in many Sci-Fi movies, the idea of combining body with machine has always seemed futuristic and foreign. However, some prostheses used today are rather high tech and are being compared to those such as Luke Skywalker's robotic hand in the *Star Wars* movies. But what does the term prosthesis actually mean? A prosthesis is defined by *Merriam Webster Dictionary* (2018) as a device that can replace part of the body that is missing or impaired. This can include a broad range of things such as an eye, tooth, knee joint, but also includes upper and lower limbs. While each missing body part comes with its own disadvantages, Stansia Raspopovic et al. (2014) writes that the loss of the hand can cause major distress and debilitation because of the loss of fine motor skills used in everyday life and the loss of tactile feedback that is normally derived from the hands. In order to try and regain some of this function, amputees will often look towards acquiring a prosthesis. But how prevalent is this need for prostheses in the United States? In the article "15 Limb Loss Statistics that May Surprise You", *Access Prosthetics* (2017) states that in the U.S. there are about 2.1 million people who are living with limb loss. Those at *Access Prosthetics*, along with other researchers, expect this number to double by 2050. Because of this growing statistic, there is a new urge to ensure that those who seek a prosthesis after losing a limb are met with the best and most useful prosthesis available. In terms of upper limb prosthesis, there are currently many types that serve different functions depending on the need of the wearer. Among these is the new Hero Arm designed by Open Bionics. Through literature review, this paper will look at the history of prosthetics and where the research is today. The argument will be that, as of today, the newly released Hero Arm is the most cost efficient and functional prosthesis available to the public.

Effects of Limb Loss

As the statistics from *Access Prosthetics* demonstrates, limb loss is prevalent and predicted to increase in the United States. But what are the main causes of limb loss? Paul Pasquina et al. (2014) provide four reasons for limb loss. The first, and most common is vascular disease. This includes diabetes and peripheral arterial disease. According to Pasquina et al. (2014), vascular disease accounts for about 53% of limb loss patients. Trauma is also very common as it is the second leading cause of limb loss. While this cause only makes up about 44% of total limb loss cases, it is mainly comprised of patients who lose their upper limbs. The last two causes of limb loss are much less common than the first two. Cancer makes up about 1.7% of limb loss. These cases are usually the result of a malignant tumor within a bone. The remaining 1.3% are congenital limb losses. There are a variety of reasons that a baby can be born without a limb, but most commonly, 58% of the time, the baby will be missing an upper extremity limb. No matter what the cause, the loss of a limb can leave a person unable to perform certain everyday activities with ease.

In chapter four, "Upper Extremity Prosthesis" of the book *The Promise of Assistive Technology to Enhance Activity and Work Participation* (2017), the authors claim that upper extremity includes both gross and fine motor skills that allow for people to perform everyday activities such as self-care and interaction with their environment. When this upper limb is lost due to any of the four causes mentioned earlier, these motor skills can also be lost. Because these skills are involved in everyday activities, some people will turn to an upper extremity prosthetic to try and regain some of the lost function. However, because of the complexity that goes into the movements of the upper limb, it can often be more difficult to replace with a prosthesis compared to a lower limb (Upper Extremity Prosthesis 2017). The chapter, "Upper Extremity Prosthesis" (2017), also points to the complexity of the upper extremity movements as a reason that wearers are often less satisfied with their prostheses compared to those who have a prosthesis to replace a lower limb. Prosthetics that most people receive are unable to fully restore function back to the limb. As with the majority of prostheses, there are many limitations that come with upper extremity prosthetics. However, research is being conducted to try and make the devices as life-like as possible.

History of Prosthesis

To better understand where upper-extremity prostheses are today, it is important to look at the evolution of the prosthetic field as a whole. Looking at the history of the field without narrowing it exclusively to upper-extremity prosthetics allows for a more cohesive view of the progression in the field. So where does the history of prostheses truly begin? Researchers are not entirely sure. They do have artifacts that date back many, many years, but they are not entirely confident in saying these are the first true prosthetics.

According to Finch et al. (2012) prosthetics date back to the Ancient Egyptians who used passive prosthetics in their burial ceremonies. The purpose was to make the body whole again so that they would be able to enter into the afterlife. These prosthetic limbs provided no function to the person. Currently, the first known functional prosthesis also dates back to this time. Finch et al. (2012) reports that scientists from the University of Manchester have discovered two toes that were more sophisticated than the ones used for burial purposes. The first toe, dating back to about 900-710 BCE, was named the Cairo Toe. The second toe, dating back to 600 BCE, was named the Greville Chester Toe. Researchers decided to conduct studies to see if these toes would have been functional in Ancient Egypt. With two different volunteers, the researchers at the University of Manchester recreated the two toes and conducted around 10 walking studies per volunteer. The trials showed that both toes were functional prostheses with the Cairo Toe performing better than the Greville Chester Toe. After the study, volunteers were asked to complete a survey regarding the functionality and comfort of the toes. Again both toes scored well in comfort and perceived functionality but the Cairo Toe scored the highest (Finch et al. 2012). In conclusion of the study, Finch et al. (2012) state that these toes are the oldest known functional prostheses, but that they would have only been available to the wealthy due to the materials used and the complexity of securing the device onto the foot.

Before the discovery of the Ancient Egyptian toes, however, the Department of Physical Medicine and Rehabilitation (PM&R) writes that the oldest prosthesis was thought to be a bronze and wooden leg known as the Capua leg. This leg dated back to about 300 BCE and was found in a wealthy Roman tomb. It was destroyed during World War II but a replica still sits in the Science Museum in London. The presence of prosthetic legs is also seen throughout the Middle Ages along with prosthetic hooks. Around this time, prosthetic legs and hooks were used by those who could afford them including knights. These prosthetics provided some function such as allowing knights to hold their shields or keeping them steady in their saddles. However, this was about the extent of their functionality. Focus on increasing the functionality of prosthetics would come later.

Throughout the history of prosthetics, wars seemed to be a major influence in advancing the prosthetics that were being used. Brian Lee et al. (2014) notes that during the Civil War the body-powered prosthetic was developed. The design of this prosthetic has not changed much since its development. Another war that had a major impact on the field was WWII. James McAleer wrote an article in 2011 that laid out the history of prosthetics post-WWII. He starts his timeline in 1945, around the time the war ended. He recounts the March on the U.S. Capital by veterans who had returned home from war to low quality prosthetic limbs (McAleer 2011). At the time, no government agency was in charge of researching and developing quality prosthetics.

That changed after the march on the capital. In February 1945, the government began funding rehabilitation research and the Committee on Prosthetics Research and Development was organized (McAleer 2011). Two years later, the budget for the research increased to $1 million dollars a year. The early 2000s would provide more funding as agencies such as Defence Advanced Research Projects Agency (DARPA) would also donate funding to the research and development of the prosthetic limbs. This increase in funding resulted in more sophisticated devices that were becoming more and more technologically advanced.

Because of the increase in funding, the 2000s saw many technological advances being made to the upper extremity prosthetic. In the late 2000s, the DEKA II arm, funded by DARPA, allowed its user to be able to lift things over their heads, a task that was once impossible with older prosthetics (McAleer 2011). The new technology being developed has helped many upper-extremity amputees in their everyday life. But some users and researchers are still not satisfied. Research is continuing to try and make these prosthetics even more life-like. Research today is looking at ways to restore tactile feedback in a prosthetic limb. How is this possible? In 2016, Samantha Cole wrote an article for *Popular Science* that explained the foundation that scientists were working on to restore a sense of touch. She writes that up until 2016, it was thought that when a person lost their limb, the brain would forget about a signal pathway because it was no longer receiving information from it. However, scientists from the University of Oxford, United Kingdom found that this was not the case. In fact, the pathways were still in tact and still usable given the right stimulation. Because of this finding, different methods of restoring sensory pathways through the nervous system have evolved.

While, today, many of the prostheses being researched and developed are not available to the public, there is one that has recently been released to consumers. In May 2018, Matthew

Field wrote an article that announced Open Bionics' release of their long awaited Hero Arm. This externally powered arm had taken four years to study and be perfected enough to be brought to the market. Open Bionics prides their arm for being the first FDA approved upper extremity prosthetic. But whether or not this is the best prosthetic limb for all upper extremity amputees remains to be seen.

Types of Upper-Extremity Prosthesis

Currently, there are four basic types of prosthetics that are available to those who do not have an upper extremity. The fours basic types are passive, body powered, externally powered, and hybrid. Each have their own advantages and disadvantages that would influence someone to choose one type over the others. Knowing the reason behind the desire to obtain a prosthesis can help a person decide which prosthetic limb is right for them.

<u>Passive Prosthesis</u>

As suggested by its name, this limb does not contain any active movement at any joints (Upper Extremity Prosthesis 2017). These limbs are also known as cosmetic prosthetics because their main purpose is to appear as similar to a real hand or arm as possible. Because they do not contain any mechanisms that would allow for movement, they are the lightest in weight (Upper Extremity Prosthesis 2017). While they are considered passive and mainly cosmetic, they can perform some functions. The wearer is able to hold down certain objects such as a piece of paper, or use the prosthetic to better stabilize an object they are holding (Upper Extremity Prosthesis 2017). Besides these benefits for everyday life, there is also a psychological benefit. The writers of the chapter "Upper Extremity Prosthesis" (2017), discuss how people with limb loss, acquired by amputation or at birth, experience a significant amount of psychological distress due to social stigma. For this reason, those who do not seek a great deal of function from their prosthetic limb can obtain a passive prosthetic limb that will help to improve their self-confidence in social situations and improve their body image. For those who seek more function, another type of prosthetic may be a better fit than the passive prosthetic limb.

Body Powered Prosthesis

The body powered prosthesis, as mentioned earlier, has been around since the Civil War (Lee et al. 2014). This machine is powered, as the name suggests, by the body. To move this prosthetic, a harness is placed around the shoulders and cables are used to connect the harness to the attached prosthetic arm (Upper Extremity Prosthesis 2017). While not as light as the passive limb, it is still relatively lightweight. Because of the added harness and cable, the body powered prosthetic has an increase of function and can give more independence to the wearer. One major disadvantage of the body powered prosthesis is the movement that is needed to be able to manipulate the device. The chapter “Upper Extremity Prosthesis” (2017), states that the body powered prosthetic requires a certain degree of strength and range of motion in order to successfully manipulate the cables to produce the desired motion of the arm or hand. If a person looking into this device is not strong enough or does not have the required range of motion, they may need to look into a different type of upper limb prosthetic.

Externally Powered Prosthesis

The externally powered prosthesis is free from the cables and harnesses that come with the body powered prosthetic limb. To power this prosthetic, batteries are added along with other mechanical parts (Upper Extremity Prosthesis 2017). In order to move the prosthetic, various types of inputs can be used. These inputs could include force-sensing resistors, pull switches, push switches, or most commonly electromyographic signals (EMG). The EMG signals are electrical signals that are given off by a muscle when the muscle contracts. A myoelectric control scheme can detect these electrical signals and translate them to the prosthetic to perform an action. Using inputs like the EMG signals takes away the restriction of the body powered prosthesis because a certain degree of strength is not needed to operate the externally powered prosthetic arm.

Another advantage of the externally powered prosthesis over the body powered is the more cosmetic appearance that it has over the body powered prosthesis's typical hook hand (Upper Extremity Prosthesis 2017). While not as life-like as the passive prosthesis, the externally powered hand is designed to look like a hand. While the externally powered prosthetic limb has many advantages due to its incorporation of technology, it also has some disadvantages that might cause people to hesitate spending the money for this type of prosthetic.

The technology aspect of the externally powered prosthesis is both an advantage and a disadvantage. While it allows for people to perform more functions than previously discussed prostheses, it is also heavier than other types of prostheses due to the added batteries and motors (Upper Extremity Prosthesis 2017). The batteries not only add to the weight, but also must be charged daily. This can be inconvenient for some people and, if forgotten, can leave a person without the use of their prosthetic arm. The addition of the technology also raises the price of this prosthesis over the passive or body powered prosthesis (Upper Extremity Prosthesis 2017). Due to the complexity of the technology, the externally powered prosthesis would require more maintenance and repairs if something were to break. This would add to the already high expense of the device. However, weight and price are not the only disadvantages of the externally powered arm. There can also be discomfort due to the electrodes that are in direct contact with the limb (Upper Extremity Prosthesis 2017). The electrodes are important for controlling the movement of the limb but can become irritating for wearers with sensitive skin. The act of controlling the device is also tricky and requires much practice. This can be yet another disadvantage to the prosthetic arm that can steer people away.

So why choose the externally powered arm? The externally powered prosthetic limb has the most potential in restoring life-like movement and sensation back to the wearer. Even with these disadvantages, the externally powered prosthesis is the main type of prosthetic arm that is being used in research and development studies. If these disadvantages can be addressed and fixed, the externally powered prosthesis could be the most functional and life-like prosthetic arm for wearers.

Hybrid Prosthesis

The last type of upper extremity prosthesis is the hybrid. The hybrid is a combination of the body powered prosthesis and the externally powered prosthesis (Upper Extremity Prosthesis 2017). In most cases, this means that the prosthetic is made up of a body powered elbow and an externally powered, myoelectric hand. This would allow for both the elbow and the hand to be operated at the same time, therefore allowing for functions that are not possible with just the externally or body powered prostheses in isolation. A hybrid prosthesis has a limited audience as it would only be available for someone who has an above the elbow amputation. The chapter, "Upper Extremity Prosthesis" (2017), states that this type of prosthesis is most commonly used by people with a transhumeral amputation or a shoulder disarticulation. The limitations of the two prosthetics discussed earlier would also apply to the hybrid as it is a combination of the two different types of prosthetic limbs. The hybrid would also require a certain degree of strength and range of motion, as well as making it expensive due to the complex technology that is incorporated into the mechanical hand. Although it provides an increase in functions, the limitations due to selective audience and design make this prosthetic less accessible than the other types of upper extremity prostheses.

Current Limitations

As stated previously, externally powered prostheses dominate the research studies and seem to be the primary focus of the industry moving forward. Research is mainly focused on ways to improve the externally powered prostheses in order to produce the best possible prosthetic limbs. For this reason, the rest of the paper will refer to externally powered prostheses exclusively when examining possible solutions to the current limitations.

While the field itself has made many advances in their prosthetic limb designs, there are still many places for improvement. As talked about earlier, the design of the prosthetic limbs are often uncomfortable and difficult to control. Another limitation to current prostheses is the lack of sensory information that the user gets from the arm (Upper Extremity Prosthesis 2017). In current research, sensation and control are often studied together because of their interaction with each other. For example, not being able to feel results in the wearer being unaware of how much pressure they are exerting (Upper Extremity Prosthesis 2017). Not knowing how much pressure they are exerting can cause the prosthetic user to either drop an item because they are not holding it tight enough, or break an object because they are applying too much pressure. While control and sensation are important to try to incorporate into future prosthetic arms, comfort also needs to be kept in mind.

Tackling the Limitations

In attempt to make prosthetics as life-like as possible, research is currently being done to address the before mentioned limitations through three exciting futuristic technologies: intrafascicular multichannel electrodes (TIMEs); brain-machine interface; and The Hero Arm. Of these technologies, the Hero Arm is the only accessible option that fully addresses all limitations outlined. It's also the only option in availability to the public as it was recently released in the United Kingdom (Hero Arm 2018). While the Hero Arm is currently both available to users and doing more than other externally powered prostheses, all three technological solutions have great potential and are worthy of critical review.

Intrafascicular Multichannel Electrodes (TIMEs)

TIMEs offers greater sensory feedback and potentially more control to prosthetic users. In order to try and restore touch sensation in a person who had lost part of their upper extremity, Raspopovic et al. (2014) conducted a study that involved surgically implanting electrodes into two nerves in the forearm. The researchers used TIMEs that were connected to both the nerves and the prosthesis. The two nerves chosen for the study were the ulnar and median nerve. These nerves were chosen because their innervation covered the most area of the palm and fingers. To restore the sensation back to the limb through the nerves, an electrical current was taken in through the prosthesis and delivered through one of the TIMEs to the nerve. The nerve would then send the signal to the brain where it would interpret the signal based on a physiological sensory map of touch (Figure 1). Raspopovic et al.'s (2014) hope was that along with restoring some sensation to the limb, there would also be an increase in control. The study included only one participant who was blindfolded and had headphones on during much of the experiment to ensure that the data would reflect only the results of using the induced touch sensation.

The study included many different trials that aimed to test the effectiveness of the TIMEs. In trials where the participant was asked to produce a certain amount of force with the sensation turned on, he was able to realize when he was using too much force and correct himself. This shows that the participant was receiving the tactile feedback and was able to adjust when necessary (Raspopovic et al. 2014). Throughout the study, he was able to improve his performance with the prosthetic index and little finger from 67 to 93% and 56 to 83% respectively. One of the trials focused on comparing the amount of feedback the participant was receiving from the TIMEs to his non-affected hand. To do this, the participant was asked to perform a staircase task with both hands. The task would be completed under three different circumstances: with his intact hand; with the prosthesis's tactile feedback turned on and no visual or audio feedback; and with the prosthesis with no tactile feedback but with visual and audio feedback (Raspopovic et al., 2014). The task involved gradually increasing the amount of pressure to a certain point before gradually decreasing the pressure. The results showed that the participant had much better control of the prosthesis when he was able to feel the amount of pressure he was producing (Figure 2).

While the results of Raspopovic et al.'s (2014) study with TIMEs show an immense amount of potential for restoring sensation and improving control in prosthetics, it does come with some drawbacks. In her 2014 article, "A Mind-Controlled Robotic Hand With a Sense of Touch", Francie Diep notes that more studies need to be done to determine how long the electrodes will be able to last in the body. Because the electrodes are a foreign object, it is likely that they will be degraded by the body. Because of this, they will need to be replaced, costing more money and requiring more surgery. With an increase in the amount of surgery needed to replace the electrodes, the risk of infection also increases. While it may be possible to develop electrodes that will not degrade in the body, or find a way to make the body accept the new foreign object, more research will be needed to find this solution. Because of the further research needed, this mechanism is not able to be implemented in the public yet. Therefore, using TIMEs as a way to tackle the limitations of current upper extremity prosthetics is not the best solution out of the three discussed in this paper.

Brain-Machine Interface

Another, slightly more invasive, solution to limited sensory and control includes creating a pathway for brain-machine communication by stimulation of the somatosensory (S1) parts of the brain (Tabot et al. 2015). Because the S1 neurons becomes activated when something touches a part of our body, Gregg Tabot and his colleagues (2015) conducted a study to see if the stimulation of the S1 area of the brain could elicit enough meaningful tactile information to improve the control of the robotic prosthetic and make it feel more life-like. The research to support this study is found with the phantom limb. Jozina De Graff et al. (2016) define phantom limbs as a vivid perception of the limb after it has been amputated. They go on to state that the sensation of phantom limbs is very common, occuring in 90-98% of amputees. Previous studies have suggested that the presence of a phantom limb in amputees comes from activity within the somatosensory area of the brain that used to receive signals from the limb (Tabot et al. 2015). To figure out which part of the S1 area correlates with the different parts of the missing limb, researchers could stimulate different nerves and ask the patient to say where they are feeling the sensation on their phantom limb. After collecting this information, the appropriate sensors could be placed so that when one sensor is set off, the corresponding part of the S1 area is stimulated. Even though it is invasive, this solution seems like a logical fix to the control and sensory limitation that current prosthetics possess.

As with TIMEs, to produce this sensory information the patient must undergo surgery to rewire the nerves. According to Sarah Fecht (2017), typical amputations involve the surgeon cutting through the patient's nerves and muscles. Without an organ to stimulate, the nerves can begin to swell and be painful. By rerouting the severed nerves in the arm, not only will scientists like Tabot et al. be able to relieve some of the pain, but they are able to use the nerves to restore some function and sensation back to the user. Katie Palmer (2011) describes what the surgery entails. She writes that the surgery will reroute the nerves from the limb to the patient's chest. To do this, the surgeon must sever the nerves in the chest so that the nerves from the arm can be attached. Once this is completed, the patient would be able to move their prosthetic simply by thinking about it. The motor nerves that were previously in the arm would fire in the chest muscle and stimulate electrodes that were implanted at the end of the nerves. These electrodes would then move the prosthesis. The sensory nerves that have been rerouted can receive information from sensors placed on the corresponding part of the prosthesis and then relay the information back to the brain. While the mechanism of the solution seems sound, there are some problems with this solution.

One problem with the solution is that the sensory information that is received through the electrical stimulation is not naturalistic or predictable (Tabot et al. 2015). Because it is not natural and difficult to predict, Tabot et al. contemplate whether or not it is worth using this method for the restoration of tactile feedback. They go on to say that their expectations are low for the solution's ability to ever evoke a natural sensory feedback that is meaningful. Their only hope for this solution is that the patients who undergo this invasive surgery, would be willing to learn what each new sensation means in relation to their prosthesis. While feasible, the wearer would have to relearn to associate different sensations with movements and contact. They discussed how it could be possible for children to make these new associations, but it is still unknown as to whether or not adults would be able to. The process would be long and difficult and may not be worth it for some users.

Another problem with this solution is that the advantages do not equal or outweigh the disadvantages. Tabot et al. (2015) writes that while users would be able to perform simple tasks, the movements would not be well controlled. Tabot et al. (2015) concludes that the risk of the surgery to reroute the nerves outweighed the benefits. Even if the patient is willing to relearn how to use their arm and the surgery is conducted, the electrodes that are implanted would not be permanent as the electrodes are not sufficient enough to survive in the body. This solution still has a few problems that would need to be addressed before it could be considered a possible solution for the limitations to current prosthetics.

Hero Arm

While some researchers may focus on one specific limitation, the Hero Arm aims to address all three of these limitations along with the high price of prosthetic limbs. Since 2014, the UK company, Open Bionics, has been working to perfect their device (Scott 2018). Their devices, released to the UK public in April of 2018, are 3D printed externally powered prosthetic limbs for below the elbow amputees. The device takes a less invasive approach to tackling the limitations of current prosthetic arms and is the first medically approved 3D printed bionic arm. While the arm has not been on the market for long, Field (2018) writes that those who have tried the Hero Arm have positively reviewed it and believe it is better than other prosthetics currently available. These positive reviews are likely due to Open Bionics attention to details that they have incorporated to deal with the current limitations of modern upper extremity prosthetics.

One limitation they examined was comfort. To tackle the discomfort that many prosthetic wearers complain about, Open Bionics designed their prosthetics to be as user compatible as possible. Much of the arm is custom made. The socket, or part of the prosthetic that comes in contact with the person's remaining limb, is designed to be breathable so that it can be comfortable in different environments (Hero Arm 2018). As people with other prosthetics begin to sweat, the device can become uncomfortable to wear. The ventilation that is built into the socket of the Hero Arm, aims to help ease some of the discomfort that comes from different temperatures. The socket is also made to be tight enough to ensure a secure fit but expandable to account for swelling that can happen with the residual limb (Hero Arm 2018). Another feature of the socket that adds to the user friendliness of the device is the life of the battery. Whereas other externally powered prosthetic arms require their batteries to be charged constantly, the Hero Arm's battery is designed to last longer so that the wearer can get an extended amount of use out of their prosthetic arm (Hero Arm 2018). What allows for the Hero Arm to be comfortable is their customization. Not only is the socket molded to ensure that it fits the wearer correctly, but the outside of the prosthetic can be personally customized as a way for the wearer to express themselves. As is seen with the passive prosthetics, a main part of successful prosthetics is helping the person to feel comfortable with how they look now that their limb is gone. With the changeable prosthetic covers, the person is able to decide how they want their prosthetic to look. One of Open Bionic goals is to change what is seen as a disability into a superpower (Hero Arm 2018). The company wants people to be not only comfortable with how the prosthetic feels, but also with how they look. This feature is important for the acceptance of prosthetic limbs, which can often be difficult to get used to, and giving people back the indepence they once had.

The look is not the only thing that can be customized. The Hero Arm has also been designed to allow users the most control over their prosthetic as possible. To do this, the Hero Arm uses myoelectric sensors to help move the arm (FAQ 2018). As discussed earlier, the myoelectric sensors detect electrical signals from the muscles and translate them to move the prosthetic (Upper Extremity Prosthesis 2017). This means that when the wearer flexes a specific muscle in their arm, the sensors will detect the signal and activate the correct parts of the prosthetic to perform the desired movement or grip (FAQ 2018). This is where another aspect of being customizable plays into the design of the arm. The device allows for the user to program specific grips that can be selected when needed (Field 2018). Having the most common grips needed by the wearer in everyday activities would add to the ease of controlling that prosthetic. For a person who spends the majority of their day writing but lost their dominant hand in an accident, a grip can be programed that would allow them to hold a pen again and continue with their writing.

There are other, less customizable features, that play into the control of the prosthetic limb. The Hero Arm comes with a Freeze Mode that would allow the hand of the prosthesis to be held in place so that the person can continue to hold the pen or a glass in their hand without having to concentrate on keeping those muscles contracted (Field 2018). The prosthetic also has the added benefit of a wrist that can rotate 180 degrees and a posable thumb. Another feature of The Hero Arm is the proportional control. This feature allows the operator to have control over the fingers so that delicate tasks can be performed, such as picking up an egg without cracking it (Hero Arm 2018). By being able to control the speed of the fingers, the wearer is able to better judge when to stop applying pressure to objects. All of these features have been added in the hopes of making the externally powered prosthetic arm easier to control, a limitation that may have steered people away from these devices in the past.

The last limitation the engineers at Open Bionics tried to tackle was feedback. While it does not produce the same sensory feedback as the other solutions have aimed to restore, the Hero arm is able to give some feedback. The bionic arm uses lights, sounds, and vibrations to send feedback to the wearer (Hero Arm 2018). While this feature could be improved upon to become more life-like, the Hero Arm is still able to provide more feedback than current prosthetic limbs.

Another advantage of the Hero Arm is the price. Field (2018) writes that high-tech prosthetics can cost between £30,000 and £60,000. That is about $34,565.61 and $69,131.22 respectively in the United States. Field (2018) also states that because of incorporating the latest technology into upper-limb prosthetics in the US, the prices of prosthetic arms tend to be even more expensive. In contrast to these high priced prosthetics, the Hero Arm is priced at about £10,000 ($11,521.87) (Field 2018). So why is it that the Hero Arm can be sold for so much less? Field (2018) writes that Joel Gibbard, founder and engineer behind the Hero Arm, saw an opportunity to make a cheaper prosthetic, that can also be maintained for lower cost, by manufacturing it through a 3D printer. While the materials may be cheaper, Open Bionics reassures its customers that the prosthetic is strong and durable. While the price of the Hero Arm is significantly lower than other high-tech arms currently available, the price of the prosthetic does not factor in insurance. Because the arm is not currently available in the US, it is difficult to say how much insurance would affect the price but it is likely that the price of the arm will ultimately be even lower.

Conclusion

For much of their existence, prosthetics have been shown to provide some sort of function. As time went on and needs changed, prosthetic limbs have evolved to try and keep up with the demand of its users. For those who need upper extremity prostheses, this demand is even higher due to the complex functions of everyday life that can no longer be done due to a limb loss. However, today there are robotic arms that are designed to be as life-like as possible by being lighter, easier to control, and providing more sensory feedback than older models.

While advances have been made in the field, many of these are still in trials waiting to be perfected and brought to market. Peter Kyberd et al. (2003) writes that in order to get a solution's prototype to become a commercial product available to the public, the device needs to cover as many individual needs as possible. By aiming to address as many limitations as possible, researchers and developers may have a better chance of meeting the most needs of the prosthetic users. The newly released Hero Arm is the only advancement talked about in this paper to have made it to market and the response from the media and wearers has thus far been positive. Devices such as the Hero arm, makes for a promising outlook for the field in their attempt to make prostheses that restore both lost function and sensory feedback at reasonable costs.

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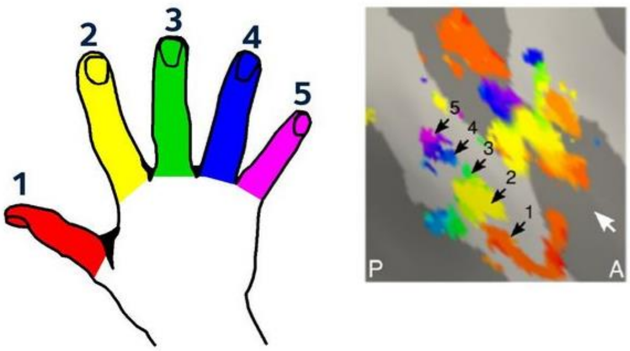
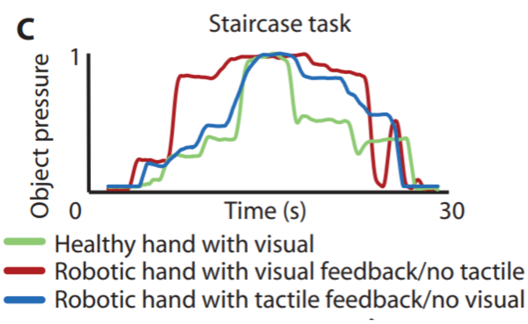
Appendix

Figure 1



(Cole 2016)

Figure 2



(Raspopovic et al. 2014)