

PHANTOM LIMB PAIN: THE PAIN OF A MISSING LIMB

by

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## **ABSTRACT**

Phantom limb pain is the perception of pain in a limb that has been amputated; this sensation has been described as cramping, burning, stabbing, crushing, etc. which can be an excruciating pain lasting years. The feeling of pain in a region of the body that is no longer present is a phenomenon that does not have one single explanation or treatment, yet a variety of theories and treatment options exist. The term Phantom Limb Pain was first coined after the Civil War because of the large number of veterans with amputations, yet this pain existed long before the medical terminology. Over 200 million Americans are living with an amputation; 85% of amputees experience PLP yet each individual has different experiences. Amputations can be the by-product of tragic motor vehicle or war accidents and also due to planned surgeries resulting from diabetes or vascular disease. There is a wide range of theories that describe PLP, most involving the central nervous system. These include cortical remapping which is brain regions taking over portions of the brain that were once controlled by the amputated limb, somatosensory plasticity which is the brain's ability to alter over time, and nerve theories such as Dorsal Root Ganglion Abnormal Activity. Additionally, there has been much more research on different types of treatment that can alleviate phantom pain such as mirror therapy, virtual reality, and reconstruction surgeries. In my capstone, I will go into detail to describe the sensation and impact of PLP as well as describe current theories and treatments. It is important for amputees and the public to understand what phantom limb pain is so that more research is done to find additional treatment options to lessen this life-altering chronic pain.

# Introduction

Phantom limb pain refers to the sensation of pain in a region of the body that is no longer present as a result of amputation. This concept may be difficult to comprehend, because how does one feel pain on a body part that has been amputated? The phenomenon of PLP (phantom limb pain) is not fully understood despite the majority of amputees experiencing this pain. There are a wide variety of theories to explain this sensation as well as many treatment methods to help relieve this pain; yet, there is no single explanation that accounts for the phenomenon nor a single cure found to be effective in relieving this pain.

## History

The phrase “Phantom Limb Pain” was first introduced and clinically described by an American Physician, Dr. Silas Weir Mitchell in 1871. Mitchell brought attention to this phenomenon after working with U.S. Civil War Veterans who had lost their limbs (Bonnan-White et al., 2016).

Although the term was coined in 1871, the sensation of phantom limb pain after an amputation has been known for much longer. The oldest proof of amputation was found in the skeletal remains of a child found in Borneo from 31,000 years ago. (Maloney et al., 2022).

An early record of PLP is from Lord Nelson who had lost his right arm from an attack on Santa Cruz de Tenerife in 1797. The sensation he experienced was “fingers digging into his phantom palm” which he described as “direct proof of the existence of the soul” (Ramachandran, 1998). As one could imagine, this sensation of pain in an amputated region of the body is quite

difficult to understand; especially for those in the past who felt these sensations yet had no medical terminology to describe it.

## Civil War Veterans

As previously mentioned, the term Phantom Limb Pain was first used after the Civil War. Many soldiers had lost their limbs due to factors such as premature explosions, locomotive accidents, frostbite, gangrene (body tissue death due to lack of blood supply or infection), being shot with “minie balls” (soft lead bullets that flatten with impact) and many other reasons. Physician Silas Wier Mitchell learned a lot from Civil War amputees, regarding their symptoms, physical health, and lifestyle changes. In a collection of surveys and letters that Mitchell collected, the majority of the soldiers described having pain before and following their operation. As for general health, participants described themselves as “cranky”, “nervous” and “irritable” and one veteran who had lost both arms described being able to feel “the whole of both limbs (and has a) hot sensation in both” (Bonnan-White et al., 2016).

Additional quotes that were collected in this study that help describe PLP included:

*“The hands, pain in the fingers and thumbs all the time, it gives me no peace”*

*“It feels like feet were at the end of stumps, but cramped”*

*“It feels as if the foot was in the place where amputated, can feel the toes... seems as tied or bandaged” (Bonnan-White et al., 2016).*

It is clear that these soldiers had physical challenges with their amputations; but, these hardships went much further having to enter post-war society. After Congress passed the 1890 Disability Pension Act there was backlash from some of the public; critics accused claimants of being undeserving of the benefits. So while these amputees were physically and mentally struggling with their disability they were pressured to “pressured to put the violence in the past in favor of a

new unified American narrative” (Bonnar-White et al., 2016) and to “consider their wounds and their accompanying suffering connected the sufferer to the higher meanings of the war, whether political or religious” (Fahs, 1999). Veterans were publicly scrutinized for their disabilities and were denied by doctors. That being said, it is imperative to understand and take disabilities seriously so that people suffering have the support they need to get help.

## Prevalence

Currently, over two million Americans are living with an amputation, and over 85% of these individuals experience PLP (Collins et al., 2018). For many, this statistic may seem very high since not many people personally know someone who has had an amputation. When thinking about limb loss many picture tragic accidents such as war or motor vehicle accidents; but, there are reasons for an amputation that are often overlooked. In many cases, amputations are a planned surgery giving individuals time to prepare and educate themselves allowing for a smoother transition into this new lifestyle. During the preoperative time it is important to focus on having a strong support system; “Keeping family members informed and involved early in the process is essential to overcoming the patient's likelihood of withdrawing or anticipating social rejection. In addition, involving family members, allows them to express their concerns and anticipate how their lives will be affected” (Butler et al., 1992). In America, approximately 250,000 amputations are performed each year (86% being lower-limbed). The leading causes of these surgeries are diabetes and vascular diseases (such as blood clots or infections) (Culp & Abdi, 2022). No matter the cause or reason for amputation, the individual is still likely to experience phantom limb pain as well as other struggles that come with the life-altering disability of amputation.

## Understanding the Sensation

Knowledge is important for progress. Understanding amputation etiology, acknowledging phantom limb pain, and being aware of the physical and mental challenges that are a result of amputation are necessary so that amputees can better cope and seek treatment. The public having a better understanding of amputations will provide a more accepting environment and encourage research progress as well.

### Phantom Limb Pain

Although the sensation of phantom limb pain is something most people won't experience in their lives, there have been many case studies, interviews, surveys, etc. for people who do not have PLP to understand what this sensation is like. Phantom limb sensation is characterized by the feeling that the amputated limb is still present; while phantom limb pain is specifically the pain felt. The pain is different for every individual yet some common descriptors include burning, crushing, cramping, and stabbing. These pain intensities range from mild to excruciating depending on the individual. Some amputees have constant pain while others have pain that comes and goes. One common painful sensation that upper limb amputees experience is the feeling of their hand being clenched in a fist, with “nails digging into the palm” (Ramachandran, 2008). Since there is no longer a hand to “unclench” this pain cannot be alleviated.

Having discomfort and no way to ease it must be very frustrating for these individuals and can hinder living a normal functioning life. “Chronic pain is physically and psychologically stressful and its constant discomfort can lead to anger and frustration with yourself and your loved ones” (American Psychological Association). Many amputees often have sleep

disturbances because of the phantom pain at night; lack of sleep can cause irritability and other mood changes. Research has demonstrated that there are factors that enhance this pain; such as whether the amputation was traumatic or not. The phantoms tend to be more vivid and painful, or longer for individuals who lost their limb in a traumatic way, or if there was excess pain before the amputation surgery. If the amputation was surgical and a non-painful limb, there tends to be less pain (Ramachandran, 1998).

### Residual Limb Pain

Not only do amputees often have pain in the phantom limb, but it is also common to have pain in the remaining part of the amputated limb; this is known as residual limb pain (RLP). Seventy-six percent of amputees experience residual limb pain (Lu et. al., 2022). A common cause of RLP is ill-fitting prosthetics or poorly padded prosthetics. Other factors that cause residual limb pain are unhealed wounds, infection, tumors of the nervous tissues, damaged skin, and nerve entrapment. Unlike phantom limb pain, residual limb pain is likely to have an identifiable cause and can be treated more directly. An amputee can discuss their symptoms with their healthcare team to come up with a treatment/management plan depending on the cause of the pain. Treatments range from simply repositioning the residual limb, to surgical nerve interventions (explained in a later section).

### Frozen Limb Pain

Another sensation that amputees often experience is “frozen limb pain” which is when the phantom is stuck in a specific position and cannot be voluntarily “unfixed” from that position. In an anecdote report, a soldier had a grenade explode in his hand, leaving behind a phantom hand stuck in a permanently clenched and painful position (Ramachandran, 1998).

There are a couple of theories that explain the reason for frozen limbs. One is because there is no visual feedback so the positions cannot be “unfrozen” and another theory is that the frozen position is the last position the limb was in before the amputation. I will be going into more detail about theories of PLP in a later section.

## Telescoping

Telescoping is the sensation of the amputated limb (most common in upper limbs) becoming “shorter” until the perception of the phantom hand is felt to be “hanging” from the stump. This phenomenon occurs in nearly 50% of cases and yet it is not clearly understood why. Some reasoning for telescoping could be because the hand has a large representation in the somatosensory cortex along with the conflict of nerve impulses. One patient reported that he felt his telescoped hand attached to the residual stump, and yet if he were to attempt to shake a hand he would remain arm's length away (Ramachandran, 1998).

## Long-Standing Habits

After losing a limb, many amputees still feel that their limb is intact since they have lived their entire life with that limb. There are “long-standing habits” in phantoms; meaning amputees attempt to do an action with a phantom limb out of reflex or routine. One right-arm amputee Civil War veteran described in a 1906 letter how he rode his tractor one day and a gust of wind made his straw hat fly back, in an attempt to catch his hat he involuntarily tried to reach with his right arm. This feeling of still having two intact arms gradually grew less and then completely went away. In his dreams however, he said he always has both intact arms (Bonnan-White et al., 2016).



## The Impact

Limb loss impacts many aspects of an individual's life, whether it be physical, mental, social, or all three. It is important to address and understand these hardships so that individuals who are struggling with the impact of an amputation will have support and resources to improve their lives.

### Emotional

Limb loss alters a person's life immensely which oftentimes results in mental health struggles. Some of these struggles include post-traumatic stress disorder, acute stress disorder, depression, general anxiety disorder, and grief. Post-traumatic stress disorder (PTSD) can occur following a traumatic event, such as limb loss in a car accident or a military injury. As described by the National Institute of Mental Health, some symptoms of PTSD include flashbacks, reoccurring dreams, avoiding places or thoughts related to the experience, sleep disturbances, negative thoughts, feeling socially isolated, and loss of interest in previous activities, to name a few.

Depression affects the way you feel, think, and act; there is a feeling of sadness and loss of enjoyment. Amputees may develop depression for many reasons such as feeling a loss of independence, not being able to do things they used to do, distorted self-image, and social isolation. It has been seen that 20 to 60% of amputees who attend surgical or rehabilitation clinics are clinically depressed (Whyte & Niven, 2001). Depending on the severity, depression may be treated through medication, psychotherapy, or a combination of the two. It is vital to acknowledge and treat mental disorders that an amputee may be struggling with to improve their quality of life.

Many amputees have anxiety about going into public areas and may end up isolating themselves to avoid receiving pity or unwanted attention from others. The following are quotes from participants who were interviewed about their post-amputation emotional experience (Rosca, 2021).

*“... a terrible frustration. Things were taken from me, my job, my independence ... it’s a terrible frustration but I am fighting it” (Participant 4).*

*“I’m talking to my brothers on the phone. But they are busy. I do not want to get in touch with a lot of people so they’ll say look at this poor fellow!” (Participant 1).*

*“The fact that I do not have an arm made me isolate myself ... I’m embarrassed by the situation I’m in. I do not want them to feel pity for me” (Participant 4).*

*“A job I was doing with pleasure (teacher) was taken away from me. How can I appear before my students without an arm?” (Participant 4).*

*“At first, the few friends and neighbors took great care of me. Now they’re coming less and less often. They also have their problems” (Participant 3).*

These quotes highlight how amputees feel about going into public areas and having to ask others for assistance. The public should be aware of these internal battles that many people with amputations struggle with so that they can provide a welcoming and judgment-free environment. Amputees already have to struggle with function, pain, and psychological impacts, if the general public can be more understanding and supportive that is one less burden an amputee has to face.

## Body Image

Body image is “the combination of an individual's psychological experiences, feelings, and attitudes that relate to the form, function, appearance, and desirability of one's own body” (Taleperos & McCabe, 2002).

Amputation of a limb is a major appearance change that can produce many emotions. To look in the mirror and see a huge body modification such as a lost arm or leg can cause feelings of shock, anguish, and sadness. These emotions especially arise when an amputee sees themselves in a full-length mirror for the first time. In a study to explore the emotions that arise when an amputee views their reflection, participants were asked a series of prompts about their experience of seeing their reflection for the first time, their feelings and emotions, what their self-talk was before/during/after, and their journey of viewing themselves. One participant in the study described her experience of mirror shock:

*“It was so surreal that I was not feeling anything...it took me a long time to feel sad about this. I thought once I started crying I thought I would not stop.”* (W. Freysteinson et al., 2017).

Individuals often do not have a clear emotion at first, the shock of not being able to recognize your own body is an experience no one can completely prepare for.

On the other hand, there could be feelings of anguish which include devastation, depression, revulsion, hopelessness, etc. These strong emotions can take over a person's mental well-being, especially with how necessary and prevalent mirrors are. Since a person seeing themselves with an amputation for the first time can be very emotional it is important for the individual to be prepared and with a person who has a rapport with the patient such as a skilled

rehabilitation nurse. One participant in the study told the story of how he saw himself in the mirror for the first time after his amputation:

*“I remember I was doing physical therapy to learn how to start working with this hand. I was still (in the hospital). They had, uh....they were understaffed that day so they let me walk down to my physical therapy instead of taking me in a wheelchair and on my way back up... I hadn't ever really realized that there were full-length mirrors there as you walk in. As I was leaving physical therapy to go back upstairs, I finally turned and looked and was completely devastated. I remember just immediately crying and I thought wow this is horrible. This is bad, bad news. Probably to this day, I'm not really crazy about....that kind of mirror”.* (W. Freysteinson et al., 2017).

Amputees should be informed about the possible emotions they could experience regarding their body image so they can prepare themselves and understand that their emotions are common and expected.

These negative emotions do not always last, many participants discussed how they were able to accept their differences by shifting their focus away from what is missing and focusing on improving the whole body. Acceptance is not easy, but it is possible. Many participants explained that being able to look into mirrors easily was a sign of acceptance of the amputation. (W. Freysteinson et al., 2017).

## Mobility and Unemployment

An amputation has the ability to affect individuals mentally. Another impact an amputation has on a person is limiting mobility. Losing an arm or leg greatly affects a person's ability to move freely and easily which may lead to them not participating in activities, unemployment, and isolation. A survey was administered in Mumbai, India to provide

information on amputees “Quality of Life” by using questions that involved: “physical functioning (PF), role limitations due to physical health problems (RP); bodily pain (BP); general health perceptions (GH); vitality, energy and fatigue (VT); social functioning (SF); role limitations due to emotional problems (RE); and general mental health covering psychological distress and well-being (MH)” (Sinha et al., 2017). At the time of the survey, 52% of the participants were unemployed while 80% of the participants were employed before their amputation. Eighty-two percent of this group of unemployed individuals claimed that their amputation was the direct cause of their unemployment. Job loss creates many problems in itself; stress, depression, anxiety, lower self-esteem, etc. . In this specific survey, there were more male participants (530 males vs 75 females). In India, the male is primarily the income earner of the family and unemployment has a direct impact on the family’s income and lifestyle.

The reasons for unemployment (or a late return to work) include mobility issues, stump, and phantom limb pain, multiple limb amputations, as well as the inability to find a suitable job. Many of these reasons can be addressed and improved via therapies such as vocational counseling, PLP treatments (explained in a later section), prosthetic physical therapy, etc. . Rehabilitation is vital in the healing process for amputees and I will describe its importance in a later section.

To improve mobility it is important for an amputee to learn how to use prosthetics and assistive devices to their full potential. Amputees often feel discomfort with their prosthetics at first for reasons such as fear of social acceptance, delayed proprioception, and lack of confidence in the prostheses (Sinha et al., 2017). Learning how to put on and use prosthetic devices properly helps regain mobility and confidence.

## Current Theories and Treatments

Despite the long history and high prevalence of phantom limb pain in amputees, the etiology of PLP remains unknown. Although there is no widely accepted explanation for PLP, many theories have been backed with evidence as to why this sensation occurs. The most common theories identify the central nervous system as the main factor in PLP; however, some theories suggest the peripheral nervous system may play an important role as well. Although some treatment options have been effective in reducing PLP for some amputees, no single treatment has been identified as superior in effectiveness. Many treatment options that have seen the most success have been therapies that create a visual illusion that the amputated limb is still intact. Every amputee has their own unique experience with the cause of their amputation, the pain and sensations they experience as well as the therapy that works for them. It is important to understand that what works for one person may not work for the next, and that is why continued research is so important.

## Phantom Limb Pain Theories

### Brain Theories

#### Neuromatrix

An often cited cause of PLP is changes in the brain neuromatrix: a term coined by psychologist Ronald Melzack (Culp, 2022). Melzack describes pain as follows: “*Pain is a*

*multidimensional experience produced by characteristic “neurosignature” patterns of nerve impulses generated by a widely distributed neural network—the “body-self neuromatrix”—in the brain. These neurosignature patterns may be triggered by sensory inputs, but they may also be generated independently of them” (Melzack, 2001).* This theorized description suggests that pain does not always have to be a direct outcome of a sensory input, in instances such as PLP pain can occur independently of an input. The neuromatrix is a theoretical model of the brain that is used to explain the neural production of chronic pain. In this matrix, “pain is a central pattern of nerve impulses in the brain” (Culp, 2022). *“The neuromatrix, which is genetically determined and modified by sensory experience, is the primary mechanism that generates the neural pattern that produces pain.” “Injury does not merely produce pain; it also disrupts the brain’s homeostatic regulation systems, thereby producing “stress” and initiating complex programs to reinstate homeostasis” (Melzack, 2001).* Perception of pain has multiple influences and is also processed across several cortical areas. The disruption an amputee has on the body’s neuromatrix creates an imbalance.

### Cortical Remapping/Cortical Reorganization

Although the body is missing a limb, the portion of the brain that corresponds with that body region is still intact, causing a mind-to-body disruption. Cortical remapping theory (CRT) is a leading theory that describes the brain disruption of amputation. The somatosensory cortex is located at the anterior part of the parietal lobe and has the function of processing sensory information. A portion of the somatosensory cortex that once corresponded to the previously intact limb is now being infringed upon by input from a nearby region. This causes the brain to perceive sensations in the amputated limb. The cortical reorganization theory has been supported in upper-limb amputations using fMRI and other brain imaging techniques: “a shift in the

receptive fields within the sensory homunculus of the cortex is seen, and the areas previously adjacent to the region covering the arm (face and stump) take over that zone”(Richardson et al., 2018).

## Somatosensory Plasticity

The somatosensory system is the network of nerves in the body and brain that produces the perception of proprioception (awareness of body position and movement), temperature, touch, and pain. Plasticity is a term which means the “ability to change”. “Neuroplasticity (brain's ability to change) occurs through cellular changes due to learning and memorizing, but also within large-scale changes of cortical remapping in response to injury” (Askenasy & Lehmann, 2013). Plasticity appears to occur in the somatosensory area following an amputation since the nerves and brain signals adapt following an amputation. The brain can be mapped out to show its different portions and what part of the body it correlates to. When a limb or body part is no longer intact, there is a loss of sensory input to the somatosensory cortex associated with that limb. As a result, the input to nearby regions begin to activate the region originally associated with the amputated limb. In an experiment in 1984, adult monkeys had their middle fingers amputated and after two months the area that corresponded to the middle digit in the brain was taken over by sensory input from nearby fingers (Ramachandran, 1998). Neuroplasticity can be seen in other instances as well; “In stroke victims, for example, neuroplasticity allows the brain to rewire itself so that functions normally controlled by a damaged part of the brain can be taken over by another part of the brain” (Lasky, 2023).

A study that demonstrates the theory of somatosensory plasticity was of a 17-year-old whose left arm was amputated above the elbow after a motorcycle accident. In his case, he experienced telescoping: feeling that his hand was attached to his stump. In the tests, the individual closed his eyes while he was brushed with a cotton swab on his face. He described feeling the sensations on his amputated limb; his



cheek corresponded to his thumb, upper lip to the index finger, and chin to the little finger. This same patient was tested by dripping warm water on his face; without being prompted, the patient reported feeling the warmth on his phantom hand as well (Ramachandran, 1998). The digits and face are near each other on the somatosensory map of the brain which explains this “take-over”.

## Proprioceptive Memory

Another theory that has been used to explain the phenomenon of phantom limb pain is “proprioceptive memory”; the memory one has of limb position. As previously mentioned, proprioception is a sense that allows us to know where our body is positioned; such as being able to drive without having to look at our feet or to eat with utensils without having to look at our hands. With repetition, actions like these become automatic and become part of one’s “proprioceptive memory bank” (Anderson-Barnes et al., 2009). After an amputation, these “memories” remain in the brain and the nerves. It is theorized that there is a network of “pain memories” that act as a postural mechanism which protects our bodies from constant injury (Anderson-Barnes et al., 2009). If the body is in a painful position, the body knows how to relieve that pain by moving into a more comfortable position. For instance, if the foot is unnaturally inverted, the body understands that this is a painful position and would reposition to alleviate this pain. In a traumatic amputation -one where the limb removal occurs while the person is conscious- the pain is immediately stored as proprioceptive memories and comes back as phantom limb pain. The theory of proprioceptive memory is often used to support the frozen limb pain phenomenon as well, since there are memories of how the limb used to be positioned (Anderson-Barnes et al., 2009).

Wounded soldiers at Walter Reed Army Medical Center in Washington D.C. were asked about their experience of PLP. One soldier described the feeling that his phantom hand was in a position of pulling a trigger while another soldier described that his phantom foot felt like it was pushing against a solid object (Anderson-Barnes et al., 2009).

## Nerve Theories

### Dorsal Root Ganglion Abnormal Activity

Apart from PLP theories involving the brain, some theories describe the spinal cord as the root of the pain. Dorsal root ganglions (DRG) emerge from the dorsal root of the spinal cord. The role of this portion of the spinal cord is to carry receptors of pain. Post amputation, there are significant changes in the DRG; so dramatic that there are alterations in gene transcription and protein expression that occur within only a few minutes after the amputation (Culp, 2022). Once these neurons are altered dramatically -such as an amputation- there is an increase in excitability firing through axon terminals. Neuron injuries have been shown to increase spontaneous electrical discharges from DRG cells (Culp, 2022).

### Peripheral Nerve

The peripheral nerves are all the nerves that are outside of the central nervous system (brain and spinal cord) which relay information between the brain and the rest of the body. When a limb is lost, neurons that are damaged grow new extensions in an attempt to repair themselves. The nerve isn't able to fully repair because of the severed limb and instead, a neuroma is formed. A neuroma is a disorganized growth of cells that forms at the end of an amputation and can become painful. Stump pain is often explained using peripheral nerve theories since this pain is more localized and may be where the axon was severed. Nerve cells can regenerate; however, the distal aspect of the amputated limb can cause disorganization of the severed nerves and the fibers may increase their expression. Hyperexcitability -a state in which there are very strong

reactions to stimuli- may be exacerbated by outside factors such as temperature extremes (Culp, 2022).

## Treatment Options

It is evident that everyone experiences amputations differently; whether it be the type of pain, duration of pain, or even the psychological effect of the pain. In the same way that there are many PLP theories, there are also many treatment options that have been developed. Treatments that work for one individual, may not work for the next; that is why it is so important to explore new treatment options so that more amputees can find relief from PLP to live a comfortable and fulfilling life. Common treatments include mirror therapy, virtual reality, visual feedback, cortical stimulation, and surgical interventions.

### Mirror Therapy

Perhaps one of the best-known phantom limb rehabilitation options is mirror therapy (MT). MT is a technique that represents movement; using the reflection of the movement of the intact limb creates a visual illusion of non-painful movement in the amputated limb (Barbin, 2016). The mirror box is a method in which a mirror is placed vertically in a box that has an open end on the top for viewing and another opening at the front so that the hands can be placed in. Once the patient puts their in-tact hand on one side, seeing the reflection creates the illusion that the amputated hand has been resurrected (Ramachandran, 1996). This sensory feedback of “seeing” the phantom limb move allows the corresponding cortical areas to make a mind-body connection; whether it be sensations of clenching, cramping, twisting, frozen, etc. . Although the

concept of MT is consistent, there could be small adjustments in how the therapist sets up the MT depending on the patient and which limb is amputated. A meta-analysis performed by World Neurosurgery concluded that out of twenty-two studies including 662 patients with 13 different interventions, mirror therapy was found to be the most effective treatment for PLP.

A patient studied by Ramachandran in 1993 had lost his left arm and had continuous excruciating phantom pain for 11 years. During his mirror therapy though, he was able to see and feel his phantom limb move and had instant pain reduction. His therapy was continued at home for two weeks, 10 minutes each day. After three weeks his phantom pain had been alleviated yet finger telescoping remained (Ramachandran, 2008).

Another patient studied in 1996 was a 55-year-old man with a left above-elbow amputation. He experienced involuntary clenching spasms with “fingernails digging into the palm” which took over an hour to relieve. In his first session of mirror therapy, he felt that all his movements “came back” after seven months of PLP. The patient was able to unclench his hand immediately when using the box and the spasm vanished completely (Ramachandran, 1996).

*“MT tricks the brain into thinking the affected limb is moving the same way as the unaffected limb. It does this by triggering motor neurons within the brain to fire just as they would if the patient were actually moving his or her limb” (Lasky, 2023). Mirror therapy relies on neuroplasticity: the brain's ability to change and adapt as conditions require. “The brain's neuroplasticity is activated by MT through special cells called mirror neurons. Neurons are cells that transmit nerve impulses. When motor neurons fire in the brain, they tell muscles in the body to move. Mirror neurons are located in the same part of the brain as motor neurons. Unlike motor neurons, however, mirror neurons fire when a person sees movement. For example, a person's mirror neurons fire when he or she sees another person move” (Lasky, 2023).*

## Virtual Reality

Virtual reality (VR) is a more modern therapeutic approach, yet it still has the same basis as MT in the way that the purpose of VR is to give the illusion that the amputated limb is still there to release the pain the brain communicates with the body. Mechanisms that VR therapy uses to improve include relaxation, distraction, social connection, and engagement (Rutledge, 2019). The difference between VR and MT is that VR is more customizable for the individual (more patient-centered) which is very important for improvement as well as ensuring adherence to the therapy. Oxford conducted a VR study that included participants from the Veterans Affairs San Diego Healthcare System using VR technology in an environment with a VR headset and a stationary bike. The participants rated the VR highly in immersion, realism, helpfulness, acceptability, and fun. The results had significant reductions in PLP and phantom sensation (Rutledge, 2019).

*The experiment developed three distinct VR environments involving the use of a basic bicycle pedaler while wearing the VR headset and a single motion sensor (developed by the VR contractor) attached to the pedal containing the participant's prosthesis. This combination allowed the participant to bicycle on the pedaler at their preferred pace in the VR environment of their choice while wearing the VR headset, with the motion sensor precisely calibrating the cadence of the VR avatar to that of the participant. (Rutledge, 2019).*

Virtual reality has been seen to decrease pain severity in both brief/single-use as well as repeated/long-lasting use. VR treatment can alleviate PLP in a therapeutic mechanism such as relaxation or distraction; or promote cortical reorganization after repeated usage. In a 2018 review, VR was used to

provide distraction from acute pain from electrical, thermal, and pressure conditions. The analysis concluded that VR allows for patients to be immersed in interaction and distracts the individual from perceiving pain (Pourmand et al., 2018).

Although virtual reality has shown high levels of immersiveness, customizability, and decreasing costs; there is much more research and development to be done. Current findings have been positive yet have been confined to small sample sizes and limited to case studies. Higher-quality studies and further research are necessary to explore the benefits of VR (Dunn et. al., 2017).

### Cortical Stimulation

A different treatment approach that has been explored is chronic subdural cortical stimulation; a method that involves a permanently implanted electrode plate to provide chronic electrical stimulation in the brain. The procedure was the implantation of an electrode array, followed by permanent spinal leads and an internalized pulse generator (Krushelnysky, 2019). Based upon a case report from *Acta Neurochirurgica*, a patient with nearly 60 years of PLP (with no success from any other treatment) experienced sustained relief after 6 months of cortical stimulation. Although a different case that was studied did not reach this same level of success, it is still very important to keep an open mind about different available treatment approaches that are being explored since every amputee has a different rehabilitation journey.

### Surgical Treatments

There has been a history of evidence that demonstrates non-surgical treatment has more success in treating phantom limb pain than surgical. Yet, in the past decade especially, there have been great surgical advancements that have opened up the possibility of new treatment options that focus on the prevention of neuroma formation. Two popular reconstruction techniques are targeted muscle reinnervation (TMR) and regenerative peripheral nerve interface (RPNI). In

TMR; “the residual peripheral nerve is transferred to the stump of a nerve innervating a native muscle with a dispensable biomechanical function.” In other words, the severed nerve is rerouted to a new muscle to innervate. In the RPNI procedure, “longitudinally dissecting the severed nerve into its main fascicles, which are then implanted into free muscle grafts” (Pettersen et al., 2023). These surgeries help prevent neuromas, lessen PLP, and improve the use and control of prosthetics.

A surgical approach requires a patient to undergo surgery which comes with the general risks of failure, infections, wound healing, etc.. Having surgical options available is helpful for the population of amputees that have not found success in non-surgical therapies.

## Pharmaceuticals

Although pain-relieving medications have risks of unwanted side effects, addiction, and may only be temporary relief; for some cases using the pharmaceutical route (along with non-drug treatment) is the best plan of action. Even though the pain is phantom, painkillers still block pain receptors in the spinal cord or the reuptake of serotonin-norepinephrine. Since most trials that experiment with the effect specific drugs have on PLP are small sample groups and have conflicting results, it is difficult to come up with a conclusion. For instance, ketamine has proven to reduce pressure pain but has long-term side effects while Memantine had an early reduction of PLP but is not lasting (Hall & Eldabe, 2018). Pharmaceuticals are often the quickest and easiest pain treatment, but it is important for amputees to know their options and explore non-drug treatments as well to ensure long-lasting relief.

# Importance

As described in previous sections, phantom limb pain and the impact of this sensation is a very real and impactful effect that the majority of amputees experience. Despite the prevalence and major impact, the public (and even the amputee community) have minimal understanding of this phenomenon. It is important to learn about PLP so that there is a greater general understanding which encourages further research to be explored. Research is what allows for the discovery of new and improved treatments so that amputees who experience PLP can find a way to relieve their pain.

## Rehabilitation and Medical Professionals

Amputation is a disability that impacts an individual greatly in many aspects of their life. It is vital for amputees to receive help in many forms so that they can live high-functioning and enjoyable lives. As previously explained, many treatment options help alleviate phantom limb pain; there are also other recovery resources that are helpful for amputees to improve other aspects of their lives.

*“The goal of rehabilitation after an amputation is to help the patient return to the highest level of function and independence possible while improving the overall quality of life—physically, emotionally, and socially” (Stanford Medical Center, 2017).*

“Quality of life (QoL) is increasingly being recognized as an important outcome for rehabilitation programs, and has mainly been used to compare the efficacy of interventions” (Sinha et. al, 2017). Rehabilitation begins immediately after surgery in an acute setting and longer rehab programs can begin after the patient's condition improves. After the amputation,



many healthcare providers are assisting the individual; such as rehab nurses with immediate care, physical and occupational therapists with progress goals, surgeons with aftercare information, prosthetists with sizing and customizing prosthetics, etc. It is very important for amputees to stretch and exercise their amputated limb as soon as possible so that they can gain strength, balance, and mobility. It is very common for an amputation to cause contractures (muscle shortening) which limit the range of motion and cause ill-fitting prosthetics. Skilled rehab nurses and therapists teach and administer stretches and movements to avoid contractures. These health professionals teach the patient about their amputation so that once they leave the acute care they can continue their care and exercises on their own. Education, communication, and transparency are very important aspects of rehabilitation.

Outside of the hospital, rehabilitation continues in many different forms that address many aspects of life such as pain management, prosthetic use, home adjustments, psychological health, support groups, vocational counseling, and educating the family. Reaching a high level of independence requires a variety of rehabilitation with the help of many healthcare professionals. It is crucial for people with amputations to be aware of the assistance and resources available, no one has to be alone in this journey.

## Awareness

Awareness allows individuals to understand themselves and others on a deeper level. Having multiple perspectives leads a person away from assumptions and biases which allows for greater inclusion. Non-amputees aren't able to fully understand what life is like for a person with limb differences; yet, learning about different experiences and sensations will allow for a greater understanding of amputations. The more the public is aware of amputations and their impact

(such as phantom limb pain, distorted body image, depression, isolation, etc.), the more involvement, funding, research, and interest in healthcare may be possible. According to Amputee Coalition (a national nonprofit organization), by 2050 the number of amputees in the U.S will nearly double. It is important to be aware of the large number of people that will be impacted by limb loss, which affects people of all backgrounds, incomes and ages.

## Conclusion

The loss of a limb is a life-altering disability that impacts an individual in many aspects of their life. Phantom limb pain is a phenomenon that is an extremely common effect of amputation, yet the understanding is limited. This pain can be excruciating and lasts years which greatly impacts the quality of life for an individual. Fortunately, some treatments have been proven to alleviate the phantom pain. With continued research, more treatments can be explored which will help many more amputees alleviate this chronic pain. PLP (and amputations in general) creates psychological struggles and provokes strong emotions since losing a limb is such an impactful disability. It is important to understand that emotional and physical reactions oftentimes follow an amputation and that there are healthcare providers and procedures to help. Awareness and education of the public are very important so that additional efforts and funding can go towards research to ensure amputees get help and live a high-quality lifestyle.

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