

UNDERSTANDING PHANTOM LIMB TELESOPING:
A MULTIMETHOD EXAMINATION OF PHENOMENOLOGY,
PAIN RELATIONSHIPS, AND PSYCHOSOCIAL CONTEXT

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Abstract

Objective: The aim of this dissertation was to examine phantom limb telescoping in individuals with limb loss and explore its relationship to key pain and mental health-related outcomes.

Method: Study 1 presents a narrative review with a systematic search of the existing literature on phantom limb telescoping. Study 2 is a case report of an individual recruited from St. John's Rehab in Toronto who completed online questionnaires and an optional interview as part of a larger study. Studies 3 and 4 draw on this broader participant pool, examining quantitative data from questionnaire responses ($N = 51$) and qualitative data from semi-structured interviews from a subset of the larger sample ($N = 12$), respectively. Quantitative measures included ratings of phantom and residual limb pain intensity, telescoping, pain interference, pain catastrophizing, neuropathic pain, pain acceptance, anxiety and depression, optimism, and resilience. Interviews explored participants' perceptions, interpretations, and adaptations related to their phantom limb and telescoping experiences.

Results: Study 1, the narrative review, synthesized findings from 100 studies that investigated or reported phantom limb telescoping. It identified key themes, patterns, limitations, and gaps, as well as potential avenues for future study to better understand the mechanisms of telescoping and its relationship to post-amputation pain, among other factors. In Study 2, the case report suggested that the onset of telescoping was preceded by a reduction in phantom limb pain intensity, raising the possibility that telescoping may be associated with lower pain levels compared to a normally perceived phantom limb length. Study 3 revealed significant differences between participants who reported telescoping and those who did were not found for phantom limb pain intensity, residual limb pain intensity, or pain interference. However, greater telescoping was associated with lower pain interference and lower phantom limb pain intensity.

Participants who reported telescoping also endorsed higher symptoms of anxiety and depression compared to those who reported a normal length phantom limb. In Study 4, telescoping was experienced as a dynamic and individualized process shaped by emotional, social, and contextual influences, extending beyond sensory changes to encompass meaning-making, adaptation, and identity.

Discussion: Across four studies, this dissertation provides a more integrated understanding of phantom limb telescoping as a sensory, psychological, and contextual experience. The narrative review (Study 1) highlighted persistent gaps in knowledge and inconsistent findings regarding mechanisms and pain. The case report (Study 2) and quantitative results (Study 3) suggested that greater telescoping may be associated with lower phantom limb pain intensity and reduced pain interference, while also co-occurring with higher anxiety and depression symptoms. The qualitative findings (Study 4) underscored that telescoping is experienced in highly individualized ways, shaped by emotional factors, personal meaning, and ongoing adaptation. Collectively, these studies demonstrate that telescoping cannot be understood solely as a perceptual change; instead, it reflects an interaction between bodily sensation and psychological processes. Clinically, normalizing discussions about telescoping may help reduce uncertainty for individuals with limb loss and support more holistic rehabilitation care.

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Chapter 1: Introduction

Section 1: Introduction to Limb Loss

Limb loss is a life-altering condition that affects millions of individuals worldwide and represents a significant public health, rehabilitation, and psychosocial concern (Xu et al., 2024). Contemporary research increasingly conceptualizes limb loss not as a discrete surgical outcome, but as a complex biopsychosocial condition with enduring sensory, psychological, and functional consequences (Gallagher & Maclachlan, 2004). The loss of an upper or lower limb involves profound changes to bodily integrity, sensory experience, identity, and participation in daily life, with effects that extend well beyond the immediate medical context (World Health Organization, 2011).

Limb loss can occur across the lifespan and arises from a variety of medical, traumatic, and congenital causes. It is considered when part of the limb is unsalvageable (e.g., due to infection), deadly (e.g., the life of the individual is threatened if the limb is retained), or quality of life would improve if the limb were amputated (Qaarie, 2023). Although advances in medical care, surgical techniques, and rehabilitation have improved survival and functional outcomes, individuals with limb loss often face long-term challenges that evolve over time. Understanding the common causes of limb loss and its broad implications is therefore essential for contextualizing the lived experience of limb loss and for appreciating the complexity of adaptation afterwards.

Common causes of limb loss

In North America, the most common cause of acquired limb loss is vascular disease, accounting for approximately 90% of cases (Rivera et al., 2024). This category includes complications associated with diabetes mellitus and peripheral arterial disease, which may result

in chronic ischemia, infection, and non-healing wounds. Diabetes-related limb loss is particularly prevalent and reflects the combined effects of neuropathy, impaired circulation, and delayed wound healing. Despite this high prevalence, individuals with vascular-related limb loss are underrepresented in research samples, where they typically comprise only 10-30% of a participants (Diers et al., 2022; Giummarra et al., 2010; Griffin et al., 2022; Sarvestani & Azam, 2013). This discrepancy is likely due to selection and participation biases, as individuals with vascular etiologies tend to be older, have greater medical complexity (e.g., multiple comorbid conditions), factors that can complicate rehabilitation and reduce the likelihood of research recruitment or participation (Dillingham et al., 2002).

Traumatic injury represents the second most common cause of limb loss, accounting for approximately five percent of cases (Rivera et al., 2024). Traumatic limb loss may result from motor vehicle collisions, occupational or agricultural accidents, military combat, or natural disasters. Compared to vascular causes, trauma-related limb loss more frequently affects younger individuals and is often sudden and unexpected. The abrupt nature of traumatic limb loss can intensify both physical and psychological adjustment demands, as individuals must adapt not only to limb loss itself but also to the broader consequences of sudden traumatic injury (Horgan & MacLachlan, 2004). In comparison to other causes of amputation, individuals who have lost a limb due to an accident or combat-related injury are at the highest risk of developing problems post-amputation, including post-traumatic stress disorder and post-amputation pain. Despite representing a relatively small proportion of limb loss cases overall, individuals with trauma-related limb loss are overrepresented in research samples, where they comprise approximately 50% of participants (Diers et al., 2022; Giummarra et al., 2010; Griffin et al., 2022; Sarvestani & Azam, 2013). This overrepresentation is likely due to recruitment and participation factors, as

trauma-related limb loss often involves younger individuals with fewer medical comorbidities, greater motivation to address high post-amputation pain, and higher likelihood of engagement in research and rehabilitation settings.

Cancer accounts for a smaller proportion of limb loss cases, estimated at approximately one percent (Rivera et al., 2024). Limb loss related to cancer typically occurs when malignant tumors of bone or soft tissue cannot be effectively treated using limb-sparing procedures. Although advances in oncologic care have reduced the frequency of cancer-related limb loss, it remains a necessary intervention in certain cases to preserve life. Individuals undergoing limb loss due to cancer often face the combined physical and emotional burden of cancer treatment and functional adaptation (Bowman et al., 2020). Despite its low prevalence, cancer-related limb loss typically accounts for approximately 10% of participants (Diers et al., 2022; Giummarra et al., 2010; Griffin et al., 2022; Sarvestani & Azam, 2013). This discrepancy may reflect recruitment patterns within specialized oncology and rehabilitation settings, as well as greater clinical stability at the time of research participation compared to individuals with vascular etiologies.

Congenital limb deficiencies, in which an individual is born with partial or complete absence of a limb, also represents less than one percent of limb loss cases (Rivera et al., 2024). Causes may include genetic factors, maternal exposure to viruses or chemicals, or vascular issues occurring during fetal limb development (Ephraim et al., 2003). Unlike acquired limb loss, congenital absence of a limb does not involve the loss of a previously present limb, and individuals often develop adaptive strategies from early childhood. Nevertheless, the congenital absence of a limb can present functional, social, and psychological challenges, particularly during developmental transitions such as adolescence or early adulthood (Ephraim et al., 2003).

Less commonly, limb loss may result from severe infection, frostbite, or other acute medical emergencies. Although these causes account for a relatively small proportion of cases, they underscore the diverse pathways through which limb loss can occur.

Physical and functional implications

The physical consequences of limb loss extend beyond the absence of the limb itself. Individuals with limb loss often experience enduring changes in mobility, balance, coordination, and overall physical function, particularly following lower-limb loss (van Velzen et al., 2006). Activities that were previously automatic, such as walking, standing, or navigating uneven terrain, may require substantial effort, adaptation, and relearning. Upper-limb loss can affect fine motor control, bilateral coordination, and the ability to perform daily activities such as dressing, cooking, and writing (Cordella et al., 2016).

Limb loss is also associated with broader musculoskeletal and biomechanical changes. Altered movement patterns may place increased strain on remaining joints and muscles, contributing to secondary conditions such as joint degeneration, muscle overuse, and postural asymmetries over time (Roeder, 2008). Energy expenditure during movement, particularly during ambulation with a prosthesis, is often elevated relative to individuals without limb loss, which can contribute to fatigue and reduced endurance (Roeder, 2008).

Rehabilitation plays a critical role in addressing these physical challenges. Physical and occupational therapy aim to support functional independence, optimize movement efficiency, and promote long-term health. The use of assistive devices or prosthetic technology can enhance function, but successful integration requires sustained training, individualized fitting, and ongoing adjustment as functional needs change (World Health Organization, 2011).

Psychosocial and emotional implications

In addition to physical changes, limb loss has significant psychological and emotional implications. Individuals often experience grief related to the loss of a limb, including feelings of sadness, anger, anxiety, or disbelief. These responses are not uniform and may fluctuate over time, particularly in response to medical complications, functional setbacks, or changes in social roles (Belon & Vigoda, 2014; Dadkhah et al., 2013; Dise-Lewis, 1989).

Anxiety and depressive symptoms are commonly reported following limb loss, especially during the early stages of adjustment. Concerns related to independence, employment, financial security, and future health are frequent and understandable. Changes in body image and self-concept may also emerge as individuals adapt to a body that feels unfamiliar or altered (Gallagher & Maclachlan, 2004). Importantly, psychological adjustment to limb loss is increasingly understood as an ongoing, dynamic process rather than a finite stage of recovery (Senra et al., 2012).

Social context and the biopsychosocial framework

Social and environmental factors play a critical role in shaping the lived experience of limb loss. Access to rehabilitation services, prosthetic care, transportation, and environmental accommodations can substantially influence functional outcomes and quality of life. Cultural attitudes toward disability, visibility of limb difference, and experiences of stigma or discrimination may further affect social functioning and psychological well-being (World Health Organization, 2011). Social support networks, including family, peers, and community resources, also contribute meaningfully to adjustment by buffering stress and facilitating engagement in rehabilitation and daily activities. Conversely, structural barriers and inequities in healthcare access may compound functional limitations and psychosocial distress over time.

Taken together, these biological, psychological, and social dimensions underscore the importance of conceptualizing limb loss as a biopsychosocial condition with enduring and interacting consequences. This framework provides essential context for understanding the complex sensory and perceptual experiences associated with limb loss, which will be addressed in subsequent sections of this dissertation.

Section 2: Phantom Limb Phenomena

Following limb loss, many individuals report a range of experiences involving the continued perception of the missing limb. In some cases, individuals awaken from anesthesia following amputation surgery with a vivid and compelling sense that their limb is still present (Katz, 2000). Some only realize it has been removed when they attempt to see or touch it. This realization does not diminish the perceived presence of the limb and may, in some cases, intensify the sensations associated with it. Collectively referred to as phantom limb phenomena, these experiences reflect complex interactions between sensory processing, motor representation, cognition, and embodiment. Phantom limb phenomena are not pathological in themselves and are widely considered a common and expected consequence of limb loss rather than an unusual complication (Flor, 2002). Importantly, these experiences are heterogeneous, varying widely across individuals in form, intensity, emotional salience, and functional impact.

Descriptions of phantom limb experiences have appeared in medical writings for centuries. The phenomenon was first documented in 1545 by the French surgeon Ambroise Paré and later discussed by Descartes (Katz, 2000). However, it was Weir Mitchell who formally coined the term “phantom limb” in 1871 and subsequently provided the first systematic account of phantom limb experiences in his seminal work on nerve injuries (Satz, 2010). The term

continues to be used today because it so precisely captures the subjective reality of the phenomenon (Katz, 2000). It has gained widespread acceptance among researchers, clinicians, individuals with limb loss, and the broader public.

Phantom limb phenomena are typically conceptualized as encompassing non-painful phantom limb sensations, phantom limb pain, and experiences related to the residual limb. Although these phenomena are often discussed together, they are phenomenologically and clinically distinct and may have different underlying mechanisms and implications. The sections below provide an overview of each, beginning with non-painful phantom limb sensations.

Non-painful phantom limb sensations

Phantom limb sensations refer to the perception of the missing limb in the absence of pain. These sensations are reported by the majority of individuals with acquired limb loss, with prevalence estimates of approximately 80% (Flor, 2002; Jensen et al., 1984). Sensations that define the non-painful phantom limb are typically described as “pins and needles”, “tingling”, and “numb”, collectively known as paresthesias, though other sensations may also be present. These sensations are so common that they are considered to be “normal” consequences of amputation (Katz, 2000). For some individuals, these phantom sensations disappear within days or weeks after amputation. For most others, these sensations persist long term, although their intensity, clarity, and salience may fluctuate over time.

Individuals frequently report a vivid sense of the presence of the limb, including its perceived position, posture, and orientation in space. For example, a person may experience the phantom limb as resting in a familiar or habitual position, such as a hand resting on the lap or a foot contacting the ground. These passive positional sensations can correspond to the limb’s last remembered configuration prior to limb loss, suggesting continuity in internal body

representations (Anderson-Barnes et al., 2009) as well as the involvement of memory-like mechanisms (Katz, 2000). Some individuals also report a sense of voluntary, active movement of the phantom limb, even in the absence of visual feedback or motor output (Ramachandran & Hirstein, 1998).

In addition to spatial and postural qualities, phantom limb sensations may include perceived temperature, weight, pressure, or texture (Schone et al., 2022). Individuals may describe the phantom limb as feeling warm or cold, heavy or light, itchy, or present with a vague sense of contact or resistance. These experiences underscore the persistence of sensory qualities associated with the limb despite the absence of peripheral input.

Phantom limb sensations are often experienced as neutral and, in some cases, reassuring, particularly in the early stages following limb loss, as they may preserve a sense of bodily continuity. For others, however, these sensations can be confusing or disorienting, especially when there is a mismatch between felt and visual information. Importantly, the presence of phantom limb sensations alone does not imply distress or dysfunction, and many individuals adapt to these experiences without clinical intervention. Nevertheless, the distinction between non-painful and painful sensations can be fluid; for example, itching may be reported as non-painful by some but bothersome or even painful by others (Schone et al., 2022). When paresthesias become intense, they are referred to as dysesthesias, which often cross the line from discomfort to pain. This suggests that such sensations may exist on a continuum of intensity (McMahon & Koltzenburg, 2005). Understanding this continuum provides an important foundation for examining the onset, characteristics, and impact of phantom limb pain, which represents the more clinically significant end of this spectrum.

Phantom limb pain (PLP)

For many individuals who have lost a limb, phantom limb pain is the cause of much distress. Phantom limb pain (PLP) refers to painful sensations perceived as arising from the missing limb, rather than from the residual limb (e.g., the part of the limb remaining after the amputation) or surrounding tissue. PLP is commonly described using a variety of sensory qualities, including sharp, electric, shooting, stabbing, throbbing, burning, and aching sensations (Hill, 1999). For example, some individuals describe PLP as sharp, shooting sensations that travel up and down the phantom limb, or as a burning pain, as if their phantom foot or hand were held close to a flame. Others experience the phantom limb in an unnatural or contorted posture, which can provoke severe, sometimes excruciating pain. Many people report pain memories, which are sensations of pain in their phantom limb that mirror the type of pain they experienced prior to amputation (Katz & Melzack, 1990). For instance, lingering soreness from pre-amputation diabetic ulcers, pressure from a crush injury, ingrown toenails, or joint pain. These experiences highlight the highly individualized, emotionally charged, and often vivid nature of PLP. In contrast to non-painful phantom sensations, PLP can significantly interfere with quality of life, mood, sleep, and daily functioning (Ephraim et al., 2005).

Prevalence estimates for PLP vary widely, commonly ranging from 50–80% of individuals with acquired limb loss, depending on factors such as time since limb loss, assessment methods, and sample characteristics (Ephraim et al., 2005; Flor et al., 2006). Some prevalence estimates are as high as 87% (Stankevicius et al., 2021). PLP may emerge immediately following limb loss or develop weeks, months, or even years later. For some individuals, symptoms diminish over time, whereas for others they persist or fluctuate across the lifespan.

The subjective experience of PLP is highly variable. Individuals may report intermittent or continuous pain episodes that differ in duration, location, quality, and intensity (Schone et al., 2022). In some cases, the pain may be triggered or exacerbated by movement, temperature, or even emotional stress. Notably, the presence and severity of PLP are not reliably predicted by the extent of tissue damage or by the medical circumstances surrounding limb loss, underscoring the limitations of explanations that focus solely on peripheral mechanisms. These observations highlight how PLP can be influenced by a variety of factors including some that are biological (e.g., cortical reorganization and residual limb conditions), psychological (e.g., attention, anxiety, depression, and coping strategies) and social (e.g., support networks and environmental context) (Ephraim et al., 2005; Flor et al., 2006). From a clinical standpoint, PLP is distinguished from non-painful phantom sensations by its functional and emotional impact, rather than by the mere presence of it.

Despite decades of research and the development of more than 50 different treatment approaches, PLP remains notoriously difficult to manage (Aternali & Katz, 2019b). More recent studies have investigated interventions such as targeted muscle reinnervation, repetitive transcranial magnetic stimulation, imaginal phantom limb exercises, mirror therapy, virtual and augmented reality, and eye movement desensitization and reprocessing therapy. Yet, the results indicate that not one of these treatments is consistently better than a control condition (Aternali & Katz, 2019b). The challenge is compounded by the heterogeneous nature of PLP. Intensity, quality, and triggers of PLP vary widely not only between individuals but even within the same person over time. This variability makes it difficult to predict which interventions might be effective, highlighting the need for continued research into personalized, multimodal approaches that address the complex neurobiological, psychological, and social factors underlying PLP.

Residual limb pain (RLP)

Residual limb pain (RLP) refers to pain localized to the remaining portion of the limb, rather than to the absent limb itself. Although it is frequently discussed alongside PLP, RLP is not a phantom phenomenon. Nevertheless, it constitutes an important component of the overall sensory experience following limb loss as it is the most common factor positively associated with PLP (Schone et al., 2022). As such, RLP may interact with phantom experiences in clinically meaningful ways.

RLP may arise from multiple sources, including surgical healing processes, musculoskeletal strain, skin irritation, or nerve-related factors. It is often influenced by prosthetic fit, activity level, and changes in residual limb volume over time. Unlike PLP, RLP is typically associated with identifiable peripheral contributors, although central processes may also contribute to its persistence (Flor et al., 2006).

The prevalence of RLP is substantial, with estimates suggesting that 20-70% of individuals with limb loss experience RLP at some point following surgery, with an intensity greater than that of PLP (Schone et al., 2022). For some individuals, RLP resolves as healing progresses, whereas for others it becomes chronic and functionally limiting.

Clinically, distinguishing RLP from PLP is critical, as these experiences often require different assessment approaches and intervention strategies. However, individuals may experience both concurrently, and the presence of RLP can amplify overall distress and complicate rehabilitation. As such, RLP should be understood as a related but distinct aspect of the limb loss experience rather than being included under phantom limb phenomena.

Taken together, phantom limb phenomena encompass a wide range of sensory experiences that reflect the continued representation of the limb following amputation. While

some are considered “normal” and to be expected following limb loss, other sensations can elicit significant distress and discomfort. Non-painful phantom limb sensations, PLP, and RLP represent distinct yet often co-occurring experiences, each with unique phenomenological characteristics and clinical implications. Clarifying these distinctions provides an essential foundation for understanding the lived experiences of individuals with limb loss and sets the stage for examining more specific phenomena, such as phantom limb telescoping, which is described in the following section.

Section 3: Phantom Limb Telescoping

In addition to non-painful phantom limb sensations and PLP, individuals with limb loss may experience another distinct form of phantom sensation called phantom limb telescoping, which is believed to arise from different underlying mechanisms than non-painful phantom sensations and PLP. Telescoping occurs when the perceived length of the phantom limb shortens over time. For some individuals, this process unfolds gradually, with progressive alterations in the perceived size and position of the phantom limb, whereas for others it occurs more abruptly, with noticeable changes emerging over a relatively short period. Rather than being experienced as a sudden disappearance of the phantom limb, telescoping is typically characterized by a perceptual transformation in which proximal portions of the phantom limb diminish in clarity or presence while distal segments (e.g., the hand or foot) remain perceptually salient. As this process continues, the phantom limb may be perceived as retracting toward the residual limb, sometimes being perceived as if directly attached to it or partially contained within it.

Telescoping has attracted sustained clinical and scientific interest since it was first described by

Guéniot (1868), owing to its striking phenomenology and its implications for understanding body representation following limb loss.

Telescoping terminology: Definition of variations in phantom limb length

Throughout this dissertation, a phantom limb is defined as the sensation of a missing limb following limb loss. A normal length phantom refers to the perception of the phantom limb as being the same length as the individual's contralateral intact limb or the length of the limb prior to limb loss, as illustrated in Figures 1A and 1D. A partially telescoped phantom limb or partial telescoping is defined as the perception of a phantom limb that is shorter than normal (Figures 1B and 1E). A completely telescoped phantom limb is defined as the perception that the phantom hand or foot is located entirely within the residual limb, with no portion extending beyond it, as shown in Figures 1C and 1F. The term telescoping or telescoped phantom is used to describe any phantom limb perceived as shorter-than-normal, regardless of its perceived distance from the residual limb.

Proposed mechanisms underlying telescoping

The mechanisms underlying telescoping are not fully understood, though several explanatory models have been proposed. Early theoretical accounts emphasized the role of a use-dependent process of cortical reorganization in shaping the perceptual experience of telescoping (Katz, 1992; Katz & Melzack, 2003). Following limb loss, sensory regions of the brain that previously processed input from the missing limb no longer receive their typical afferent signals. These deprived cortical areas may undergo use-dependent neuroplastic changes, including re-occupation by neighboring body part representations from the distal areas of the residual limb. This re-occupation is thought to proceed from proximal to distal regions and to be reflected perceptually, such that as increasing portions of cortical tissue are re-assigned, the phantom hand

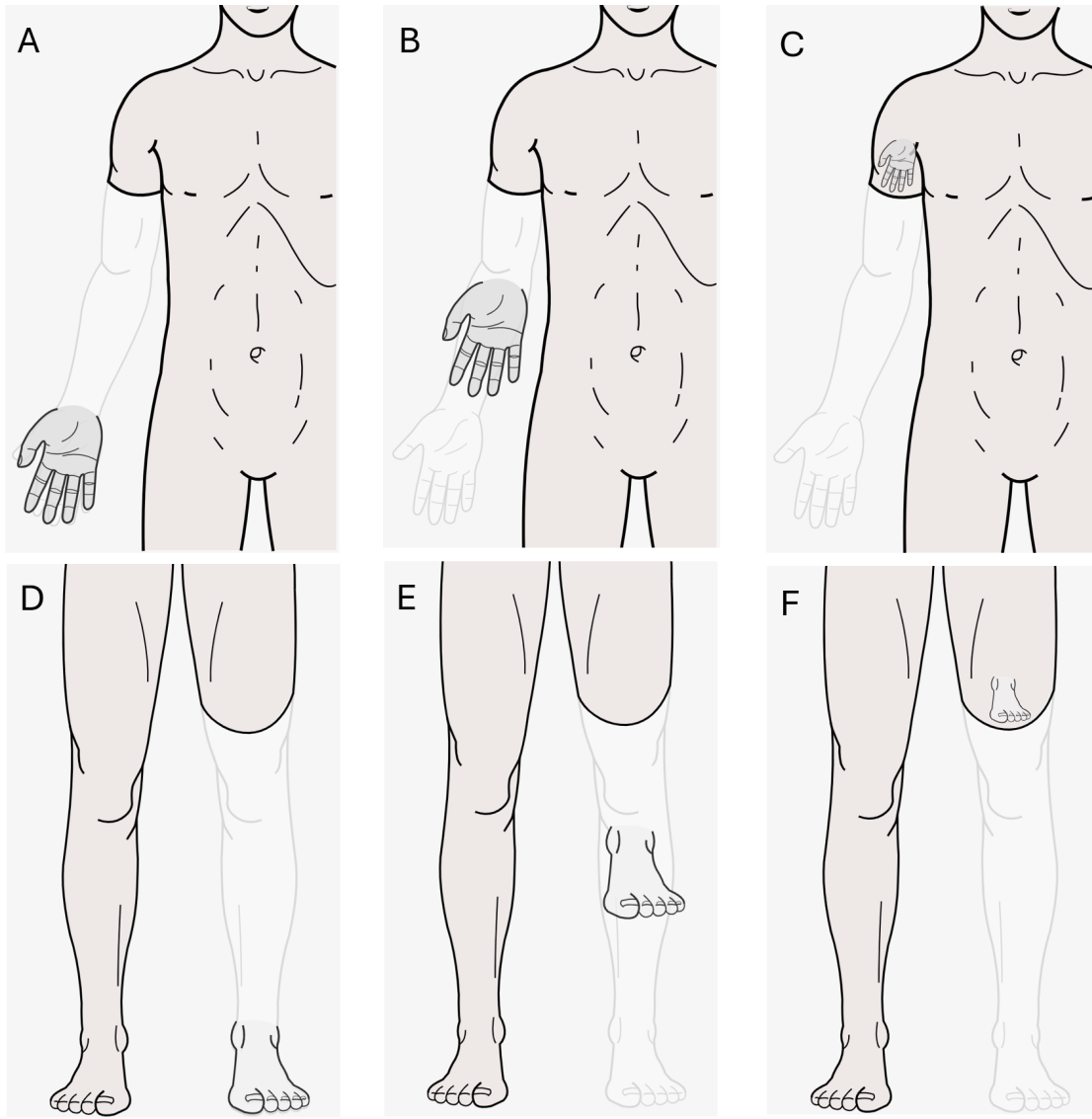


Figure 1. Examples of telescoping in upper and lower phantom limbs: (A) normal length upper limb, (B) partially telescoped upper limb, (C) completely telescoped upper limb, (D) normal length lower limb, (E) partially telescoped lower limb, and (F) completely telescoped lower limb. Illustrations were generated at <https://demo.phantomlimbs.ca/>. Note that the partially telescoped phantom limbs shown in (B) and (E) are only one instance of partial telescoping which include any phantom limbs that are shorter than the normal length phantom limbs shown in (A) and (D) (i.e., in which the distance between the phantom extremity and residual limb is less than the distance between the extremity and residual limb of a normal length phantom).

or foot is experienced as gradually and proportionally moving closer to the residual limb.

Accordingly, the perceived length and size of the phantom limb have been conceptualized as perceptual indicators of the extent to which sensory input from the residual limb has taken over previously deprived cortical areas (Katz, 1992; Katz & Melzack, 2003).

Although cortical reorganization has been a dominant explanatory model, other accounts emphasize the role of sensory incongruence and multisensory integration. From this perspective, telescoping arises in part from mismatches between visual, proprioceptive, and tactile information. After limb loss, visual confirmation of the limb is absent, while proprioceptive and somatosensory signals associated with limb position are altered or incomplete, or biased toward the residual limb. In resolving this incongruence, the nervous system may preferentially weigh more proximal sensory input. As a result, the internal representation of the limb may progressively contract toward the residual limb, yielding the perception of a phantom that is shorter than its pre-amputation length, rather than arbitrarily extended or reoriented.

Peripheral mechanisms have also been proposed as contributing factors. Spontaneous activity in severed nerves that have regenerated and formed neuromas, changes in afferent input from nerve fibers in the residual limb, or alterations in how sensory signals are weighted may bias perception toward distal limb segments, such as the hand or foot. When these distal sensations are experienced in the absence of corresponding proprioceptive or visual cues specifying limb length, the perception of the phantom limb may become increasingly dissociated from a full limb representation. Over time, interactions between peripheral input and central processes may favour a perceptual ‘collapse’ of the phantom toward the body, shaping the phenomenology of telescoping, rather than a random alternation of phantom limb perception.

In addition to neurophysiological mechanisms, psychological and contextual factors may influence how telescoping is experienced and reported. Attention directed toward the phantom limb, emotional responses to limb loss, and individual differences in coping styles may modulate the salience and interpretation of perceptual changes. Importantly, these factors do not imply that telescoping is psychological in origin, but rather highlight the role of higher-order processes in shaping bodily awareness and perception (Gallagher, 2006; Giummarra et al., 2010).

Variability and clinical significance

One of the defining features of phantom limb telescoping is its marked variability. Not all individuals with phantom limbs experience telescoping, and among those who do, the timing, extent, and stability of the phenomenon differ substantially. Telescoping may occur soon after limb loss, emerge gradually over months or years, or fluctuate across time. For some individuals, the experience is subtle and easily accommodated, for others it is abrupt and destabilising, whereas still others perceive it to become a salient, integrated, and enduring aspect of bodily experience.

This variability has made telescoping both challenging to study and theoretically informative. As a perceptual phenomenon that unfolds over time, telescoping offers a unique window into the processes by which the nervous system maintains, updates, and reorganizes representations of the body following profound physical change. Understanding telescoping as an experience in its own right, rather than solely in relation to clinical outcomes, allows for a more nuanced appreciation of the ways in which individuals adapt to limb loss.

At the same time, the marked heterogeneity of telescoping has prompted growing interest in its potential clinical relevance, particularly in relation to post-amputation pain experiences. Differences in the presence, degree, and temporal course of telescoping may reflect meaningful

variation in underlying neuroplastic and perceptual processes that also shape other limb loss outcomes. As such, telescoping has been increasingly examined not only as a perceptual phenomenon, but also as a factor that may intersect with broader symptom profiles following limb loss. The following section builds on this foundation by examining the relationship between phantom limb telescoping and post-amputation pain.

Section 4: Telescoping and Post-Amputation Pain

Considerable attention has been devoted to the relationship between phantom limb telescoping and post-amputation pain, particularly PLP. This interest reflects the possibility that changes in the perceived size and position of the phantom limb may index underlying sensory, perceptual, or neuroplastic processes that also shape pain experiences after limb loss. Across decades of research, however, findings regarding the association between telescoping and PLP have been notably inconsistent, with evidence supporting negative (e.g., shorter phantom limbs associated with the presence of PLP), positive (e.g., shorter phantom limbs associated with the absence of PLP), and null relationships (e.g., lack of a significant relationship between telescoping and PLP). Rather than converging on a single explanatory pattern, the link between telescoping and post-amputation pain remains equivocal.

Negative association between telescoping and PLP

Some research has suggested that telescoping is more common among individuals who experience PLP, and that greater shortening of the phantom limb is associated with higher pain intensity. In particular, Flor et al. (1998) (N = 14) reported that individuals with telescoping tended to report more severe PLP, suggesting a negative association between the perceived size of the phantom limb and the intensity of pain experienced. Subsequent work by Draganski et al.

(2006) (N = 28) further supported this association, demonstrating that phantom limb shortening was associated with higher pain ratings.

Together, these findings suggest that telescoping may reflect underlying changes in the representation of the missing limb that are also relevant to the experience of pain. This research would suggest that telescoping may be intertwined with maladaptive sensory and cortical processes that contribute to PLP severity. However, the directionality and causal nature of this relationship remain unclear, as it is not known whether increased telescoping contributes to the development or maintenance of PLP, whether higher pain intensity promotes changes in phantom limb perception, or whether both arise from shared underlying mechanisms.

Positive association between telescoping and PLP

In contrast, other studies have found an inverse relationship: telescoping occurring alongside reduced PLP or in the absence of pain altogether. Studies by Weiss and Fishman (1963) (N = 239), Katz and Melzack (1987) (N = 3), Ramachandran et al. (2009) (N = 1), have reported that individuals with telescoping tended to report less severe or absent PLP, suggesting a positive association between the perceived length of the phantom limb and the intensity of pain experienced.

Collectively, these findings raise the possibility that telescoping may reflect an adaptive or protective change in phantom limb representation rather than a maladaptive one. From this perspective, a reduction in the perceived length of the phantom limb may correspond to decreased pain-related processes. However, as with studies reporting negative associations between telescoping and PLP, the mechanisms underlying this relationship remain unclear, and it is uncertain whether telescoping contributes to pain reduction, emerges as a consequence of reduced pain, or reflects a parallel process influenced by other factors.

No clear association between telescoping and PLP

Adding further complexity, other studies have failed to identify a significant association between telescoping and PLP. Specifically, Diers et al. (2010) (N = 14) and Montoya et al. (1997) (N = 32) reported that individuals with telescoped phantoms were no more likely to experience PLP than those with normal-length phantoms. In these investigations, the presence or degree of telescoping did not reliably differentiate between individuals with and without pain, nor was it consistently related to pain intensity.

These findings suggest that telescoping and PLP may, in some cases, represent partially independent phenomena rather than being systematically linked. From this perspective, changes in the perceived length of the phantom limb may occur without necessarily altering pain experiences, and vice versa. The absence of a clear association in these studies highlights the heterogeneity of phantom limb experiences and suggests that the relationship between telescoping and PLP may be moderated by additional factors, such as individual differences in sensory processing, time since limb loss, or contextual influences not directly captured in these analyses.

Implications

Taken together, the literature examining the relationship between phantom limb telescoping and PLP is strikingly mixed. Evidence exists to support negative associations, positive associations, and the absence of any reliable relationship. It remains unclear if there is a singular association between telescoping and post-amputation pain, or if the relationship depends on a variety of factors that has yet to be fully understood. This relationship may be impacted by factors including time since amputation, age, individual differences in sensory processing and

neuroplasticity, peripheral inputs, psychological context, and the dynamic evolution of body representation over time. This heterogeneity may help explain why telescoping has been linked to both maladaptive and potentially adaptive outcomes across different individuals and clinical contexts. These and other issues will be examined in subsequent sections of the present dissertation.

Methodological considerations in the study of telescoping

Despite being first documented in the clinical literature over 150 years ago, the empirical investigation of phantom limb telescoping poses a number of methodological challenges that warrant careful consideration. Telescoping is a subjective bodily experience that varies across individuals and within the same person over time. As such, its study shares features with other areas of research that examine complex bodily experiences (e.g., chronic pain, interoceptive awareness, etc.), where interpretation is shaped not only by measurement choices but also by conceptual framing. Awareness of these broader methodological considerations is important for situating existing findings and for guiding future empirical work.

One consideration concerns the types of study designs commonly used to investigate uncommon or clinically heterogeneous phenomena. In many areas of clinical neuroscience and rehabilitation psychology, early understanding is often shaped by detailed case descriptions and smaller exploratory studies. Such approaches are particularly valuable for identifying novel phenomena, generating hypotheses, and capturing phenomenological richness. At the same time, reliance on smaller samples may influence how patterns are detected and interpreted, especially when individual experiences vary widely. As research on telescoping continues to develop, it is therefore important to remain attentive to how sample characteristics and study design may shape reported associations and observed variability.

A related consideration involves how complex perceptual experiences are defined within research. Telescoping has been defined here as related to changes in the perceived length of a phantom limb, yet, in research more broadly, differences in how phantom limb length is conceptualized, labelled, and described can lead to differences in what is ultimately measured. Subtle variations in definitions or assessment strategies may capture distinct aspects of an experience that are not always equivalent. Remaining attentive to these possibilities is particularly important when comparing findings across studies or attempting to integrate results into broader theoretical models.

Measurement approach represents another area where caution is warranted. Subjective bodily experiences are often assessed using a range of methods, including self-report, interviews, drawings, or rating scales, each of which carries its own assumptions and constraints. Some approaches may prioritize ease of administration, whereas others may emphasize descriptive depth. In fields examining perception and body representation, differences in measurement strategy can influence not only the precision of assessment but also the aspects of experience that are most salient to participants. As such, variability in how telescoping is assessed may have implications for how consistently the phenomenon is captured and interpreted across studies.

Temporal factors also merit consideration. Many perceptual and sensory experiences following limb loss are described as dynamic rather than static, evolving in response to changes in the body, environment, and psychological context. Cross-sectional approaches provide valuable snapshots of experience but may not fully capture trajectories of change. In research domains characterized by adaptation and plasticity, longitudinal perspectives are often necessary to clarify whether observed phenomena reflect transient states, stable characteristics, or

fluctuating patterns. Awareness of these temporal considerations is important when interpreting findings related to telescoping and its relationship with other phantom limb experiences.

Finally, research on subjective bodily phenomena often benefits from integrating multiple methodological perspectives. Quantitative approaches are well suited to identifying patterns and testing associations between factors in groups of individuals, whereas qualitative methods can provide insight into how experiences are understood, interpreted, and embedded in daily life. In many areas of health and clinical research, combining these approaches has helped clarify discrepancies and refine theoretical models. Considering how different methodological traditions contribute distinct forms of knowledge may therefore be particularly relevant for advancing understanding of telescoping.

Taken together, these considerations highlight the importance of approaching the existing literature on phantom limb telescoping with attentiveness to how methodological choices may shape empirical findings. Rather than assuming uniformity in how telescoping is experienced or assessed, it is useful to remain open to the possibility of variability arising from differences in study design, conceptualization, and measurement. Maintaining this perspective provides a foundation for more careful interpretation of existing work and supports the development of future research that can more precisely characterize the nature and significance of telescoping within the broader landscape of phantom limb phenomena.

Section 5: Purpose and Overview of the Present Dissertation

Phantom limb telescoping is a perceptual phenomenon experienced by many individuals following limb loss, yet it remains poorly understood in terms of its underlying characteristics, its relationship to other phantom limb experiences, and its relevance for daily functioning and adaptation. Although phantom limb sensations and PLP have been the focus of extensive

empirical and clinical investigation, telescoping has received comparatively limited and fragmented attention. As a result, fundamental questions remain regarding how telescoping is experienced, how it relates to pain and other sensory phenomena, and what it may signify for individuals' broader post-amputation adjustment. This gap in understanding is particularly consequential given that telescoping reflects an alteration in body representation that may intersect with sensory processing, emotional responses, and functional outcomes after limb loss.

The present dissertation was designed to address these gaps by investigating telescoping through multiple complementary approaches, aiming to integrate existing evidence with new empirical data in order to advance both scientific understanding and clinical practice.

Objectives and rationale

The primary objective of this dissertation is to examine phantom limb telescoping in individuals with limb loss and to explore its potential associations with key health-related outcomes, including PLP, RLP, and mental health symptoms. In addition to its relevance for sensory and pain research, telescoping is conceptualized here as a multifaceted phenomenon that encompasses perceptual, emotional, and contextual dimensions. Recognizing that individuals' experiences of telescoping may be shaped by psychological processes, social interactions, and adaptation strategies, the dissertation adopts a biopsychosocial perspective, aiming to move beyond a purely neurophysiological or pain-centered framework. By integrating literature synthesis, case study, qualitative, and quantitative approaches, this work seeks to provide a comprehensive understanding of telescoping that reflects the complexity of one aspect of the post-amputation experience.

Methodological overview

To achieve these objectives, the dissertation comprises four interconnected studies, each designed to address distinct aspects of telescoping. Study 1 is a narrative review synthesizing existing literature on phantom limb telescoping. A systematic search of databases identified studies that explicitly examined or reported telescoping across a variety of limb loss populations, study designs, and outcome measures. The review aimed to consolidate findings regarding the prevalence, phenomenology, and proposed mechanisms of telescoping, as well as to highlight gaps in knowledge and limitations in methodology. Through this synthesis, Study 1 provides the foundational context for the empirical components of the dissertation, establishing the current state of knowledge and motivating further investigation.

Study 2 presents a detailed case report of an individual recruited from St. John's Rehab in Toronto. The participant completed online questionnaires and participated in a semi-structured interview as part of a larger study on post-amputation experience. This case study was intended to capture detailed information about the temporal dynamics and phenomenology of one person's experience of telescoping, illustrating how changes in phantom limb perception may unfold and interact with broader post-amputation adaptation processes. By examining one individual in depth, Study 2 provides a nuanced examination of the complex interplay between perception, emotion, and coping that cannot be fully captured in larger-scale quantitative studies.

Studies 3 and 4 expand the scope of inquiry to a broader participant sample. Study 3 examines quantitative questionnaire data from 51 individuals. Measures included ratings of PLP and RLP, telescoping, pain interference, pain catastrophizing, neuropathic pain, pain acceptance, anxiety, depression, optimism, and resilience. Study 4 draws on the same participant pool to conduct semi-structured qualitative interviews with 12 individuals with limb loss to explore

perceptions, interpretations, and adaptive strategies related to telescoping. These interviews gave participants an opportunity to describe the meaning and impact of telescoping in their daily lives, including how it interacts with identity, emotional well-being, and social experiences. The combination of qualitative and quantitative data provides a comprehensive perspective on both the subjective experience and the measurable outcomes associated with telescoping.

Together, these four studies are designed to address multiple aspects of inquiry: the narrative review consolidates existing knowledge and identifies gaps in the literature, the case report provides an illustrative, detailed account of individual experience, and the larger quantitative and qualitative studies examine patterns and associations across a broader sample. Collectively, the dissertation advances understanding of phantom limb telescoping as a phenomenon that is simultaneously sensory, psychological, and contextual, emphasizing that it cannot be fully understood solely through its neurophysiological or pain-related dimensions. Importantly, the dissertation highlights telescoping as a meaningful post-amputation experience, encouraging consideration of how individuals interpret, adapt to, and integrate this phenomenon into their lives.

The rationale for this multi-method approach stems from the recognition that telescoping is highly variable across individuals. Some experience gradual changes, others abrupt alterations, and the emotional and social implications of these experiences differ substantially. As such, no single methodological approach is sufficient to capture the full complexity of telescoping. By integrating narrative review, case study, and both quantitative and qualitative empirical approaches, this dissertation provides a greater understanding of the phenomenon than can be achieved through any single method. This approach also lays the groundwork for future research

on mechanisms, functional outcomes, and potential interventions related to phantom limb telescoping.

In summary, the present dissertation is guided by the goal of advancing both theoretical and applied knowledge about phantom limb telescoping. By examining the phenomenon from multiple perspectives, the work aims to illuminate the sensory, psychological, and contextual factors that shape how telescoping is experienced. The studies included in this dissertation provide a comprehensive overview of what is currently known, how telescoping manifests across and within individuals, and how it may relate to broader post-amputation outcomes. Ultimately, this integrated approach is intended to inform both future research and clinical practice, helping clinicians understand, communicate about, and support individuals experiencing phantom limb telescoping in ways that are sensitive to the complex interplay of perception, emotion, and adaptation.

Chapter 2: Telescoping Narrative Review (Study 1)

Section 1: Study Objective and Conceptual Framework

Objective

The objective of Study 1 was to conduct a narrative review based on a systematic search of the literature to examine the existing body of research on phantom limb telescoping. Specifically, this review aimed to (1) synthesize published original research findings related to telescoping; (2) examine reported associations between telescoping and PLP, RLP, and any other factors related to the experience of limb loss; (3) evaluate methodological strengths and limitations within the literature, and (4) identify key themes, patterns, gaps, and directions for future research.

By integrating findings across disciplines, including neuroscience, psychology, rehabilitation, and pain research, this narrative review seeks to provide a nuanced and integrative perspective on telescoping. A deeper understanding of telescoping has the potential to offer valuable insights into brain plasticity, body schema, and the subjective experience of amputation. Ultimately, clarifying the role of telescoping may inform more effective and individualized approaches to managing phantom limb sensations and, most critically, contribute to improved understanding of its impact on post-amputation pain.

Conceptual framework

Given this study employed a narrative review methodology rather than an empirical design, formal hypotheses were not proposed. Instead, the review was guided by a set of overarching conceptual questions intended to organize and interpret the existing literature. These guiding questions included:

1. How has phantom limb telescoping been defined and measured across studies?

2. What evidence exists regarding the relationship between telescoping and PLP, RLP, and any other factors related to the experience of limb loss?
3. What neurobiological, psychological, and contextual mechanisms have been proposed to explain telescoping-related findings?
4. What methodological limitations and inconsistencies constrain current interpretations of the literature?
5. What critical gaps remain, and how can future research more effectively characterize the clinical significance of telescoping?

This question-driven approach allowed for a structured yet flexible synthesis of the literature, consistent with the exploratory and integrative goals of a narrative review. Rather than testing specific predictions, Study 1 sought to clarify the current state of knowledge and establish a conceptual foundation to inform subsequent empirical studies within this dissertation.

Section 2: Manuscript

This manuscript has not yet been submitted to a peer-reviewed journal; however, it has been prepared in accordance with the standards of peer-reviewed publication. The text that follows represents a version in preparation for future submission.

Unravelling the Mystery of Phantom Limb Telescoping: A Narrative Review

1. INTRODUCTION

After amputation, approximately 80% of individuals experience a phantom limb, in which they feel that the amputated arm or leg is still attached to their body (Flor & Birbaumer, 2000). Typically, the phantom limb is perceived to be continuous with the residual limb such that the phantom occupies the same spatial location and is of the same dimensions as their limb was before amputation. For some, as time passes, the phantom limb begins to change shape and size. The proximal parts of the phantom begin to fade and soon disappear, leaving a gap between the residual limb and the phantom hand or foot. Next, the phantom hand or foot is perceived to gradually approach the residual limb as the gap between them closes. As the process of shortening continues, the individual may find that the phantom hand or foot is “attached” to the residual limb. Later, it may partially retract into the residual limb until, in some cases, it is contained completely within the residual limb. This phenomenon, known as “telescoping”, has attracted the attention of many clinical observers since it was first described by Guéniot (1861).

The mechanisms underlying telescoping are not fully understood, but several theories have been proposed to explain it. One early explanation involves cortical reorganization (Katz, 1992; Katz & Melzack, 2003). Following amputation, sensory brain areas corresponding to the missing limb undergo use-dependent neuroplastic changes (i.e., re-occupation), with neighboring body part representations (e.g., distal parts of the residual limb) expanding into deprived cortical regions that originally subserved the amputated limb and now represent the phantom limb. This process of reoccupation is assumed to occur in a proximal to distal direction that is mirrored in the perceptual experience so that as more and more cortical tissue is re-occupied, the person experiences the phantom hand or foot to gradually, and proportionally, approach the residual

limb. Thus, the length (and size) of the phantom limb is thought to be a perceptual marker of the extent to which sensory inputs from the residual limb have re-occupied deprived cortical regions (Katz, 1992; Katz & Melzack, 2003). From a cortical representation perspective, the disproportionate representation of the distal limb segments relative to the proximal regions of the limb may promote reorganization of proximal representations such that they fade away, perhaps paving the way for the possibility of a phantom limb shortening (Makin & Flor, 2020). Other accounts emphasize the incongruence between visual, proprioceptive, and tactile feedback leads the brain to update its internal representation of the limb, resulting in the perception of a shorter than normal length phantom. Peripheral mechanisms may also play a role, such as spontaneous activity in severed nerves or changes in residual limb input that bias cortical representation toward distal segments, such as the hand or foot. Further, psychosocial factors, such as attention to the phantom limb, emotional distress, and individual differences in coping strategies, may influence telescoping. The variability in telescoping and its possible relationship to post-amputation pain, make it a subject worth further investigation. This is especially true when considering the possible influence of these factors on the lives of individuals with limb loss (Fuchs et al., 2018; Horgan & MacLachlan, 2004). Understanding how and why telescoping occurs may provide insights into the neural processes involved in body representation and the plasticity of the somatosensory cortex following limb loss.

Telescoping has since been studied and documented to better understand its prevalence, cause, and clinical implications, especially regarding post-amputation pain. The majority of individuals with limb loss experience phantom limb pain (PLP) and/or residual limb pain (RLP), with rates between 49-59%, and lifetime prevalence estimates as high as 87% (Diers et al., 2022; Stankevicius et al., 2021). Clinically, telescoping may hold high significance based on its

relationship to PLP (Aternali et al., 2024). Telescoping has been associated with both PLP and non-painful phantom sensations, yet the relationships between telescoping and these phenomena remain unclear. Despite its potential significance, it remains to be seen how telescoping impacts individuals with limb loss. The literature on phantom limb telescoping shows considerable variability in study design, measurement techniques, and definitions.

This narrative review is based on a systematic search of the literature and aims to examine the existing published research to identify key themes, patterns, gaps, limitations, areas of consensus, and potential avenues for future study. A systematic search of original research was completed to obtain a comprehensive understanding of where the literature stands on various topics related to telescoping. By synthesizing findings from multiple disciplines, this review aims to provide a nuanced perspective on telescoping that accounts for its neurobiological, psychological, and contextual dimensions. Ultimately, a deeper understanding of telescoping may offer valuable insights into brain plasticity, body schema, and the subjective experience of amputation. This has the potential to inform more effective approaches to managing phantom limb sensations in individuals with limb loss. Most importantly, it may clarify the impact of telescoping on post-amputation pain.

2. METHODS

This narrative review followed a systematic review methodology to evaluate the state of the literature on phantom limb telescoping. It adhered to all relevant guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher et al., 2009), which ensures a comprehensive and transparent approach to evidence

synthesis. Although a systematic search and risk of bias appraisal were conducted, a narrative review framework was selected to allow for broader synthesis and interpretation of the literature on telescoping. Meta-analysis was not feasible due to substantial conceptual and methodological heterogeneity across studies, including diverse outcome measures that made aggregating results infeasible. A scoping review was also considered but deemed less appropriate because it is primarily designed to map the literature, clarify definitions, and catalogue measurement approaches rather than to synthesize and interpret findings. A narrative review provides a broad, integrative synthesis of a conceptually complex and methodologically heterogeneous body of literature. This approach allowed for flexibility in scope and interpretation, facilitating theoretical integration across diverse definitions, methodologies, and findings.

2.1 Search strategy

Systematic searches were conducted on Medline, Embase, CINAHL, PsycInfo from inception to September 29, 2024. Each database was searched using the title, abstract, and keyword lists with search terms specific to amputation, PLP, and telescoping. There were no restrictions placed on the searches related to study type or language. The following search terms were used "phantom limb" OR "phantom limb#" OR "phantom arm#" OR "phantom hand#" OR "phantom finger#" OR "phantom forearm#" OR "phantom fore-arm#" OR "phantom leg#" OR "phantom feet#" OR "phantom foot" OR "phantom toe#" OR "phantom pain" OR "kinesthesia" OR kinaesthe* OR kinesthe* OR synaesthe* OR "proprioception" OR proprioception# OR "sensation" OR phantom (pain* or phenomenon* or non-pain* or nonpain* or sensation# or syndrome) OR length* or short* OR feel* OR sensation# OR experienc* OR limb# (extend* or extension# or length* or shrink) OR telescop*.

2.2 Eligibility criteria

Studies were eligible for inclusion if they were original research articles published in English that investigated adults who had undergone an amputation. Studies were included if their samples consisted predominantly of adults, permitting only a minimal number of participants under 18 years. Included articles must have reported findings related to phantom limb telescoping. This broad criterion encompassed research ranging from studies that made mention of telescoping within their sample to those that examined associations between telescoping and other factors related to limb loss (e.g., demographic, clinical, or sensory variables). Prospective, retrospective, case-control, and cohort studies were included. Studies primarily evaluating participants with congenitally missing limb, phantom phenomena after mastectomy or removal of eyes, fingers, toes, or genitalia were excluded from the review. Animal studies, published poster abstracts, reviews, meta-analyses, and books were not included.

2.3 Definition of Telescoping

Phantom limb was defined as the sensation of a missing limb after amputation. A normal length phantom was defined as the perception of the phantom limb as the same length as the individual's contralateral intact limb or the length of the limb prior to amputation, as illustrated in Figures 1A and D. A partially telescoped phantom limb or partial telescoping was defined as the perception of a shorter-than-normal length phantom limb (Figures 1B and E). A completely telescoped phantom limb was defined as the perception that the phantom hand or foot occupied a space within the residual limb, with no part protruding, as illustrated in Figures 1C and F. The term telescoping or telescoped phantom was used to describe a shorter-than-normal length phantom limb, regardless of how near or far it was perceived to be from the residual limb. Studies were included in which participants described partially or completely telescoped phantom limbs.

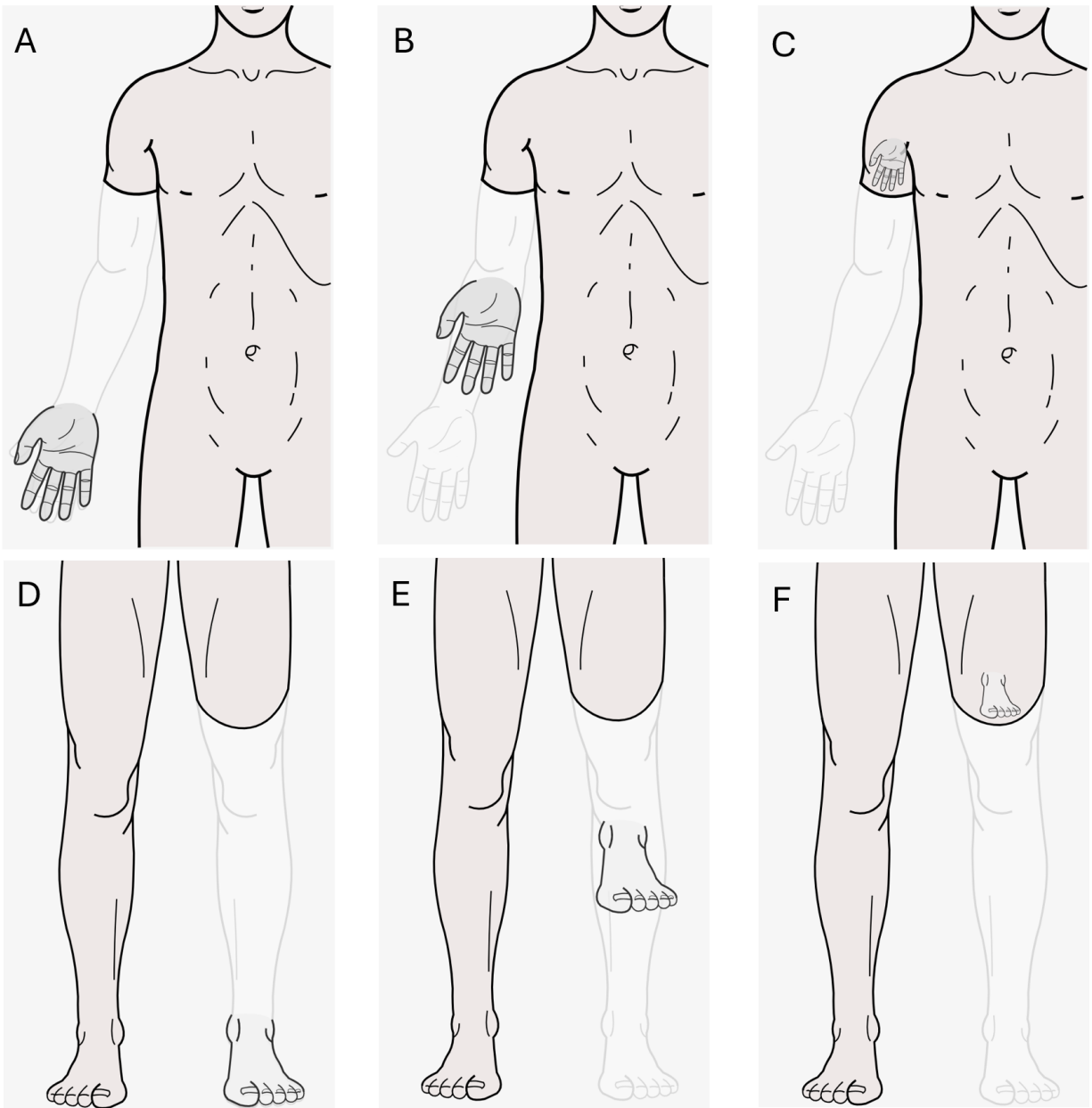


Figure 1. Examples of telescoping in upper and lower phantom limbs: (A) normal length upper limb, (B) partially telescoped upper limb, (C) completely telescoped upper limb, (D) normal length lower limb, (E) partially telescoped lower limb, and (F) completely telescoped lower limb. Illustrations were generated at <https://demo.phantomlimbs.ca/>. Note that the partially telescoped phantom limbs shown in (B) and (E) are only one instance of partial telescoping which include any phantom limbs that are shorter than the normal length phantom limbs shown in (A) and (D) (i.e., in which the distance between the phantom extremity and residual limb is less than the distance between the extremity and residual limb of a normal length phantom).

2.4 Study inclusion and exclusion processes

Two independent reviewers (Andrea Aternali and Heather Lumsden-Ruegg) screened the titles and abstracts of the studies identified by the search strategy. First, they excluded studies that were clearly not on topic based on the abstract. Second, they retrieved the full texts of potentially eligible studies and assessed if the inclusion criteria were met. If full texts could not be retrieved, they were excluded due to access limitations. Discrepancies between reviewers were resolved through discussion or by consulting a third reviewer (Joel Katz). Both reviewers searched the reference lists of the articles and of relevant systematic reviews and meta-analyses to identify other potentially eligible studies.

2.5 Methodological quality assessment

The quality of the research studies included in this review was appraised using the risk of bias assessment tools recommended by Ma et al. (2020). Two independent reviewers (Andrea Aternali and Heather Lumsden-Ruegg) determined the study type, decided on the appropriate tool for each study type, and independently completed risk of bias assessments for all articles meeting inclusion criteria. Disagreements between reviewers were resolved through discussion or involvement of a third reviewer (Joel Katz). The results of these assessments were used to inform the overall quality of the evidence.

Study Type. The included articles were categorized according to established study type definitions (Grimes & Schulz, 2002). Study type was determined based on each article's stated objectives, data collection methods, and analytic approach, ensuring that the most appropriate risk of bias tool was applied. Study designs were categorized by first determining whether the study involved an intervention. If an intervention was used, the next step was to assess whether a control group was included. Intervention studies with a control group were classified as either

randomized controlled trials (RCTs), when allocation to conditions occurred randomly, or non-randomized controlled trials when allocation was not random. Intervention studies without a control group were classified as before-after (pre-post) studies when outcomes were measured in the same group before and after the intervention, or as case series when they provided uncontrolled longitudinal descriptions of outcomes in individuals administered an intervention.

If the study did not involve an intervention, it was considered observational.

Observational studies were further categorized into case control studies, which identify individuals with and without an outcome and then examine prior exposures, retrospectively; cohort studies, which prospectively follow exposed and unexposed groups over time to observe subsequent outcomes; and cross-sectional studies, which collect data at a single time point. Cross-sectional studies were further categorized as analytical, where researchers tested hypotheses regarding the associations between variables, or descriptive, which often reported estimates such as prevalence or characteristics without testing hypotheses. Incidence studies similarly quantified the number of existing or new cases within defined populations.

Case reports provided detailed descriptions of one or multiple individuals with similar conditions. Qualitative studies solely explored experiences and processes through methods such as interviews or focus groups, using interpretive analytic approaches. Finally, outcome measurement studies examined the psychometric properties of specific assessment tools, including their validity, reliability, and responsiveness.

Risk of Bias Tools. Risk of bias in case reports was assessed via the JBI critical appraisal checklist for case reports (Moola et al., 2017). The quality of descriptive cross-sectional studies was assessed using the JBI critical appraisal checklist for studies reporting prevalence and incidence data (Munn et al., 2015). The JBI critical appraisal checklist for analytical cross-

sectional studies was used to evaluate risk of bias in analytical cross-sectional studies (Moola et al., 2017). The methodological quality of before-after (pre-post) studies and case series was measured using the National Institutes of Health (NIH) quality assessment tool for before-after (pre-post) and case series studies, respectively (Tuzzio et al., 2021). The risk of bias in RCTs was evaluated using the Cochrane Collaboration's tool for assessing risk of bias (Higgins et al., 2011). The Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) assessment tool was used to evaluate methodological quality in a non-randomized RCT (Sterne et al., 2016). The methodological quality of qualitative studies was evaluated using the JBI critical appraisal checklist for qualitative research (Lockwood et al., 2015). The quality of cohort studies was measured using the Newcastle-Ottawa quality assessment scale (NOS) for case control studies and NOS for cohort studies, respectively (Wells et al., 2017). The risk of bias of outcome measurement studies was evaluated using the Consensus-based Standards for the selection of health Measurement Instruments (COSMIN) Risk of Bias checklist (Mokkink et al., 2016). All tools were selected because they were frequently used and recommended as valid and reliable measures of risk of bias for the various study designs (Ma et al., 2020).

Inter-rater Reliability. To assess inter-rater reliability for the risk of bias ratings, a weighted Cohen's kappa (κ_w) was calculated. This statistic quantifies the level of agreement between raters while adjusting for agreement expected by chance and accounting for the degree of disagreement between ratings. Since the rating scale was ordinal (e.g., low, moderate, and high risk of bias), weighted kappa was chosen over the unweighted version to reflect that smaller discrepancies represent greater agreement than larger discrepancies. Interpretation of κ_w values were as follows; values less than 0.20 suggested no agreement, 0.21-0.39 as minimal, 0.40-0.59 as weak, 0.60-0.79 as moderate, 0.80-0.90 as strong, and above 0.90 as almost perfect (McHugh, 2012).

3. RESULTS

3.1 Search results

The database searches yielded 4,277 results. After removing duplicate entries, the titles and abstracts of 2,981 studies were screened. Of these, 2,467 articles were excluded because they did not meet eligibility criteria. The full text was retrieved for the remaining 514 studies, of which an additional 414 articles were excluded, reasons for which are provided in greater detail in the PRISMA Flow Diagram in Figure 2. A total of 100 studies were included in the present review. Table 1 shows relevant information related to each study, including author and year, sample size, demographics, amputation-related variables, percent of the sample reporting telescoping, PLP, and RLP, study type, and overall risk of bias assessment rating. The following section provides a brief overview of the data presented in each column of Table 1 across the included studies.

3.2 Characteristics of included studies

Research Design. Of the included studies, 34 were case reports (Aglioti et al., 1994; Belleggia & Birbaumer, 2001; Bradbrook, 2004; Condes-Lara et al., 2000; Cuberovic et al., 2019; Davies, 2013; Desmond et al., 2006; Dietrich et al., 2018; Fukui et al., 2002; Giummarra et al., 2011; Graczyk et al., 2018; Grüsser et al., 2004; Grüsser, Winter, Schaefer, et al., 2001; Halligan et al., 1994; Iida et al., 2004; Katz et al., 1989; Katz & Melzack, 1987; Lee & Donovan, 1995; Liaw et al., 1998; McAvinue & Robertson, 2011; Morgenstern, 1964; Muraoka et al., 1996; Ortiz-Catalan et al., 2014; Pascual-Leone et al., 1996; Ramachandran et al., 2009; Restrepo-Garces et al., 2011; Rognini et al., 2019; Rosen et al., 2001; Roux et al., 2001; Schmalzl et al., 2014; Schmitt et al., 2022; Stannard & Porter, 1993; Stone, 1950; Topfner et al., 2001), 22 were analytical studies

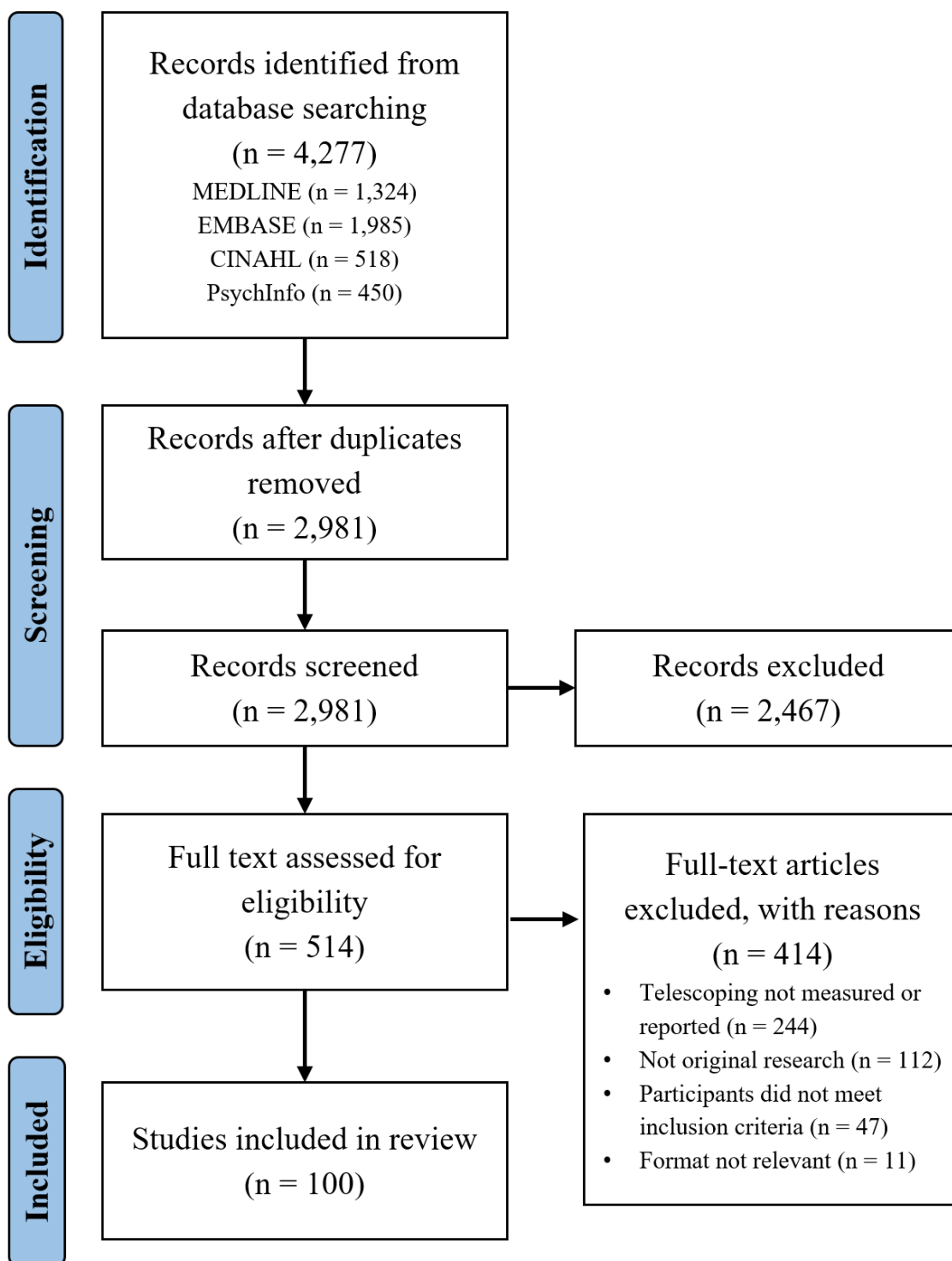


Figure 2. Flow diagram illustrating article screening, reasons for exclusion, and final study inclusion.

Author (year)	Sample size	Sex (%)	Reason(s) for amputation (%)	Mean age $\pm$ SD (range)	Mean time since amputation $\pm$ SD (range)	Level of amputation (%)	% Telescoping Reported	% PLP Reported	% RLP Reported	Study Type and ROB Assessment
Aglioti et al. (1994)	N = 3	Male (66.7%) Female (33.3%)	Trauma (33.4%) Idiopathic obliterans arteriopathy (33.3%) Diabetic arteriopathy (33.3%)	45.3 years (31-54 years)	NR (5 months - 2 years 11 months)	Above knee (33.3%) Below knee (66.7%)	33.3%	66.7%	NR	Case report; high risk
Ahmed et al. (2017)	N = 139	Male (73.4%) Female (26.6%)	Cancer (100.0%)	38.3 $\pm$ 1.5 years (NR)	0 days, and follow-up at 3, 6, 12 months	Above elbow (18.0%) Below elbow (7.9%) Above knee (43.2%) Below knee (30.9%)	32.4%	41.0% (3 months) 45.3% (6 months) 41.0% (12 months)	14.4% (3 months) 18.8% (6 months) 15.8% (12 months)	Prevalence; moderate risk
Aldington et al. (2014)	N = 48	NR	Trauma (100.0%)	28.8 $\pm$ 6.7 years (18-46 years)	NR (13 weeks - 15 years)	Upper limb (16.9%) Lower limb (83.1%)	33.3%	49%	65%	Prevalence; moderate risk
Bamford (2006)	N = 25	Male (60.0%) Female (40.0%)	Trauma (52.0%) Vascular (40.0%) Cancer (8.0%)	57 years (27-78 years)	NR	Upper limb (28.0%) Lower limb (72.0%)	16.0%	100.0%	NR	Before-after (pre-post); moderate risk
Belleggia and Birbaumer (2001)	N = 1	Male (100%)	Infection (100.0%)	69 years	3 years	Above elbow (100.0)	100.0%	100%	0.0%	Case report; low risk
Björkman (2010)	N = 28	Male (42.9%) Female (57.1%)	Cancer (64.3%) Vascular-diabetes (25.0%) Trauma (10.7%)	NR (18-65+ years)	NR	Upper/lower limb (71.4%) Mastectomy (28.6%)	3.6%	60.7%	NR	Qualitative; low risk
Bjorkman et al. (2016)	N = 10	Male (50.0%) Female (50.0%)	Trauma (100.0%)	NR (23-56 years)	NR (1-28 years)	Below elbow (100.0%)	60.0%	70.0%	NR	Analytical cross-sectional; high risk
Bradbrook (2004)	N = 3	Male (66.7%) Female (33.3%)	Congenital (33.4%) Cancer (33.3%) Trauma (33.3%)	40 years (19-68 years)	NR	Below knee (33.3%) Above knee (66.7%)	33.3%	100.0%	NR	Case report; low risk
Carlen et al. (1978)	N = 73	Male (100.0%)	Trauma (100.0%)	26.1 $\pm$ 5.9 years (19-45 years)	NR (1 - 6 months)	Above elbow (12.3) Below elbow (8.2%) Above knee (31.5%) Below knee (37.0%) Multiple limbs (11.0%)	Lower limb (45.0%) Upper limb (62.0%)	67.0%	43.0%	Prevalence; high risk
Casale et al. (2009)	N = 8	Male (75.0%) Female (25.0%)	Trauma (37.5%) Ischemia (62.5%)	70.1 $\pm$ 7.7 years (60-81 years)	NR (9-15 months)	Above knee (100.0%)	12.5%	100.0%	0.0%	Randomized controlled trial; low risk
Collins et al. (2018)	N = 17	Male (82.4%) Female (17.6%)	Trauma (58.8%) Disease (41.2%)	49.8 $\pm$ 12.8 years (34-69 years)	NR (<1 year - >5 years)	Upper limb (11.8%) Lower limb (88.2%)	17.6%	N/A	N/A	Prevalence; high risk
Condes-Lara et al. (2000)	N = 1	Male (100.0%)	Gangrene (100.0%)	64 years	NR	Above knee (100.0%)	100.0%	100.0%	NR	Case report; moderate risk

Cuberovic et al. (2019)	N = 1	Male (100.0%)	Trauma (100.0%)	NR	NR	Below elbow (100.0%)	100.0%	0.0%	NR	Case report; moderate risk
Davies (2013)	N = 1	Male (100.0%)	Trauma (100.0%)	45 years	12 weeks	Above elbow (100.0%)	100.0%	100.0%	NR	Case report; low risk
De Graaf et al. (2016)	N = 8	Male (87.5%) Female (12.5%)	Trauma (100.0%)	NR (27-76 years)	NR (6 - 392 months)	Above elbow (75.0%) Below elbow (25.0%)	25.0%	NR	NR	Analytical cross-sectional; high risk
De Nunzio et al. (2018)	N = 10	Male (50.0%) Female (50.0%)	Trauma (80.0%) Vascular disease (10.0%) Tumor (10.0%)	57.7 ± 12.4 years (28-75 years)	17.7 ± 16.0 years (6-52 years)	Above elbow (40.0%) Below elbow (60.0%)	40.0%	100.0%	20.0%	Before-after (pre-post); low risk
Desmond et al. (2006)	N = 3	Male (66.7%) Female (33.3%)	Cancer (33.3%) Trauma (66.7%)	38 years (25-49 years)	7 years (3 - 12 years)	Above elbow (33.4%) Forequarter (33.3%) Below elbow (33.3%)	33.3%	100.0%	NR	Case report; low risk
Dettmers et al. (2001)	N = 16	Male (87.5%) Female (12.5%)	Trauma (87.5%) Osteomyelitis (6.3%) Infection (6.2%)	38 years (13-69 years)	NR (0-38 years)	Above elbow (75.0%) Below elbow (25.0%)	31.3%	50.0%	NR	Analytical cross-sectional; moderate risk
Diers et al. (2010)	N = 14	Male (78.6%) Female (21.4%)	Trauma (92.9%) Vascular disease (7.1%)	PLP (n = 7) 54.3 ± 8.6 years (36-62 years) Non-PLP (n = 7) 50.3 ± 7.2 years (41-60 years)	PLP (n = 7) 18.5 ± 14.2 years (NR) Non-PLP (n = 7) 35.6 ± 13.3 years (NR)	Upper limb (100.0%)	57.1%	50.0%	NR	Analytical cross-sectional; moderate risk
Diers et al. (2022)	N = 3374	Male (80.5%) Female (19.5%)	Accident (53.5%) Vascular disease (11.4%) Tumor (7.5%) Injury (7.3%) Infection (4.7%) Congenital (2.9%) Other (12.7%)	64.1 ± 16.0 years (18-98 years)	33.2 ± 22.7 years (0 – 86 years)	Upper limb (26.9%) Lower limb (73.0%) Missing data (0.01%)	22.2%	59.6%	49.0%	Prevalence; moderate risk
Dietrich et al. (2018)	N = 1	Female (100.0%)	Trauma (100.0%)	56 years	1 year	Below elbow (100.0%)	100.0%	100.0%	NR	Case report; moderate risk
Draganski et al. (2006)	N = 28	Male (71.4%) Female (28.6%)	Trauma (82.1%) Non-systemic causes (17.9%)	41.9 ± 13.8 years (18-68 years)	119.3 ± 140 months (9-444 months)	Upper limb (10.7%) Above knee (64.3%) Below knee (21.4%) Upper/lower limb (3.6%) Upper limb (100.0%)	89.3%	100.0%	NR	Analytical cross-sectional; low risk
Flor et al. (1998)	N = 14 (with limb loss)	Male (64.3%) Female (35.7%)	Trauma (64.3%) Congenital (35.7%)	PLP (n = 4) 58.4 ± 18.8 years (NR) Non-PLP (n = 5) 50.8 ± 19.2 years (NR)	PLP (n = 4) 37.2 ± 24.2 years (NR) Non-PLP (n = 5) 28.6 ± 28.6 years (NR)	Upper limb (100.0%)	42.9%	28.6%	NR	Analytical cross-sectional; high risk

Flor et al. (2000)	N = 14	Male (92.9%) Female (7.1%)	NR	57.4 years (39-74 years)	414.9 months (174-612 months)	Upper limb (100.0%)	42.9%	71.4%	42.9%	Analytical cross-sectional; high risk
Foell et al. (2014)	N = 13	Male (69.2%) Female (30.8%)	Trauma (92.3%) Vascular disease (7.7%)	50.6 ± 15.8 years (26-74 years)	21.3 ± 12.7 years (6-49 years)	Upper limb (100.0%)	61.5%	100.0%	23.1%	Before-after (pre-post); moderate risk
Frank and Lorenzoni (1989)	N = 84	Male (100.0%)	Trauma (100.0%)	63 years (56-78 years)	38 years (NR)	Upper limb (82.1%) Lower limb (17.9%)	25.0%	100.0%	NR	Qualitative; moderate risk
Fukui et al. (2002)	N = 1	Male (100.0%)	Trauma (100.0%)	58 years	10 years	Above elbow (100.0%)	100.0%	100.0%	NR	Case report; low risk
Giordano et al. (2021)	N = 20	Male (75.0%) Female (25.0%)	Soft tissue sarcoma (50.0%) Bone sarcoma (50.0%)	53.9 ± 24.6 years (NR)	2.6 ± 1.0 weeks (NR)	Upper limb (45.0%) Lower limb (55.0%)	35.0%	NR	40.0%	Cohort study; moderate risk
Giummarra et al. (2010)	N = 283	Male (72.4%) Female (27.6%)	Trauma (46.6%) Vascular disease (17.4%) Cancer (8.9%) Infection/gangrene (6.8%) Diabetes and vascular disease (4.6%) Diabetes only (5.0%) Other (10.7%)*	59.0 ± 15.0 years (22-96 years)	19.0 ± 17.7 years (9 days - 70 years)	Upper limb (14.8%)* Lower limb (85.2%)*	21.6%*	67.5%	N/A	Prevalence; moderate risk
Giummarra et al. (2011)	N = 1	Male (100.0%)	Trauma (100.0%)	68 years	49 years	Above knee (100.0%)	100.0%	100.0%	100.0%	Case report; low risk
Graczyk et al. (2018)	N = 2	Male (100.0%)	Trauma (100.0%)	NR	NR	Below elbow (100.0%)	100.0%	NR	NR	Case report; moderate risk
Griffin et al. (2022)	N = 649	Male (65.0%) Female (35.0%)	Trauma (59.7%) Diabetes/vascular (12.1%) Cancer (8.4%) Infection (15.2%) Congenital (4.6%)	47.0 ± 16.6 years (NR)	NR (3 moths - >10 years)	Upper limb (7.1%) Lower limb (84.4%) Both (8.5%)	21.6%	81.8%	N/A	Prevalence; moderate risk
Grusser, Winter, Schaefer, et al. (2001)	N = 2	Female (50.0%) Male (50.0%)	Cancer (100.0%)	66 years (65 - 67 years)	7 days	Above elbow (50.0%) Below elbow (50.0%)	50.0%	100.0%	0.0%	Case report; moderate risk
Grusser, Winter, Muhn timer, et al. (2001)	N = 16	Male (87.5%) Female (12.5%)	Trauma (93.8%) Osteosarcoma (6.2%)	57.5 ± 10.7 years (39-74 years)	50.3 ± 15.1 years (15-65 years)	Upper limb (100.0%)	31.3%	68.8%	37.5%	Analytical cross-sectional; high risk
Grusser et al. (2004)	N = 2	Male (100.0%)	Cancer (100.0%)	49 years (37 - 61 years)	18.6 years (14.5 - 22.7 years)	Above elbow (100.0%)	50.0%	100.0%	50.0%	Case report; moderate risk

Haber (1958)	N = 24	Male (100.0%)	Trauma (100.0%)	33 years (27-43 years)	NR	Above elbow (100.0%)	50.0%	NR	NR	Analytical cross-sectional; moderate risk
Halligan et al. (1994)	N = 1	Female (100.0%)	NR	43 years	2.5 years	Above elbow	100.0%	100.0%	NR	Case report; moderate risk
Hunter et al. (2003)	N = 13	Male (84.6%) Female (15.4%)	Trauma (84.6%) Osteosarcoma (7.7%) Polycythemia (7.7%)	NR (20-57 years)	NR (1.5-14 months)	Above elbow (15.4%) Below elbow (84.6%)	38.5%	84.6%	NR	Analytical cross-sectional; low risk
Hunter et al. (2005)	N = 12	Male (83.3%) Female (16.7%)	Trauma (100.0%)	34.7 ± 11.8 years (20-55 years)	3.9 ± 1.3 months (1.5-5.5 months)	Above elbow (8.3%) Below elbow (91.7%)	25.0%	75.0%	100.0%	Analytical cross-sectional; low risk
Hunter (2008)	N = 11	Male (90.9%) Female (9.1%)	Trauma (100.0%)	35.4 ± 11.8 years (20-55 years)	4.6 ± 1.6 months (2.5-8 months)	Above elbow (9.1%) Below elbow (27.3%) Wrist (18.1%) Hand/fingers (45.5%)	18.2%	72.7%	81.8%	Cohort study; moderate risk
Iida et al. (2004)	N = 1	Male (100.0%)	Trauma (100.0%)	65 years	16 years	Above elbow/Below knee (100.0%)	100%	100.0%	NR	Case report; low risk
Jalavisto (1950)	N = 173	Male (100.0%)	Trauma (100.0%)	(17-45 years)	NR (21 days-3 years and 9 months)	Upper limb (100.0%)	14.5%	68.2%	NR	Analytical cross-sectional; high risk
Jensen et al. (1983) & Jensen et al. (1984)	N = 58	Male (50.0%) Female (50.0%)	PVD (87.9%) Neoplasm (8.7%) Osteomyelitis (1.7%) Plexus avulsion (1.7%)	69.8 ± 14.6 years (24-91 years)	8 days	Above knee (39.7%) Knee (1.7%) Below knee (55.2%) Above elbow (1.7%) Below elbow (1.7%)	30.0%	72.4%	NR	Cohort studies; moderate risk
Karl et al. (2004)	N = 8	Male (62.5%) Female (37.5)	Trauma (75.0 %) Sepsis (12.5%) Osteosarcoma (12.5%)	56.3 ± 13.5 years (33-72 years)	431.9 ± 266.9 months (7-778 months)	Upper limb (100.0%)	25.0%	50.0%	37.5%	Analytical cross-sectional; moderate risk
Katz and Melzack (1987)	N = 3	Male (66.7%) Female (33.3%)	Trauma (33.4%) Cancer (33.3%) NR (33.3%)	56 years (54-60 years)	NR (2-3 years)	Forequarter (66.7%) Bilateral lower limb (33.3%)	33.3%	100.0%	NR	Case report; moderate risk
Katz et al. (1989)	N = 1	Male (100.0%)	Trauma (100.0%)	23 years	138 days	Above knee (100.0%)	100.0%	100.0%	NR	Case report; moderate risk
Kawashima and Mita (2016)	N = 12	Male (100.0%)	Trauma (91.7%) Tumour (8.3%)	59.0 ± 16.6 years (33-76 years)	NR	Below elbow (100.0%)	91.7%	33.3%	NR	Outcome measurement; high risk
Kew et al. (1994)	N = 6	Male (83.3%) Female (16.7%)	Trauma (50.0%) Congenital (50.0%)	NR (21-52 years)	NR (2-12 years)	Above elbow (16.7%) Below elbow (83.3%)	33.3%	NR	NR	Analytical cross-sectional; moderate risk
Kew et al. (1997)	N = 2 (1 control)	Male (100.0%)	Trauma (100.0%)	NR (31-49 years)	NR (15-34 years)	Above elbow (100.0%)	100.0%	50.0%	NR	Case control; low risk

Kikkert et al. (2018)	N = 27 (31 controls)	NR	Trauma (88.9%) Infection (7.4%) Tumor (3.7%)	49.2 ± 2.4 years (24-71 years)	NR	Above elbow (55.6%) Below elbow (44.4%)	51.9%	81.5%	59.3%	Analytical cross-sectional; moderate risk
Kulkarni et al. (2020)	N = 9	Male (77.8%) Female (22.2%)	NR	NR (46-80 years)	NR (2 - >3 years)	Above elbow (55.6%) Below elbow (44.4%)	22.2%	100.0%	NR	Before-after (pre-post); moderate risk
Lacoux et al. (2002)	N = 40	Male (80.0%) Female (20.0%)	Trauma (100%)	39.4 (16-68 years)	22 months (10 months - 4 years)	Above elbow (4%) Below elbow (96%)	25.0%	32.5%	100.0%	Prevalence; moderate risk
Lee and Donovan (1995)	N = 1	Female (100.0%)	Infection (100.0%)	62 years	NR	Above elbow (100.0%)	100.0%	100.0%	NR	Case report; moderate risk
Liaw et al. (1998)	N = 3	Male (100.0%)	Trauma (100.0%)	31.7 years (18 - 56 years)	NR (5 weeks - 2.5 months)	Knee disarticulation (66.7%) Below knee (33.3%)	33.3%	100.0%	33.3%	Case report; moderate risk
Lyu et al. (2016)	N = 27 (27 controls)	Male (77.8%) Female (22.2%)	Accident (96.3%) Trauma (3.7%)	48.5 ± 9.3 years (29-69 years)	NR (7 months - 36 years)	Above elbow (37.0%) Below elbow (63.0%)	14.8%	11.1%	25.9%	Analytical cross-sectional; low risk
Machin and Williams (1998)	N = 26	Male (100.0%)	Trauma (100.0%)	NR (71-92 years)	NR	Upper limb (33.3%) Lower limb (66.7%)	7.7%	100.0%	84.6%	Analytical cross-sectional; moderate risk
Makin et al. (2013)	N = 18	NR	Trauma (72.2%) Nerve injury (11.1%) Infection (11.1%) Tumor (5.6%)	46 ± 3 years (21-60 years)	18 years (NR)	Above elbow (45.5%) Below elbow (54.5%)	33.3%	94.4%	33.3%	Analytical cross-sectional; moderate risk
Mall et al. (1997)	N = 25	Male (100.0%)	Emergency (92.0%) Elective (8.0%)	NR (16-25 years)	< 6 weeks (NR)	Upper limb (28.0%) Lower limb (72.0%)	44.0%	68.0%	NR	Analytical cross-sectional; high risk
Mayer et al. (2008)	N = 51	Male (86.3%) Female (13.7%)	Trauma (37.3%) Vascular (62.7%)	58.4 ± 15.3 years	87.0 ± 160.0 months (1 week-60 years)	Above elbow (2.0%) Below elbow (3.9%) Above knee (25.5%) Below knee (33.3%) Bilateral lower limb (35.3%)	NR	NR	NR	Prevalence; moderate risk
McAvinue and Robertson (2011)	N = 4	Male (75.0%) Female (25.0%)	Trauma (75.0%) Burns (25.0%)	44 years (25 - 66 years)	NR (1 year 8 months - 19 years 3 months)	Below knee (25.5%) Above knee (50.0%) Above and below knee (25.5%)	25.0%	100.0%	50.0%	Case report; low risk
Middleton and Ortiz-Catalan (2020)	N = 3	Male (100.0%)	Trauma (66.7%) Cancer (33.3%)	NR (43-46 years)	NR	Above elbow (100.0%)	100.0%	66.7%	NR	Qualitative; low risk
Montoya et al. (1997)	N = 32	Male (90.6%) Female (9.4%)	Trauma (93.8%) Congenital (6.2%)	41.0 ± 11.7 years (20-58 years)	12.2 ± 10.5 years (10 months - 49 years)	Above elbow (25.0%) Below elbow (75.0%)	53.1%	50.0%	34.4%	Analytical cross-sectional; low risk

Morgenstern (1964)	N = 4	Male (100.0%)	Trauma (75.0%) Osteomyelitis (25.5%)	48 years (36-57 years)	9.8 years (3-20 years)	Bilateral above knee (25.0%) Below knee (75.0%)	50.0%	75.0%	100.0%	Case report; moderate risk
Muraoka et al. (1996)	N = 1	Male (100.0%)	Trauma (100.0%)	58 years	27 years	Above knee (100.0%)	100.0%	100.0%	100.0%	Case report; moderate risk
Murray et al. (2006)	N = 5	Male (60.0%) Female (40.0%)	NR	NR (56-65 years)	NR (1-39 years)	Above elbow (20.0%) Below elbow (40.0%) Above knee (20.0%) Below knee (20.0%)	20.0%	100.0%	NR	Before-after (pre- post); high risk
Ortiz-Catalan et al. (2014)	N = 1	Male (100.0%)	Trauma (100.0%)	72 years	48 years	Below elbow (100.0%)	100.0%	100.0%	NR	Case report; low risk
Osumi et al. (2019)	N = 19 (7 controls)	Male (73.7%) Female (26.3%)	Trauma (41.7%) Sarcoma (50.0%) Limb cellulitis (8.3%)	48.1 ± 11.3 years (23-71 years)	NR (2-20 years)	Above elbow (83.3%) Below elbow (16.7%)	31.6%	100.0%	NR	Before-after (pre- post); high risk
Pascual-Leone et al. (1996)	N = 1	Male (100.0%)	Trauma (100.0%)	22 years	NR (5 weeks-11 months)	Above elbow (100.0%)	100.0%	100.0%	NR	Case report; moderate risk
Price (1976)	N = 32 (10 controls)	Male (66.7%) Female (33.3%)	Leprosy complications (93.8%) Gangrene (6.2%)	49.5 years (12-70 years)	8.6 years (3 months - 33 years)	Upper limb (9.4%) Lower limb (90.6%)	6.3%	75.0%	NR	Analytical cross- sectional; high risk
Probstner et al. (2010)	N = 75	Male (66.7%) Female (33.3%)	Cancer (100.0%)*	54.5 ± 18.5 years (19-88 years)	49.0 ± 58.1 months (0-247 months)	Upper limb (8.0%) Lower limb (92.0%)	3.8%	46.7%	32.0%	Prevalence; moderate risk
Ramachandran and Rogers-Ramachandran (1996)	N = 10	NR	Trauma (50.0%) Self-inflicted (10.0%) Brachial plexus avulsion (20.0%) Cancer (20.0%)	NR (23-73 years)	NR (19 days- 9 years)	Shoulder (20.0%) Above elbow (50.0%) Below elbow (30.0%)	10.0%	50.0%	NR	Case series; moderate risk
Ramachandran et al. (2009)	N = 1	Male (100.0%)	Trauma (100.0%)	42 years	NR (11-23 years)	Above elbow (100.0%)	100.0%	100.0%	NR	Case report; moderate risk
Restrepo-Garces et al. (2011)	N = 1	Male (100.0%)	Osteomyelitis (100.0%)	45 years	1, 3, and 6 months	Knee (100.0%)	100.0%	0.0%	100.0%	Case report; low risk
Richardson et al. (2015)	N = 89	Male (71.9%) Female (28.1%)	PVD (59%) Diabetes and PVD (36%) Diabetes (5%)	65.5 ± 11.4 years (NR)	2.9 ± 4.6 months (1 week-20 months)	Above knee (36%) Below Knee (64%)	14.0-15.0%	63.0%	48%	Prevalence; high risk
Richardson et al. (2006) & Richardson et al. (2007)	N = 52	Male (63.3%) Female (36.7%)	PVD (100.0%)	63.8 ± 10.4 years (NR)	6 months (NR)	Above knee (49.1%) Below knee (45.8%) Bilateral above knee (1.7%) Bilateral below knee (3.4%)	67.3%	78.8%	51.2%	Prevalence; moderate risk

Richardson et al. (2018)	N = 122	Male (72.1%) Female (27.9%)	PVD and Diabetes (23.8%) Trauma (45.9%) Cancer (7.4%) Infection (13.1%) Congenital (8.2%) Other (1.6%)	67.8 ± 14.5 years (NR)	NR (6 months - >10 years)	Above knee (32.0%) Through knee (0.8%) Below knee (67.2%)	27.0%	84.0%	52.0%	Prevalence; moderate risk
Rognini et al. (2019)	N = 2	NR	NR	NR	NR	Below elbow (100.0%)	100.0%	NR	NR	Case report; high risk
Rosen et al. (2001)	N = 2	Male (100.0%)	Trauma (100.0%)	30 years (22-38 years)	4 years (3-5 years)	Above elbow (50.0%) Fingers (50.0%)	50.0%	100.0%	0.0%	Case report; moderate risk
Rothgangel et al. (2018)	N = 75	Male (69.3%) Female (30.7%)	Trauma (33.3%) Diabetes (10.7%) Dysvascular (29.4%) Tumour (13.3%) Other (13.3%)	61.1± 14.2 years (NR)	NR	Hip (1.3%) Above knee (60.0%) Knee (6.7%) Below knee (29.3%) Foot (2.7%)	25.3%	100.0%	NR	Randomized controlled trial; low risk
Roux et al. (2001)	N = 1	Male (100.0%)	Trauma (100.0%)	45 years	2 years	Above elbow (100.0%)	100.0%	100.0%	NR	Case report; moderate risk
Schmalzl et al. (2011)	N = 8	Male (87.5%) Female (12.5%)	Trauma (100.0%)	50 ± NR (23-65 years)	NR (1-65 years)	Below elbow (100.0%)	100.0%	50.0%	NR	Non-randomized controlled trial; moderate risk
Schmalzl et al. (2014)	N = 2	Female (50.0%) Male (50.0%)	Trauma (100.0%)	45.5 years (38 - 53 years)	20.5 years (5 - 36 years)	Below elbow (100.0%)	100.0%	50.0%	NR	Case report; moderate risk
Schmitt et al. (2022)	N = 1	Male (100.0%)	Trauma (100.0%)	68 years	18 years	Below knee (100.0%)	100.0%	NR	NR	Case report; moderate risk
Shukla et al. (1982)	N = 72	NR	NR	NR	5.2 ± 1.1 weeks (NR)	Upper limb (54.8%) Lower limb (45.2%)	62.9%	69.4%	NR	Prevalence; moderate risk
Sin et al. (2013)	N = 49	Male (75.5%) Female (24.5%)	Diabetes related infection (46.9%) Atherosclerosis (32.7%) Trauma (8.2%) Tumour (2.0%) Thromboembolism (10.2%)	62 ± 11 years (38-87 years)	17 ± 8 months (4 - 29 months)	Below knee (71.4%) Above knee (20.4%) Through knee (4.2%) Hip disarticulation (2.0%) Hemipelvectomy (2.0%)	22.4%	24.5%	38.8%	Prevalence; moderate risk
Solonen (1962)	N = 1000	Male (100%)	Trauma (100.0%)	42 years (21-71 years)	14 years (12 - 38 years)	Above elbow (16.3%) Below elbow (9.7%) Above knee (26.7%) Below knee (43.3%) Foot (0.9%) Double limb loss (3.1%)	22.0%	67.8%	85.0%	Prevalence; high risk
Stannard and Porter (1993)	N = 3	Male (66.7%) Female (33.3%)	Trauma (66.7%) Vascular disease (33.3%)	37.3% (28 - 53 years)	NR	Above knee (66.7%) Upper limb (33.3%)	33.3%	100.0%	NR	Case report; moderate risk
Stone (1950)	N = 3	Male (66.7%) Female (33.3%)	Trauma (66.7%) Other (33.3%)	37.7 years (27 - 58 years)	NR	Below elbow (33.4%) Above knee (33.3%) Shoulder (33.3%)	33.3%	100.0%	NR	Case report; moderate risk

Thogersen et al. (2020)	N = 7	Male (71.4%) Female (28.6%)	Trauma (71.4%) Cancer (28.6%)	NR (33-75 years)	NR (4-42 years)	Above elbow (57.1%) Below elbow (42.9%)	100.0%	100.0%	NR	Before-after (pre-post); moderate risk
Topfner et al. (2001)	N = 2	Female (50.0%) Male (50.0%)	Trauma (100.0%)	46 years (39 - 53 years)	6 months	Below elbow (100.0%)	50.0%	100.0%	0.0%	Case report; moderate risk
Trevelyan et al. (2016)	N = 15	Male (80.0%) Female (20.0%)	Vascular (20.1%) Vascular/ulcer (33.3%) Trauma (13.3%) Trauma/Infection (33.3%)	NR (26-84 years)	NR (1-3 months)	Above knee (40.0%) Knee (6.7%) Below knee (53.3%)	6.7%	100.0%	NR	Qualitative; low risk
Trivedi et al. (1997)	N = 25	NR	Emergency (92.6%) Elective (7.4%)	NR (16-55 years)	6 months-2 years	Upper limb (40.0%) Lower limb (60.0%)	56.0%	16.0%	NR	Analytical cross- sectional; moderate risk
Vaso et al. (2014)	N = 31	Male (80.6%) Female (19.4%)	Trauma (64.6%) Diabetes (9.7%) Vascular (12.9%) Trauma and Vascular (3.2%) Scleroderma (3.2%) Septic (3.2%) Malignancy (3.2%)	NR (22-77 years)	NR (5 days - 30 years)	Above knee (32.4%) At knee (3.2%) Below knee (48.3%) Hip (3.2%) Foot (12.9%)	9.7%	100.0%	22.6%	Before-after (pre-post); moderate risk
Wakolbinger et al. (2018)	N = 8	Male (87.5%) Female (12.5%)	Trauma (50.0%) Peripheral artery disease (12.5%) Tumour (12.5%) Compartment syndrome (12.5%) Extravasation (12.5%)	NR (28-70 years)	NR (0.2-12 years)	Above elbow (25.0%) Below elbow (12.5%) Above knee (50.0%) Below knee (12.5%)	87.5%	100.0%	NR	Non-randomized controlled trial; high risk
Weiss and Fishman (1963)	N = 239	Male (92.1%) Female (7.9%)	Trauma (NR) Circulation problems (NR) Diabetes (NR) Osteomyelitis (NR) Infections (NR) Cancer (NR)	42.8 years (15-76 years)	13.9 years (1-59 years)	Above elbow (9.6%) Below elbow (11.3%) Above knee (33.9%) Below knee (30.1%) Missing (15.1%)	24.7%	40.0%	NR	Prevalence; high risk
Willoch et al. (2000)	N = 8	Male (75.0%) Female (25.0%)	Trauma (100.0%)	NR (25-68 years)	2.5 years (1-36 years)	Shoulder (25.0%) Above elbow (62.5.0%) Hand (12.5%)	50.0%	100.0%	NR	Before-after (pre- post); high risk
Yildirim and Kanan (2016)	N = 15	Male (86.7%) Female (13.3%)	Vascular disease (46.7%) Other (53.3%)	52.1 ± 16.7 years (NR)	NR	Lower limb (86.7%) Upper limb (13.3%)	20.0%	100.0%	NR	Before-after (pre-post); moderate risk
Zheng et al. (2009)	N = 14	Male (85.7%) Female (14.3%)	Trauma (100.0%)	55.6 ± 7.1 years (42-69 years)	NR (11 months -32 years)	Shoulder (42.9%) Arm (57.1%)	14.3%	100.0%	7.1%	Before-after (pre- post); moderate risk

Table 1. Overview of included studies

Note. SD, standard deviation; PLP, phantom limb pain; RLP, residual limb pain; PVD, peripheral vascular disease; NR, not reported; N/A, not applicable, *Described in greater detail within the source article.

(Bjorkman et al., 2016; De Graaf et al., 2016; Dettmers et al., 2001; Diers et al., 2010; Draganski et al., 2006; Flor et al., 1998; Flor et al., 2000; Grüsser, Winter, Muhlnickel, et al., 2001; Haber, 1958; Hunter et al., 2003, 2005; Jalavisto, 1950; Karl et al., 2004; Kew et al., 1994; Kikkert et al., 2018; Lyu et al., 2016; Machin & Williams, 1998; Makin et al., 2013; Mall et al., 1997; Montoya et al., 1997; Price, 1976; Trivedi et al., 1997), 16 were cross-sectional prevalence studies (Aldington et al., 2014; Carlen et al., 1978; Collins et al., 2018; Diers et al., 2022; Giummarra et al., 2010; Griffin et al., 2022; Lacoux et al., 2002; Mayer et al., 2008; Probstner et al., 2010; Richardson et al., 2015; Richardson et al., 2006; Richardson et al., 2018; Shukla et al., 1982; Sin et al., 2013; Solonen, 1962; Weiss & Fishman, 1963), 11 were before-after (pre-post) intervention studies (Bamford, 2006; De Nunzio et al., 2018; Foell et al., 2014; Kulkarni et al., 2020; Murray et al., 2006; Osumi et al., 2019; Thogersen et al., 2020; Vaso et al., 2014; Willoch et al., 2000; Yildirim & Kanan, 2016; Zheng et al., 2009), five were cohort studies (Giordano et al., 2021; Hunter et al., 2008; Jensen et al., 1983; Jensen et al., 1984; Richardson et al., 2007), four were qualitative studies (Bjorkman et al., 2010; Frank & Lorenzoni, 1989; Middleton & Ortiz-Catalan, 2020; Trevelyan et al., 2016), two were RCTs (Casale et al., 2009; Rothgangel et al., 2018), and two were non-randomized trials, (Schmalzl et al., 2011; Wakolbinger et al., 2018). The remaining four were prospective (Ahmed et al., 2017), case control (Kew et al., 1997), case series (Ramachandran & Rogers-Ramachandran, 1996), and outcome measurement (Kawashima & Mita, 2016) studies.

Sample Size. Sample size across studies ranged from 1 to 3,374 individuals with limb loss. Richardson et al. (2007) and Richardson et al. (2006) used the same participant cohort, as did Jensen et al. (1983) and Jensen et al. (1984). Moreover, the two participants included in Schmalzl et al. (2011) were also included as part of the eight participants reported on in Schmalzl et al.

(2014). Each publication focused on different research questions and reported unique outcome data; thus, all were included as separate studies in this review. To avoid inflating sample size estimates, the studies reporting the same participant group were counted only once when reporting total sample numbers. All other studies investigated independent samples.

Sex and Age Distribution. Most studies recruited more males than females, with the exception of 11 studies, where one recruited more female than male participants (Bjorkman et al., 2010), seven reported equal numbers of males and females (Bjorkman et al., 2016; De Nunzio et al., 2018; Grüsser, Winter, Schaefer, et al., 2001; Jensen et al., 1983; Jensen et al., 1984; Schmalzl et al., 2014; Topfner et al., 2001), and three were single case reports of females with limb loss (Dietrich et al., 2018; Halligan et al., 1994; Lee & Donovan, 1995). Several studies did not report the sex of their participants (Aldington et al., 2014; Kikkert et al., 2018; Makin et al., 2013; Mall et al., 1997; Ramachandran & Rogers-Ramachandran, 1996; Rognini et al., 2019; Shukla et al., 1982). All studies investigated adults (≥ 18 years old) as per the search strategy listed above, although six studies included individuals between the ages of 12-17 years within their sample consisting of mostly adults (Dettmers et al., 2001; Jalavisto, 1950; Mall et al., 1997; Price, 1976; Trivedi et al., 1997; Weiss & Fishman, 1963). Four studies did not provide the age, average age, or age range of their adult participants (Cuberovic et al., 2019; Graczyk et al., 2018; Rognini et al., 2019; Shukla et al., 1982).

Reason for Amputation. Thirty-five studies evaluated only individuals who had lost their limb due to trauma (Aldington et al., 2014; Bjorkman et al., 2016; Carlen et al., 1978; Cuberovic et al., 2019; Davies, 2013; De Graaf et al., 2016; Dietrich et al., 2018; Frank & Lorenzoni, 1989; Fukui et al., 2002; Giummarra et al., 2011; Graczyk et al., 2018; Haber, 1958; Hunter et al., 2005, 2008; Iida et al., 2004; Jalavisto, 1950; Katz et al., 1989; Kew et al., 1997; Lacoux et al.,

2002; Liaw et al., 1998; Lyu et al., 2016; Machin & Williams, 1998; Muraoka et al., 1996; Ortiz-Catalan et al., 2014; Pascual-Leone et al., 1996; Ramachandran et al., 2009; Rosen et al., 2001; Roux et al., 2001; Schmalzl et al., 2014; Schmalzl et al., 2011; Schmitt et al., 2022; Solonen, 1962; Topfner et al., 2001; Willoch et al., 2000; Zheng et al., 2009). Five studies evaluated only individuals who lost a limb due to cancer (Ahmed et al., 2017; Giordano et al., 2021; Grüsser et al., 2004; Grüsser, Winter, Schaefer, et al., 2001; Probstner et al., 2010). Another four studies only evaluated individuals who lost a limb due to infection (Belleggia & Birbaumer, 2001; Condes-Lara et al., 2000; Lee & Donovan, 1995; Restrepo-Garces et al., 2011). Two studies evaluated the same sample of participants who lost their limb due to peripheral vascular disease (Richardson et al., 2007; Richardson et al., 2006). Forty-eight studies evaluated participants with various reasons for amputation (Aglioti et al., 1994; Bamford, 2006; Bjorkman et al., 2010; Bradbrook, 2004; Casale et al., 2009; Collins et al., 2018; De Nunzio et al., 2018; Desmond et al., 2006; Dettmers et al., 2001; Diers et al., 2010; Diers et al., 2022; Draganski et al., 2006; Flor et al., 1998; Foell et al., 2014; Giummarra et al., 2010; Griffin et al., 2022; Grüsser, Winter, Muhlnickel, et al., 2001; Hunter et al., 2003; Jensen et al., 1983; Jensen et al., 1984; Karl et al., 2004; Katz & Melzack, 1987; Kawashima & Mita, 2016; Kew et al., 1994; Kikkert et al., 2018; Makin et al., 2013; Mall et al., 1997; Mayer et al., 2008; McAvinue & Robertson, 2011; Middleton & Ortiz-Catalan, 2020; Montoya et al., 1997; Morgenstern, 1964; Osumi et al., 2019; Price, 1976; Ramachandran & Rogers-Ramachandran, 1996; Richardson et al., 2015; Richardson et al., 2018; Rothgangel et al., 2018; Sin et al., 2013; Stannard & Porter, 1993; Stone, 1950; Thogersen et al., 2020; Trevelyan et al., 2016; Trivedi et al., 1997; Vaso et al., 2014; Wakolbinger et al., 2018; Weiss & Fishman, 1963; Yildirim & Kanan, 2016). Finally, six studies

did not report the reason for amputation within their samples (Flor et al., 2000; Halligan et al., 1994; Kulkarni et al., 2020; Murray et al., 2006; Rognini et al., 2019; Shukla et al., 1982).

Time Since Amputation. Seventeen studies did not report the time since amputation (exact, average, or range) (Bamford, 2006; Bjorkman et al., 2010; Bradbrook, 2004; Condes-Lara et al., 2000; Cuberovic et al., 2019; Graczyk et al., 2018; Haber, 1958; Kawashima & Mita, 2016; Kikkert et al., 2018; Lee & Donovan, 1995; Machin & Williams, 1998; Middleton & Ortiz-Catalan, 2020; Rognini et al., 2019; Rothgangel et al., 2018; Stannard & Porter, 1993; Stone, 1950; Yildirim & Kanan, 2016). Across the remaining 83 studies, participants were included who had undergone amputation from 0 days (on the day of amputation) to 86 years after amputation.

Extremity Amputated. Fifty studies evaluated only individuals who underwent an amputation of an upper limb (Belleggia & Birbaumer, 2001; Bjorkman et al., 2016; Cuberovic et al., 2019; Davies, 2013; De Graaf et al., 2016; De Nunzio et al., 2018; Desmond et al., 2006; Dettmers et al., 2001; Diers et al., 2010; Dietrich et al., 2018; Flor & Birbaumer, 2000; Flor et al., 1998; Foell et al., 2014; Fukui et al., 2002; Graczyk et al., 2018; Grüsser et al., 2004; Grüsser, Winter, Muhlneckel, et al., 2001; Grüsser, Winter, Schaefer, et al., 2001; Haber, 1958; Halligan et al., 1994; Hunter et al., 2003, 2005, 2008; Jalavisto, 1950; Karl et al., 2004; Kawashima & Mita, 2016; Kew et al., 1997; Kew et al., 1994; Kikkert et al., 2018; Kulkarni et al., 2020; Lacoux et al., 2002; Lee & Donovan, 1995; Lyu et al., 2016; Makin et al., 2013; Middleton & Ortiz-Catalan, 2020; Montoya et al., 1997; Ortiz-Catalan et al., 2014; Osumi et al., 2019; Pascual-Leone et al., 1996; Ramachandran et al., 2009; Ramachandran & Rogers-Ramachandran, 1996; Rognini et al., 2019; Rosen et al., 2001; Roux et al., 2001; Schmalzl et al., 2014; Schmalzl et al., 2011; Thogersen et al., 2020; Topfner et al., 2001; Willoch et al., 2000; Zheng et al., 2009), 20 studies investigated people who had lost only a lower limb (Aglioti et al.,

1994; Bradbrook, 2004; Casale et al., 2009; Condes-Lara et al., 2000; Giummarra et al., 2011; Katz et al., 1989; Liaw et al., 1998; McAvinue & Robertson, 2011; Morgenstern, 1964; Muraoka et al., 1996; Restrepo-Garces et al., 2011; Richardson et al., 2015; Richardson et al., 2007; Richardson et al., 2006; Richardson et al., 2018; Rothgangel et al., 2018; Schmitt et al., 2022; Sin et al., 2013; Trevelyan et al., 2016; Vaso et al., 2014), and the remaining 30 studies recruited individuals with both upper or lower limb loss (Ahmed et al., 2017; Aldington et al., 2014; Bamford, 2006; Bjorkman et al., 2010; Carlen et al., 1978; Collins et al., 2018; Diers et al., 2022; Draganski et al., 2006; Frank & Lorenzoni, 1989; Giordano et al., 2021; Giummarra et al., 2010; Griffin et al., 2022; Iida et al., 2004; Jensen et al., 1983; Jensen et al., 1984; Katz & Melzack, 1987; Machin & Williams, 1998; Mall et al., 1997; Mayer et al., 2008; Murray et al., 2006; Price, 1976; Probstner et al., 2010; Shukla et al., 1982; Solonen, 1962; Stannard & Porter, 1993; Stone, 1950; Trivedi et al., 1997; Wakolbinger et al., 2018; Weiss & Fishman, 1963; Yildirim & Kanan, 2016).

Percent Telescoping Reported. Across the 99 studies reporting the proportion of the sample who reported telescoping, rates ranged from 3.6% to 100.0%. The 100% prevalence values largely reflect case reports, which by definition must have reported telescoping due to our inclusion criteria. Figure 3 presents a histogram illustrating the distribution of telescoping prevalence as a function of sample size. One study (Mayer et al., 2008) noted the presence of telescoping but did not provide the proportion of participants who reported the phenomenon. It was therefore not included in these estimates. Figure 4 shows a bubble plot illustrating the distribution of telescoping prevalence as a function of sample size and time since amputation. Variability in telescoping prevalence across time since amputation and other factors is discussed in subsequent sections of the manuscript.

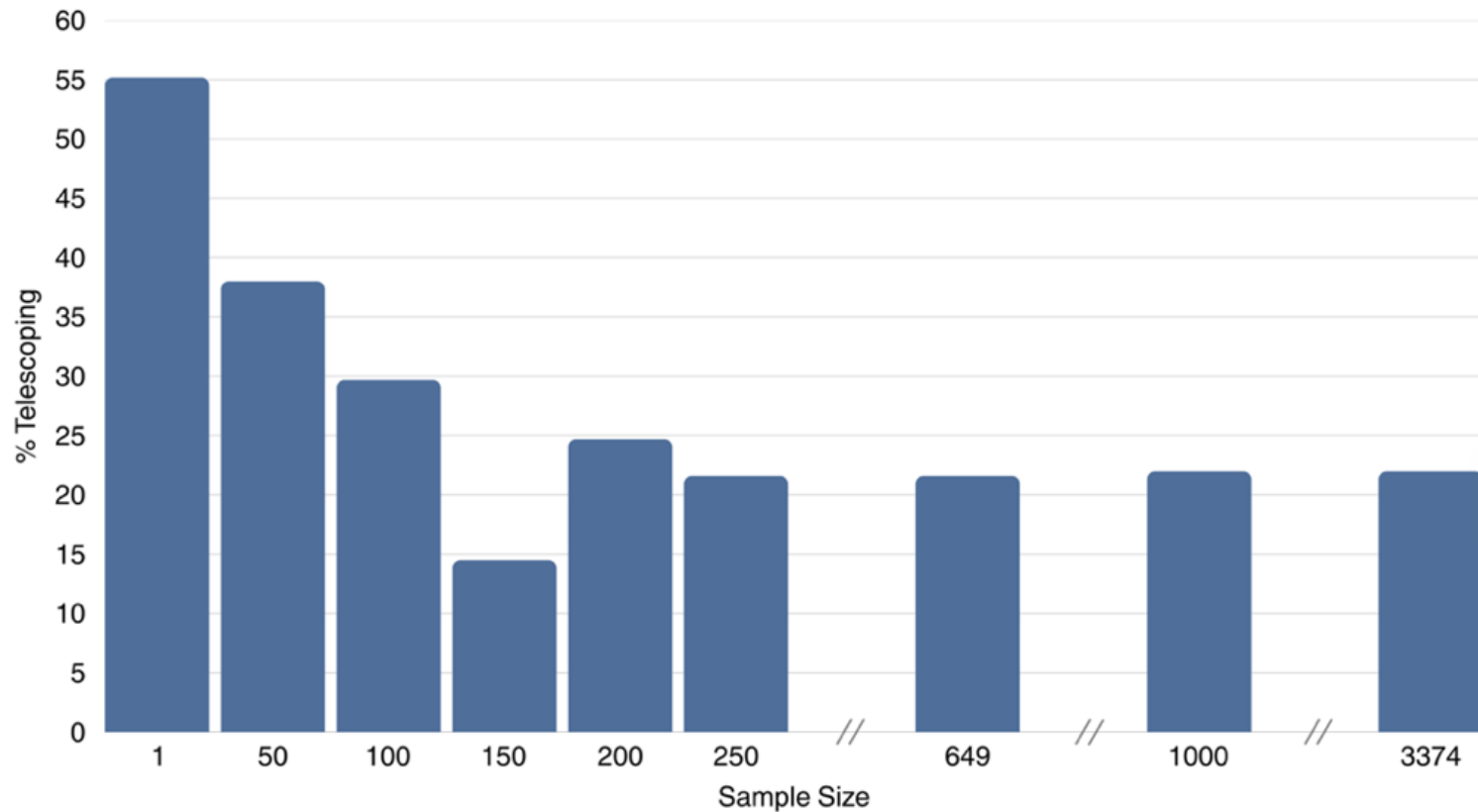


Figure 3. Distribution of Reported Telescoping by Study Sample Size

Histogram displaying the distribution of reported telescoping percentages across 99 studies by sample size. Bars depict the average percentage of participants reporting telescoping within grouped study sample size bins. The y-axis represents the percentage of participants who reported telescoping, and the x-axis shows study sample size, collapsed into 50-participant increments (e.g., 1-49, 50-99, 100-149, etc.) with the exception of the last three bars representing three studies of 649, 1000, and 3374 participants, respectively.

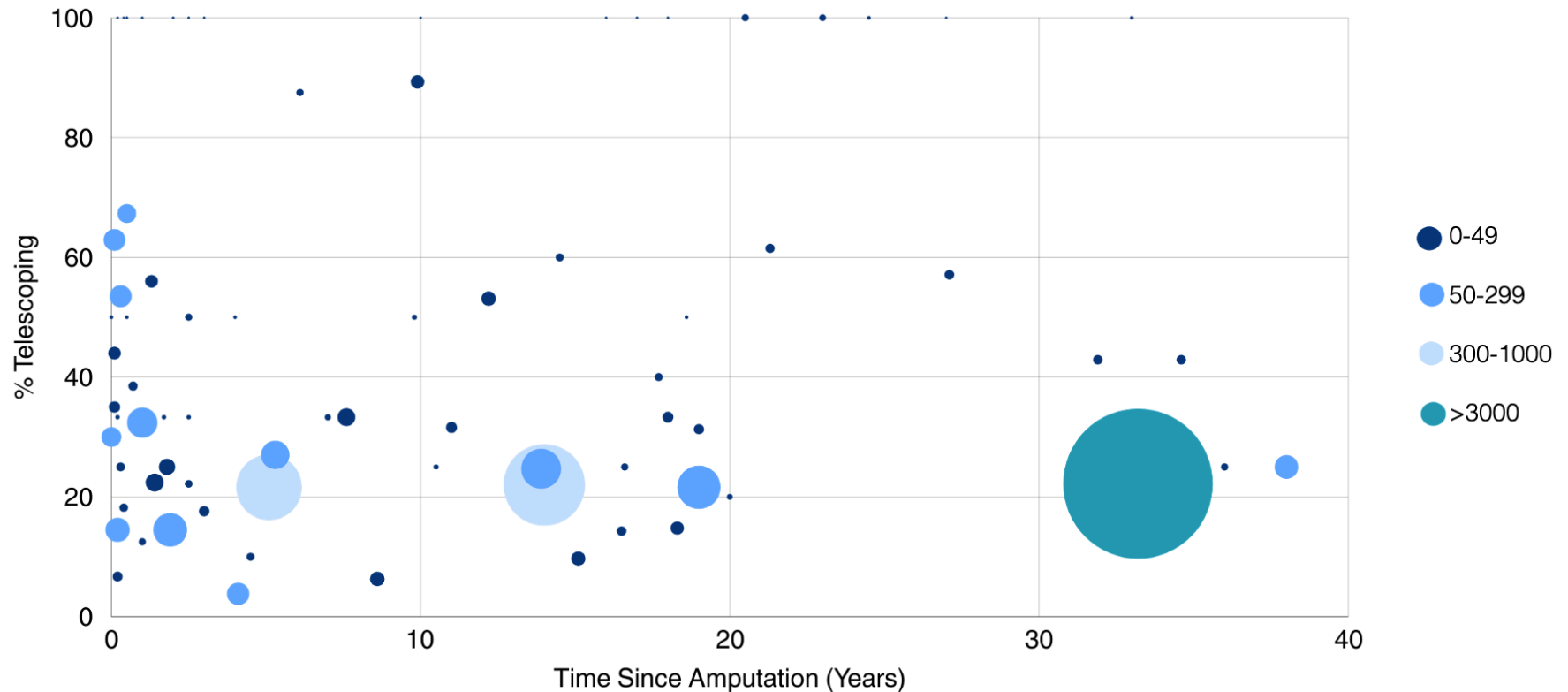


Figure 4. Reported Telescoping by Time Since Amputation and Study Sample Size

Bubble chart illustrating the percentage of participants reporting telescoping as a function of years since limb loss and study sample size for 82 studies. The y-axis shows the percentage of participants within the sample who reported telescoping, and the x-axis shows time since amputation. Bubble size reflects study sample size, with four size categories: ● 0-49, ● 50-299, ● 300-1000, and ● >3000 participants. Time since amputation was entered as the mean value reported in each study; when a mean was not available, the midpoint of the reported range was used. Studies that did not report time since amputation were excluded from this plot.

Percent PLP and RLP Reported. Nine studies (Collins et al., 2018; De Graaf et al., 2016; Giordano et al., 2021; Graczyk et al., 2018; Haber, 1958; Kew et al., 1994; Mayer et al., 2008; Rognini et al., 2019; Schmitt et al., 2022) did not report rate of PLP in their sample. In the remaining 91 studies, the prevalence rate of PLP varied between 11.1% and 100.0%, excluding single case reports in which the participant either had or did not have PLP. Finally, only 39 studies evaluated and/or reported RLP in their sample (Ahmed et al., 2017; Aldington et al., 2014; Belleggia & Birbaumer, 2001; Carlen et al., 1978; Casale et al., 2009; De Nunzio et al., 2018; Diers et al., 2022; Flor et al., 2000; Foell et al., 2014; Giordano et al., 2021; Giummarra et al., 2011; Grüsser et al., 2004; Grüsser, Winter, Muhlneckel, et al., 2001; Grüsser, Winter, Schaefer, et al., 2001; Hunter et al., 2005, 2008; Karl et al., 2004; Kikkert et al., 2018; Lacoux et al., 2002; Liaw et al., 1998; Lyu et al., 2016; Machin & Williams, 1998; Makin et al., 2013; McAvinue & Robertson, 2011; Montoya et al., 1997; Morgenstern, 1964; Muraoka et al., 1996; Probstner et al., 2010; Restrepo-Garces et al., 2011; Richardson et al., 2015; Richardson et al., 2007; Richardson et al., 2006; Richardson et al., 2018; Rosen et al., 2001; Sin et al., 2013; Solonen, 1962; Topfner et al., 2001; Vaso et al., 2014; Zheng et al., 2009), where rates varied between zero and 100% in studies with sample sizes greater than one.

3.3 Risk of bias

There was strong interrater agreement ($\kappa_w = .82$) for risk of bias assessment between reviewers Andrea Aternali and Heather Lumsden-Ruegg (McHugh, 2012). A summary of the risk-of-bias assessments is presented in Table 2, which details the number of studies in each design category rated as having low, moderate, or high risk of bias. Comprehensive item-level ratings for each study, based on the corresponding risk of bias instruments, are provided in Supplementary Tables 1-22. Tables 1-11 summarize ratings for each risk of bias domain, while

Tables 12-22 provide detailed, complete item-level responses used to determine the overall risk of bias rating for each study.

Of the 34 case reports, most had moderate risk of bias, where 10 had an overall rating of low risk of bias, 22 had moderate risk of bias, and 2 had high risk of bias (see Supplementary Tables 1 and 12). Most analytical cross-sectional studies were rated as either having a moderate risk ($n = 9$) or high risk of bias ($n = 8$). The remaining five were rated as having low risk (see Supplementary Tables 2 and 13). Twelve of the prevalence studies were rated as having a moderate risk of bias and five were rated as having a high risk of bias (See Supplementary Tables 3 and 14). Most before-after studies were rated as having an overall moderate risk of bias ($n = 7$), though three were rated as having high risk and one rated as having low risk of bias (see Supplementary Tables 4 and 15). The five cohort studies were rated as having a moderate risk of bias (see Supplementary Tables 5 and 16). Three of the qualitative studies were rated as having low risk of bias, though one was rated as having moderate risk (see Supplementary Tables 6 and 17). Both randomized controlled trials were rated as having an overall low risk of bias (see Supplementary Tables 7 and 18). The two non-randomized controlled trials were respectively rated as having a moderate and a high risk of bias overall (see Supplementary Tables 8 and 19). The single case control and case series studies included in the review were rated as having a low and moderate risk of bias overall, respectively (see Supplementary Tables 9-10 and 20-21). Finally, the outcome measurement study was rated as having high risk of bias (see Supplementary Tables 11 and 22). Taken together, most studies included in this review have a moderate risk of bias, with approximately one third of the studies consisting of case reports.

3.4 Outcomes

3.4.1 Prevalence of telescoping: Relationships with other factors

Overall rates. Several studies prospectively followed participants after amputation surgery while obtaining prevalence estimates of telescoping over time. In one study (Sin et al., 2013), telescoping was reported by 22.4% participants who had undergone amputation between four and 29 months earlier. In another study (Ahmed et al., 2017), 32.4% reported telescoping with a time since amputation between three and 12 months. In a longitudinal study, the incidence of telescoping decreased over time: three weeks after surgery, 35% of the sample endorsed telescoping, whereas at follow up, four to six months after surgery, 25% endorsed telescoping. (Giordano et al., 2021). In contrast, the incidence of telescoping increased over time in a sample followed by Jensen et al. (1983) and Jensen et al. (1984) longitudinally. Approximately 8% of participants reported telescoping at eight days post-amputation, increasing to about 30% at six

<i>Type of Study/Design</i>	<i>Low Risk</i>	<i>Moderate Risk</i>	<i>High Risk</i>
<i>Case reports (n = 34)</i>	10	22	2
<i>Cross-sectional (n = 22)</i>	5	9	8
<i>Prevalence (n = 17)</i>	0	12	5
<i>Before-after (pre-post) (n = 11)</i>	1	7	3
<i>Cohort (n = 5)</i>	0	5	0
<i>Qualitative (n = 4)</i>	3	1	0
<i>Randomized-controlled trials (n = 2)</i>	2	0	0
<i>Non-randomized trials (n = 2)</i>	0	1	1
<i>Case control (n = 1)</i>	1	0	0
<i>Case series (n = 1)</i>	0	1	0
<i>Outcome measurement (n = 1)</i>	0	0	1
<i>Total (N = 100)</i>	22	58	20

Table 2. Risk of Bias Assessments. Overall categorization according to type of study or design.

months and remaining relatively constant at 25% at two years. Another study followed two participants from before surgery to seven days after limb loss (Grüsser, Winter, Schaefer, et al., 2001). One of the participants developed telescoping, illustrating that telescoping can appear shortly after surgery.

Fourteen studies evaluated the prevalence of telescoping at one point in time, ranging between 1 week and 86 years after amputation (Aldington et al., 2014; Carlen et al., 1978; Collins et al., 2018; Diers et al., 2022; Giordano et al., 2021; Giummarra et al., 2010; Griffin et al., 2022; Lacoux et al., 2002; Probstner et al., 2010; Richardson et al., 2015; Richardson et al., 2006; Richardson et al., 2018; Shukla et al., 1982; Solonen, 1962; Weiss & Fishman, 1963). In the largest sample, consisting of 3,374 individuals with limb loss, 22.2% endorsed telescoping an average of 33.2 years (range: 0 to 86 years) after amputation (Diers et al., 2022). In addition to these prevalence studies, other investigations reported the presence of telescoping in the context of aims and analyses unrelated to telescoping. Across these studies, reports of telescoping varied substantially. Some documented relatively low prevalence between 3.5-14.5% (Bjorkman et al., 2010; Jalavisto, 1950; Price, 1976; Trevelyan et al., 2016), while others reported moderate levels between 22.2% and 42.8% (De Graaf et al., 2016; Dettmers et al., 2001; Flor et al., 2000; Hunter et al., 2003, 2005; Kew et al., 1994; Kulkarni et al., 2020; Liaw et al., 1998; Makin et al., 2013; Osumi et al., 2019) or even high rates over 90% (Katz et al., 1989; Kawashima & Mita, 2016). Together, these studies illustrate that telescoping is observed across a wide range of methodologies, samples, and time points but a reasonable estimate based on large scale studies suggests it occurs in approximately 20-25% of people between an average of five to 30 years after amputation.

Reason for Amputation. The samples included individuals who lost their limb due to cancer, trauma, vascular disease, infection, diabetes, and other reasons. Rates of telescoping varied from 3.8% to 67.3% overall. Rates were lowest in a cancer sample consisting of 75 individuals with limb loss (Probstner et al., 2010) and highest in a sample of 52 individuals who lost their limb due to peripheral vascular disease (Richardson et al., 2006). Giummarra et al. (2010) specifically investigated if reason for amputation was associated with rate of telescoping in their sample of 283 individuals with limb loss. They compared each etiological group (e.g., vascular-, diabetes-, cancer-, and trauma-related amputations) to a combined group consisting of all remaining causes. Telescoping was significantly less common among individuals who lost a limb due to vascular disease (6.9%) when compared to those with other causes of limb loss (25.9%). A similar pattern was observed for diabetes-related limb loss, with significantly lower telescoping rates (4.0%) compared to the combined group of non-diabetic causes (23.5%). Telescoping was significantly more frequent among those who experienced a traumatic amputation (29.7%) and cancer-related amputation (44.0%) compared to the combined group of those with other causes of limb loss (13.4% and 19.1%, respectively). Similarly, Weiss and Fishman (1963) reported a greater number of individuals experiencing shorter phantoms following traumatic limb loss compared to circulatory disease for both upper and lower limb loss. However, detailed prevalence data were only reported for lower limb loss: 25% of individuals whose limb loss was due to trauma reported telescoping, compared to 17% of those whose limb loss was attributed to vascular disease.

Small sample sizes limit the reliability of these findings and make generalization risky, but the results from Giummarra et al. (2010) and Weiss and Fishman (1963) suggest that telescoping occurs less frequently in disease states which require amputation due to peripheral vascular

insufficiency and peripheral neuropathy. On the other hand, telescoping is considerably more prevalent when amputation results from disease or trauma which leaves the peripheral vasculature and peripheral nervous system intact.

Extremity, Level, and Side of Amputation. Across the three studies that separately measured and compared telescoping rates in individuals with upper versus lower limb loss, all found that individuals with upper limb loss more frequently endorsed telescoping than those with lower limb loss (Carlen et al., 1978; Giummarra et al., 2010; Weiss & Fishman, 1963). Rates of telescoping for those with upper limb loss varied from 35.1% to 62.0%, whereas for those with lower limb loss, it varied from 16.7% to 45.0%. In a study including 11 individuals with bilateral limb loss and 29 with unilateral limb loss, the prevalence of telescoping was higher among those with unilateral limb loss (28.0%) compared to those with bilateral limb loss (9.0%) (Lacoux et al., 2002). The single participant with bilateral limb loss who reported telescoping experienced it in both limbs. In a case report, an individual with loss of both an upper and lower limb reported telescoping of the upper limb only, with no telescoping experienced in the lower limb (Iida et al., 2004). Weiss and Fishman (1963) reported that participants with distal amputations (e.g., below elbow, below knee) were more likely to endorse completely telescoped phantom limbs, whereas those with proximal amputations (e.g., above elbow, above knee) were more likely to endorse partially telescoped phantoms. Further, participants with proximal amputations were more likely to report a gradual shortening of their limb whereas those with a distal amputation usually reported that their phantom limb had always been telescoped (Weiss & Fishman, 1963). Giummarra et al. (2010) found that across individuals with upper and lower limb loss, higher level of amputation was associated with a greater likelihood of reporting telescoping. They also reported that telescoping was significantly less common among individuals who reported

functional impairment prior to limb loss (15.0%) compared to those without functional impairment (31.0%). In another investigation of 72 right-handed persons with upper or lower limb loss, all participants who had lost their left upper limb ($n = 10$) reported telescoping, whereas only half of the 24 individuals who had lost their right upper limb ($n = 12$) reported telescoping (Shukla et al., 1982).

Changes in Phantom Limb Length and Perceived Control. The degree to which the length of a person's phantom limb may change has also been explored. Giummarra et al. (2010) reported that seven individuals with limb loss in their sample (2.5%) endorsed changes in phantom length throughout the day (e.g., with movement, when waking, when going to bed, when putting on/taking off their prosthetic arm/leg, etc.). One study investigated the degree to which individuals could control their telescoping experience (e.g., contracting/expanding the phantom limb at will). Of the 21.6% of individuals who endorsed telescoping in the 649 person sample, 15% ($n = 21$) endorsed being able to control the degree to which their limb telescoped in a given moment (Griffin et al., 2022).

3.4.2 Telescoping and PLP

Thirty-nine studies investigated the relationship between telescoping and PLP (Aglioti et al., 1994; Bamford, 2006; Belleggia & Birbaumer, 2001; Bradbrook, 2004; Davies, 2013; Diers et al., 2010; Diers et al., 2022; Draganski et al., 2006; Flor et al., 1998; Fukui et al., 2002; Giummarra et al., 2011; Griffin et al., 2022; Grüsser et al., 2004; Grüsser, Winter, Muhl nickel, et al., 2001; Grüsser, Winter, Schaefer, et al., 2001; Hunter et al., 2008; Jensen et al., 1983; Karl et al., 2004; Katz & Melzack, 1987; Kikkert et al., 2018; Lacoux et al., 2002; Lee & Donovan, 1995; Machin & Williams, 1998; Montoya et al., 1997; Morgenstern, 1964; Muraoka et al., 1996; Murray et al., 2006; Ortiz-Catalan et al., 2014; Pascual-Leone et al., 1996; Ramachandran

et al., 2009; Ramachandran & Rogers-Ramachandran, 1996; Restrepo-Garces et al., 2011; Richardson et al., 2007; Richardson et al., 2006; Rosen et al., 2001; Roux et al., 2001; Schmalzl et al., 2011; Stone, 1950; Weiss & Fishman, 1963). Of these, 12 (n = 4127) reported a negative relationship (i.e., shorter phantom limbs associated with higher rates of PLP), 19 (n = 369) reported a positive relationship (i.e., shorter phantom limbs associated with lower rates of PLP), and eight (n = 171) did not find a relationship between phantom limb length and PLP.

Negative Association Between Phantom Limb Length and PLP. A substantial body of research indicates a negative association between phantom limb length and PLP, where shorter limbs (i.e., telescoping) are associated with a higher prevalence of PLP or greater PLP intensity. Griffin et al. (2022), Diers et al. (2022), Grüsser, Winter, Muhlneckel, et al. (2001), Flor et al. (1998), Karl et al. (2004), Draganski et al. (2006), Giummarra et al. (2011), Grüsser et al. (2004), Grüsser, Winter, Schaefer, et al. (2001), Machin and Williams (1998), Ortiz-Catalan et al. (2014), and Schmalzl et al. (2011) all reported findings consistent with this association.

In an analysis of 508 participants with limb loss, Griffin et al. (2022) found that, after statistically controlling for age and gender, participants who reported telescoping (n = 140) (vs. those who did not report telescoping) also reported significantly higher levels of PLP, including pain over the past day, average PLP, and worst PLP ever experienced. Diers et al. (2022) similarly observed that telescoping occurred significantly more frequently among individuals with higher-intensity PLP than those with absent or low PLP. In their sample of 3,374 participants, the proportion of individuals who reported telescoping was significantly lowest in the group who did not report PLP (15.6%), moderate in the group that reported low intensity PLP (32.1%), and highest in the group that reported high intensity PLP (45.9%) (Diers et al., 2022). Their multiple regression analysis results further indicated that a greater extent of telescoping

(i.e., shorter phantom length) was associated with higher PLP intensity. In two smaller studies consisting of eight and 16 subjects respectively, a significant positive relationship between PLP and telescoping was reported (Grüsser, Winter, Muhlneckel, et al., 2001; Karl et al., 2004).

Additional studies, though not explicitly focused on telescoping and PLP, documented their co-occurrence. Draganski et al. (2006) reported that 25 of 28 participants experienced telescoping and PLP. Giummarra et al. (2011) described a case of late-onset PLP and telescoping that emerged during chemotherapy, highlighting the potential relationship between telescoping and PLP in this context. Other studies have likewise noted participants reporting both phenomena (Grüsser et al., 2004; Grüsser, Winter, Schaefer, et al., 2001). Flor et al. (1998) found that among nine participants with traumatic limb loss, all four individuals who experienced PLP reported telescoping, whereas only two of the five participants without PLP did so. Moreover, Machin and Williams (1998) observed that the two participants who endorsed telescoping in their sample of 26 participants also reported PLP, one with stable pain and one with worsening pain.

Two intervention-related studies provide further support for a negative association between phantom limb length and PLP. In a case report, Ortiz-Catalan et al. (2014) described an individual with upper-limb loss whose telescoped phantom gradually returned to a normal length after engaging in a virtual reality intervention, coinciding with reductions in PLP. In a study of eight individuals with limb loss, Schmalzl et al. (2011) found that a full-body illusion temporarily reversed the sensation of telescoping and reduced PLP intensity in two out of the four individuals experiencing pain.

Positive Association Between Phantom Limb Length and PLP. Multiple studies have reported a positive association between phantom limb length and PLP, where shorter phantom limbs (i.e., telescoped) are associated with the absence of PLP or less intense PLP. Work by

Jensen et al. (1983), Hunter et al. (2008), Pascual-Leone et al. (1996), and Weiss and Fishman (1963) demonstrated that shortened phantoms were more often associated with reduced PLP. Others, including Bamford (2006), Belleggia and Birbaumer (2001), Bradbrook (2004), Davies (2013), Fukui et al. (2002), Katz and Melzack (1987), Lee and Donovan (1995), Morgenstern (1964), Muraoka et al. (1996), Murray et al. (2006), Ramachandran et al. (2009), Ramachandran and Rogers-Ramachandran (1996), and Rosen et al. (2001) have reported reductions in PLP that occur alongside telescoping. Similarly, Restrepo-Garces et al. (2011) and Roux et al. (2001) have reported reductions in PLP in individuals reporting telescoping.

In a large sample of 239 individuals with limb loss, Weiss and Fishman (1963) found that unpleasant phantom sensations, including PLP, were more frequently reported with same (as contralateral intact limb) length phantoms than with shortened phantoms for participants with lower limb amputations. Similar findings were reported in a six-month longitudinal study by Jensen et al. (1983) of 58 individuals with limb loss. Approximately 30% of participants reported a noticeable shortening of their phantom limb, which was most often observed in those who did not experience PLP. However, the authors did not report the exact frequency of this occurrence, nor whether this was statistically significant. Additional longitudinal evidence from Hunter et al. (2008) reported similar findings. Eleven participants were followed to examine the development of PLP in relation to non-painful phantom sensations, telescoping, and prosthesis use. Three participants reported telescoping at baseline (less than 6 months post-surgery) and again at least 11.5 months later. Notably, two of these three individuals who reported telescoping never reported any PLP (Hunter et al., 2008). Further case evidence supports this pattern: Pascual-Leone et al. (1996) described a spontaneous reduction in PLP accompanied by phantom arm shortening 11 months post amputation.

A substantial number of studies have documented telescoping that accompanied reductions in PLP during or after various PLP interventions. Eleven case reports described individuals with limb loss who underwent an intervention, including electromyographic biofeedback, acupuncture, electroconvulsive therapy, transcutaneous electrical stimulation, hypnosis, mirror therapy, immersive virtual reality, sensory deconditioning, interscalene brachial plexus block or general anesthesia (Belleggia & Birbaumer, 2001; Bradbrook, 2004; Davies, 2013; Fukui et al., 2002; Katz & Melzack, 1987; Lee & Donovan, 1995; Morgenstern, 1964; Muraoka et al., 1996; Murray et al., 2006; Ramachandran et al., 2009; Rosen et al., 2001). In each case, after the intervention, the individuals reported a reduction in PLP and a shortening of their phantom limb. For several, these results were maintained over extended periods of time, including five months (Katz & Melzack, 1987), one year (Lee & Donovan, 1995; Morgenstern, 1964), and three years later (Katz & Melzack, 1987). In a study investigating the effectiveness of mirror therapy in 10 individuals with limb loss, one of the participants experienced a “permanent disappearance” of PLP with repeated practice of mirror therapy along with telescoping of the phantom limb (Ramachandran & Rogers-Ramachandran, 1996). Bamford (2006) examined the effectiveness of a combination of hypnosis, visualization, psychological therapies, and self-hypnosis in treating PLP in a sample of 25 individuals with limb loss. They reported a significant reduction in PLP following six weekly sessions and, in most cases, this reduced pain was associated with telescoping of the phantom limb.

Additional case reports have reported reductions in PLP among individuals exhibiting telescoping at the start of PLP treatment. Restrepo-Garces et al. (2011) described a participant who reported telescoping and experienced a successful reduction in their post-amputation pain following pulsed radiofrequency ablation. Roux et al. (2001) investigated if motor cortex

stimulation could be effective for treating PLP in a person who reported both persistent PLP and telescoping. This individual achieved a 70% reduction in PLP.

Absence of a Significant Association Between Telescoping and PLP. The remaining studies investigated the relationship between PLP and telescoping with sample sizes between three and 52 participants. Aglioti et al. (1994), Diers et al. (2010), Kikkert et al. (2018), Lacoux et al. (2002), Montoya et al. (1997), Richardson et al. (2007), Richardson et al. (2006) and Stone (1950) did not find the presence of telescoping to be significantly associated with PLP. Lacoux et al. (2002) found that the presence of telescoping was not associated with the presence of PLP in their sample of 40 individuals with limb loss. However, they identified a significant relationship between neuromas (e.g., disorganized growth of nerve fibres in the residual limb that can develop after ligation and transection of major nerve trunks) and telescoping. Specifically, 70% of telescoped phantoms ($n = 7/10$) were associated with the presence of neuromas whereas only 16% of normal-length phantoms ($n = 4/25$) were associated with the presence of neuromas. Montoya et al. (1997) examined PLP in 32 individuals who lost a limb, half of whom experienced PLP. They found no significant difference in the extent of phantom limb telescoping between the participants who reported PLP (mean shortening of 84.2%) and those who did not report PLP (mean shortening of 99.0%), where greater percentage shortening refers to shorter phantom limbs. In a sample of 27 individuals with limb loss, Kikkert et al. (2018) reported that they did not find a significant difference in chronic PLP severity between individuals who reported telescoping ($n = 14$) and those who had normal length phantoms ($n = 13$). Richardson et al. (2007) and Richardson et al. (2006), drawing on the same cohort of 52 individuals followed over six months, found no evidence of an association between PLP and telescoping. In the sample studied by Diers et al. (2010), eight of the 14 participants reported telescoping; among

them, half reported PLP while the other half did not. Stone (1950) investigated the effectiveness of surgical resection of specific brain regions to treat PLP in three individuals. In this study, all three individuals experienced complete elimination of PLP; however, only one had reported telescoping before surgery, and this was the only participant to remain aware of their shortened phantom limb afterward. Finally, in a case report of three individuals, Aglioti et al. (1994) found that one experienced both telescoping and PLP, while another experience PLP without telescoping.

Taken together, the evidence suggests that telescoping is more likely to be associated with the presence of and/or a greater intensity of PLP, particularly when considering the collective weight and methodological quality of the available studies. Findings supporting a negative association between phantom limb length and PLP are driven by studies with the largest sample sizes and are predominantly derived from studies rated as having moderate risk of bias, including large cross-sectional analyses and longitudinal designs. This represents the comparatively strongest level of evidence currently available in this literature. Studies suggesting that telescoping is associated with the absence of PLP or less intense phantom limb pain, while informative, largely consist of small sample sizes and case reports, which inherently carry a higher risk of bias despite often being rated as moderate to high in methodological quality. Finally, studies reporting no association between telescoping and PLP represent the smallest collective sample size overall and are similarly characterized by low to moderate risk of bias. As such, although studies investigating the relationship between telescoping and PLP are mixed, the evidence taken together supports an association between telescoping and the presence of PLP.

3.4.3 Telescoping and PLP treatment response

Thirteen studies have investigated the possible relationship between telescoping and PLP treatment response (Casale et al., 2009; De Nunzio et al., 2018; Desmond et al., 2006; Foell et al., 2014; McAvinue & Robertson, 2011; Rothgangel et al., 2018; Stannard & Porter, 1993; Thogersen et al., 2020; Topfner et al., 2001; Vaso et al., 2014; Wakolbinger et al., 2018; Yildirim & Kanan, 2016; Zheng et al., 2009). Of these, four studies (n = 92) found that individuals with telescoped phantoms experienced greater benefit from PLP treatments than those with normal-length phantoms; three studies (n = 20) reported that telescoping was associated with a poorer treatment response; and four studies (n = 64) found no relationship or reported inconclusive findings regarding the association between telescoping and treatment response.

Telescoping Associated with Greater Relief of PLP in Response to Treatment. Four studies highlighted a positive relationship between telescoping and response to various PLP treatments. Rothgangel et al. (2018), Thogersen et al. (2020), Topfner et al. (2001), and Wakolbinger et al. (2018) reported that individuals with telescoped phantoms experienced greater benefit from PLP treatments compared to those with normal length phantoms. Rothgangel et al. (2018) explored the effectiveness of traditional mirror therapy, teletreatment, and sensorimotor exercises in a three-arm RCT. In their sample of 75 individuals with lower limb loss, mirror therapy resulted in significantly greater reductions in average PLP intensity in participants, who, prior to treatment, reported telescoped phantoms than in participants with normal length phantoms (Rothgangel et al., 2018). Thogersen et al. (2020) investigated the effectiveness of an augmented reality-based intervention for the treatment of PLP in seven individuals with telescoped upper-extremity phantoms. A significant reduction in PLP was reported by six of the seven participants. They also reported that embodiment and agency scores

were significantly correlated to telescoping such that the more telescoped, the less agency and embodiment the participants experienced over their phantom limb. The authors suggest that this may be indicative of a reduced ability to mentally integrate the visual representation of the phantom limb into their overall body representation, which can be related to the degree of telescoping and PLP. Wakolbinger et al. (2018) explored the effectiveness of tactile discrimination training in reducing PLP in a controlled trial. They investigated eight individuals with limb loss, seven of whom experienced phantom limb shortening at baseline. Significant change in phantom length was not observed over the course of the study in either the treatment or control group. Nevertheless, there was a significant correlation between decrease in PLP intensity and increase in phantom length four weeks after the intervention (Wakolbinger et al., 2018). Finally, a case report of two individuals investigated the use of pre-emptive analgesia to reduce PLP after amputation surgery (Topfner et al., 2001). One individual developed intensive PLP which persisted six months after surgery and the other, who also reported telescoping, had PLP that significantly decreased over the course of six months, despite similar pain management.

Telescoping Associated with Poor or No Relief of PLP in Response to Treatment. Foell et al. (2014) investigated the effects of daily mirror training over four weeks in 13 individuals with upper limb loss and chronic PLP. They found that individuals who reported telescoping prior to treatment ($n = 8$) showed little improvement from mirror training, whereas those without a telescoped phantom ($n = 5$) reported a significant reduction in PLP intensity. Both groups had comparable PLP intensity at baseline but differed significantly by the end of treatment. The authors also measured “perceived intensity” of telescoping (rated from 0 = no telescope to 100 = very intense) which appears to refer to percentage telescoping. Although it is unclear how “intensity” was measured, telescoping intensity was negatively correlated with treatment

effectiveness (e.g., the more telescoped the phantom limb, the poorer the treatment response). Moreover, three additional small-sample studies found evidence for a pattern suggesting that telescoping was associated with poor response to treatment. Desmond et al. (2006) conducted an exploratory case study evaluating standard mirror box and augmented-reality mirror box interventions for PLP in three individuals with limb loss, one of whom reported telescoping. The intervention increased two participants' ability to move their phantom limb and induced PLP in the third, the same participant who reported telescoping. McAvinue and Robertson (2011) investigated the effectiveness of a motor imagery training and phantom limb movement therapy in four participants with PLP. The only participant to report telescoping, despite experiencing infrequent PLP at baseline, ultimately withdrew from treatment after the re-emergence of a previously resolved phantom pain. This is in contrast to the three participants without telescoping, two of whom demonstrated some improvement from therapy while one showed no appreciable change.

No Evidence of an Association Between Telescoping and PLP Treatment Response. In contrast to the findings described above, six studies did not find evidence supporting an association between telescoping and PLP treatment outcomes. Four studies (De Nunzio et al., 2018; Stannard & Porter, 1993; Yildirim & Kanan, 2016; Zheng et al., 2009) did not find that individuals with telescoped phantoms experience more or less benefit to treatment than those with normal length phantoms. Two studies (Casale et al., 2009; Vaso et al., 2014) indirectly suggest that there is not relationship between telescoping and PLP treatment outcomes.

Yildirim and Kanan (2016) examined the effectiveness of four weeks of at-home mirror therapy to reduce PLP in 15 individuals with upper or lower limb loss. The effectiveness of the treatment and amputation-related characteristics, including telescoping, were not related.

Interestingly, only individuals who were not using a prosthesis reported a significantly greater benefit from the intervention (Yildirim & Kanan, 2016). De Nunzio et al. (2018) similarly investigated whether targeted training of phantom limb movement control could reduce chronic PLP in 10 individuals with limb loss. All participants, including four who reported telescoping at baseline, showed a reduction in PLP immediately after training, which was maintained at follow-up six weeks later. These studies suggest that those with and without a telescoped phantom may benefit equally from PLP interventions. Zheng et al. (2009) examined outcomes following dorsal root entry zone (DREZ) lesioning in 14 individuals with PLP, two of whom reported telescoping before and after the intervention. Overall, nine participants experienced satisfactory pain relief, including one individual with telescoping. Among the five participants with poor treatment response, one also reported telescoping (Zheng et al., 2009). These results suggest that DREZ lesioning yielded mixed outcomes for individuals regardless of the presence of telescoping. Stannard and Porter (1993) described three cases of individuals treated with ketamine infusions for PLP. They all experienced pain relief; however, two found the treatment psychologically distressing. One of these individuals, who did not report telescoping, discontinued use, whereas the other individual who reported telescoping prior to treatment limited ketamine use to nighttime only (Stannard & Porter, 1993). This suggests that ketamine may be similarly effective for individuals with and without telescoping and its distressing side effects can occur in either group.

In a study of 31 individuals with limb loss, including at least three who reported telescoping, Vaso et al. (2014) demonstrated that lidocaine blocks effectively reduced PLP. However, the authors did not report whether outcomes differed for participants with telescoped versus non-telescoped phantoms; the overall pain reduction was described only at the group

level. Finally, a double-blind crossover study in eight patients with PLP reported that an injection of bupivacaine significantly reduced PLP in comparison to saline (Casale et al., 2009). The authors reported that in one participant, saline induced a transient telescoping sensation, though the authors do not report how many (if any) of the participants who received bupivacaine reported telescoping or whether the saline-induced telescoping also reduce PLP intensity. Thus, even when telescoping was briefly observed, it occurred in response to a control saline injection and presumably was not associated with PLP relief.

To summarize, although the findings are somewhat mixed, the literature suggests that individuals with telescoped phantoms may derive greater benefit from PLP treatments than those with normal-length phantoms. Support for this pattern is driven largely by studies with stronger designs and larger samples, including two RCTs, one with low risk of bias and one with high risk of bias, that collectively account of the greater number of participants and report superior treatment response among those reporting telescoping. In contrast, evidence linking telescoping to poorer treatment outcomes or to no differential response is derived from studies with smaller sample sizes and lower methodological quality, including case reports and before-after (pre-post) designs with predominantly moderate risk of bias. Overall, the small sample sizes in many studies limit the reliability of these findings and make generalizations difficult. However, the weighting of higher-quality and higher-powered studies would suggest that individuals with telescoped phantoms may derive greater benefit from PLP treatments.

3.4.4 Telescoping and biological and psychosocial factors

Four studies reported on the relationship between telescoping and psychosocial factors (Giordano et al., 2021; Mall et al., 1997; Trivedi et al., 1997; Weiss & Fishman, 1963). One study investigated the relationship between telescoping and demographic factors. In a sample of

239 individuals with limb loss, Weiss and Fishman (1963) did not find a significant relationship between phantom length and age, time since amputation, or sex. Two studies explored the relationship between telescoping and mental health. In an investigation of 25 individuals who had their limb amputated six weeks prior, telescoping was reported more frequently by individuals without a psychiatric diagnosis than those with a psychiatric diagnosis, though this difference was not statistically significant (Mall et al., 1997). Investigators also looked at this relationship in individuals who had reported limb loss six months to two years prior and did not find a significant difference in the presence of telescoping experienced by individuals with or without a psychiatric diagnosis (Trivedi et al., 1997). These researchers also reported that the presence of telescoping did not significantly differ between side of limb (e.g., right/left) or level of limb (e.g., upper/lower) in persons who experienced limb loss six weeks (Mall et al., 1997) or six months to two years earlier (Trivedi et al., 1997). Finally, the relationship between presurgical pain and telescoping has also been investigated. Giordano et al. (2021) reported that presurgical pain was significantly associated with the report of telescoping approximately three weeks after surgery in a sample of 20 patients who underwent limb amputation for sarcoma.

3.4.5 Telescoping and other non-painful phantom sensations

Four studies have investigated the relationship between telescoping and non-painful phantom sensations. For example, Weiss and Fishman (1963) reported that of the 239 individuals with limb loss included in their sample, those who reported a consistently strong or very strong phantom sensation experience predominantly had phantom limbs of normal length rather than a shortened phantom. Moreover, Haber (1958) investigated several other non-painful sensations in their sample of 24 individuals with limb loss. They reported that individuals with telescoped phantoms had better residual limb sensitivity than those who did not report telescoping. There

was also greater improvement of tactile discrimination in persons with telescoped phantoms. In the same study, they reported that none of the participants with telescoped phantoms reported being able to penetrate solid objects with their phantoms, though 50% of those with non-telescoped phantoms reported that they could move their phantom through solid objects (Haber, 1958). Additionally, Bjorkman et al. (2016) examined a sample of 10 individuals with unilateral forearm limb loss. All participants experienced referred sensations, such as phantom finger sensations elicited by stimulation of specific skin areas on the residual limb, known as a phantom hand map. Of the 10 participants, six endorsed telescoping, providing support for a possible association between telescoping and certain non-painful phantom sensory phenomena. Finally, Lyu et al. (2016) investigated phantom limb perception and its potential impact on motor imagery performance in 27 individuals with upper limb loss. Four participants reported telescoping of the limb, which the authors suggested may have interfered with the motor imagery task in these individuals.

3.4.6 Telescoping and cortical reorganization

Ten studies have examined cortical reorganization in individuals who report telescoping. Eight of these studies, Condes-Lara et al. (2000), Grüsser, Winter, Muhlneckel, et al. (2001), Dietrich et al. (2018), Kew et al. (1997), Topfner et al. (2001), Pascual-Leone et al. (1996), Halligan et al. (1994), and Willoch et al. (2000), reported evidence of cortical reorganization in participants with telescoped phantoms ($n = 32$). Flor et al. (1998) and Karl et al. (2004), involving a combined total of 22 participants, found no evidence of such reorganization.

Evidence of Cortical Reorganization in Telescoping. In a case report using functional magnetic resonance imaging, the presence of telescoping was associated with intense activation of the left lenticular nucleus and bilateral ventral posterolateral thalamic nuclei (Condes-Lara et

al., 2000). Another study of 16 individuals with limb loss reported that the percentage of telescoping (i.e., the degree of telescoping) was significantly positively associated with the amount of cortical reorganization in the primary somatosensory cortex (S1) observed (Grüsser, Winter, Muhl nickel, et al., 2001). Those who reported a shorter phantom length (e.g., greater percentage of telescoping) exhibited significantly more cortical reorganization than those without telescoping (Grüsser, Winter, Muhl nickel, et al., 2001). However, because percentage of telescoping was also significantly positively correlated with PLP in this sample, it was not possible to determine whether the cortical changes were specifically related to telescoping or PLP. The authors state that it is possible that telescoping is more related to changes in brain regions that are not related to PLP, such as those in the posterior parietal cortex (Grüsser, Winter, Muhl nickel, et al., 2001). Similarly, Dietrich et al. (2018) presented a case report examining neural activity associated with cramping PLP in an individual who also reported telescoping. Functional imaging showed activation of the hand area in S1 during the referred cramping sensation, suggesting a link between altered somatosensory representation and the patient's phantom experiences (Dietrich et al., 2018).

Kew et al. (1997) investigated cortical responses to referred sensations to the phantom limb in two individuals with limb loss, both of whom reported telescoping. Both individuals underwent body surface tactile stimulation on the side of their upper limb amputations (e.g., pectoral region or upper scapula). This stimulation elicited referred sensations, produced substantially larger S1 activation, and increased cerebral blood flow compared to stimulation of the intact side. In one participant, the extent of activation exceeded that observed during digit stimulation in a healthy control, suggesting marked somatosensory reorganization associated with phantom-related phenomena. Topfner et al. (2001) examined two individuals who both

received a brachial plexus block following amputation surgery. The two cases showed different clinical and neural outcomes: the participant who reported telescoping showed significant reorganization of S1, accompanied by a substantial reduction in PLP at six months, whereas the other showed minimal S1 plasticity and persistent pain (Topfner et al., 2001). This suggests that reorganization in S1 may vary independently of analgesic regimen and may be associated with specific phantom limb phenomena such as telescoping.

Pascual-Leone et al. (1996) described a case involving an individual with an upper-extremity amputation who reported telescoping. Over time, the phantom sensations (e.g., thumb movements) evoked by non-invasive transcranial magnetic stimulation (TMS) changed over time: early after amputation, eleven weeks after amputation, and four months after amputation. Initially, TMS evoked phantom thumb movements, but later it evoked motor potentials in the face and residual limb. This suggests that that cortical area of the original representation of the amputated hand was re-occupied by nearby representations of the face and arm. Likewise, Halligan et al. (1994) reported a single case involving a woman with an above elbow amputation who exhibited progressive changes in referred facial sensations over time. Initially, stimulation of specific regions on the right side of the face evoked precisely mapped sensations in the phantom limb. One year later, she reported a telescoped phantom, and this mapping had become highly disorganized, and a new, similarly disrupted pattern of referred sensations emerged on the left side of the face. The authors suggested that these evolving patterns may reflect ongoing morphological changes following early somatotopic reorganization (Halligan et al., 1994). Finally, Willoch et al. (2000) investigated phantom limb experiences in eight individuals with upper limb loss, four of whom reported telescoping at the start of the study. Using hypnosis, researchers were able to elicit phantom sensations that closely resembled the phantom sensations

participants' experienced daily. Functional imaging revealed distinct patterns of brain activation for phantom movement versus PLP, with painful movements resembling involuntary actions (Willoch et al., 2000). However, the study did not specifically analyze or compare outcomes in relation to telescoping.

No Evidence of Cortical Reorganization in Telescoping. Two studies have not found telescoping to be associated with cortical reorganization. Flor et al. (1998) reported that cortical reorganization was not significantly correlated with non-painful phantom sensations, including telescoping, in an investigation of 14 individuals with congenital and traumatic upper-extremity limb loss. In a sample of eight individuals who lost an upper limb, of whom two endorsed telescoping, significant correlations were not observed between percentage of telescoping and movement-related cortical potential-amplitudes to tongue protrusions, hand movements, and foot movements on the amputated and intact sides (Karl et al., 2004). Moreover, the authors reported no significant correlations between telescoping and the distance separating the tongue movement representation from the mirrored movement representation of the intact hand. Likewise, telescoping was not significantly correlated with cortical reorganization of foot movement representations.

Overall, telescoping has been associated with cortical reorganization, particularly within primary somatosensory cortex and adjacent sensorimotor networks. Several studies suggest that telescoping may co-occur with more pronounced alterations in somatotopic representation, as reflected in changes to S1 activation, referred sensations, and changing cortical maps. The studies supporting an association between telescoping and cortical reorganization collectively comprise larger overall sample sizes and were almost uniformly rated as having moderate risk of bias, even though it consisted of case reports and small sample studies. Nevertheless, two studies

failed to detect significant associations between telescoping and measures of cortical reorganization. Among these two studies, one was rated as high risk of bias and the other as moderate risk. Taken together, when weighted by sample size and study quality, the evidence favors an association between telescoping and cortical reorganization. But the frequent co-occurrence of telescoping and PLP limits causal inference and makes it difficult to determine whether observed cortical changes are specific to telescoping or reflect neural alterations related to post-amputation pain more broadly.

3.4.7 Telescoping and Wearing of a Prosthesis

Eight studies have investigated telescoping in the context of wearing a prosthetic arm or leg. Only one study has investigated the relationship between telescoping and prosthetic ownership, referring to the subjective feeling that a prosthetic limb is part of one's own body. The remaining seven studies investigated the relationship between prosthesis use and/or embodiment (e.g., the extent to which the individual experiences their prosthetic limb as their own).

Schmalzl et al. (2014) examined prosthetic ownership in two individuals with upper limb loss, both of whom reported telescoping. Using a rubber-hand-type illusion, an illusion in which a person is made to feel that a prosthetic hand is part of their own body, both participants experienced strong ownership over the artificial hand. In addition, both individuals perceived the position of their phantom had shifted toward the body midline and distally toward the location of the artificial hand, thereby elongating the length of their phantom arm. The authors argued that such visuotactile stimulation can recalibrate central body representations, producing a perceptual fusion of the phantom and artificial hand when the stimulated residual limb locations correspond

to referred-sensation points. This work further supports the idea that multisensory embodiment processes can modify telescoping.

Cuberovic et al. (2019), Giummarra et al. (2010), Graczyk et al. (2018), Mayer et al. (2008), Middleton and Ortiz-Catalan (2020), and Rognini et al. (2019) reported a negative relationship between telescoping and prosthesis use and/embodiment (e.g., greater use/embodiment was associated with normal length phantoms). One study (Schmitt et al., 2022) found the opposite to be true (e.g., greater prosthesis use was associated with telescoping). Giummarra et al. (2010) investigated prosthesis embodiment in 283 individuals with limb loss. Prosthesis embodiment was significantly more common among individuals with a normal-length phantom (32%) compared to a telescoped phantom (15.0%) (Giummarra et al., 2010). In a sample of 51 individuals with unilateral and bilateral limb loss, Mayer et al. (2008) reported that those who endorsed the presence of telescoping either did not wear a prosthesis or only had been using one for a short time. Similarly, a case study described the experience of an individual with upper limb loss whose telescoped phantom disappeared when he puts on his prosthesis, and experienced greater embodiment over time and with greater daily prosthesis use (Cuberovic et al., 2019). Moreover, another case report described two individuals with below elbow amputations who experienced greater embodiment of their prosthetic hands during synchronous stimulation and visual illumination, an immersive digital technology that the authors fail to define. This embodiment was accompanied by an increase in phantom limb length (e.g., reduced telescoping) (Rognini et al., 2019). In a qualitative study exploring the experience of three individuals with upper limb amputations using a neuromusculoskeletal prosthesis, the presence of telescoping (yes/no) of the limb was reported by all participants when not wearing their prosthesis. However, when they put on their neuromusculoskeletal prosthesis, they all reported

that their phantom hand lengthened to the seen position of the prosthetic hand, such that they no longer experienced telescoping (Middleton & Ortiz-Catalan, 2020). Graczyk et al. (2018) investigated the use of a naturalistic sensory restoration prosthesis (i.e., a prosthesis that provides the wearer with sensory stimulation that restores naturalistic sensation) with direct nerve stimulation in two individuals with upper limb loss who used it in their home settings. Both participants endorsed telescoping, as measured in terms of their perceived phantom length. They perceived their limbs to be significantly longer in length (e.g., closer to the length of their intact limb) when their prosthesis was sensation-enabled and received nerve stimulation corresponding to readings from the sensors than when they did not receive nerve stimulation for sensation from their prosthesis did not have sensation enabled. In contrast to these studies, Schmitt et al. (2022) reported that high stimulation levels from a similar sensory neuroprosthesis induced telescoping in an individual with a lower limb amputation.

3.4.8 Telescoping and Sleep/Dreaming

Only two studies have remarked on telescoping and sleep (Frank & Lorenzoni, 1989; Schmitt et al., 2022). In 84 males with upper and lower limb loss, Frank and Lorenzoni (1989) described how the experience of telescoping varied based on the participant's waking state. For instance, of the 45 participants who reported a normal length phantom while awake, 10 reported telescoping in their dreams. Moreover, among the 21 participants who endorsed telescoping while awake, seven continued to perceive a telescoped phantom in their dreams, eight experienced a phantom of normal length, five did not perceive their phantom during sleep, and one perceived their phantom only intermittently while asleep. Eleven perceived intermittent telescoping while awake and, of these, three endorsed having had dreams during which their

phantom was telescoped. Moreover, of those who did not perceive a phantom while awake, only one experienced it telescoped while dreaming. Schmitt et al. (2022), who investigated telescoping and use of a sensory neuroprosthesis in a case report, described how the experience of telescoping gave the participant nightmares and disrupted his sleep. When the sensory neuroprosthesis was used at a low level, the telescoping experience and its impact on his sleep stopped.

4. DISCUSSION

4.1 Rationale for Narrative Review Approach

This narrative review followed a systematic review methodology to examine the existing research on phantom limb telescoping in order to identify key themes, patterns, limitations, and gaps, as well as potential avenues for future study. The authors discussed whether the review should be classified as a systematic or narrative review with a systematic search and ultimately chose the latter. Although a systematic search was conducted and study quality was appraised using relevant risk of bias tools, the goal was to synthesize and interpret information about telescoping more broadly. A narrative review was selected over scoping review given that scoping reviews generally aim to clarify definitions and catalogue measurement approaches rather than to synthesize and interpret findings. The possibility of conducting a meta-analysis was also considered; however, this was not feasible due to substantial conceptual and methodological heterogeneity across studies, including inconsistent definitions of telescoping, wide variability in outcome measures, and a predominance of case-based, or descriptive designs that did not yield comparable quantitative data or effect sizes. As such, the review aimed to identify recurring themes and conceptual patterns in the literature rather than to statistically aggregate findings or evaluate evidence for a specific

hypothesis. For these reasons, a narrative review framework was determined to be the most appropriate approach.

4.2 Scope and Strength of the Existing Evidence Base

Although telescoping has been documented in the literature, the overall evidence base remains relatively limited, with only 100 published articles reporting outcomes related to this phenomenon retrieved from this search, one third of which were small sample case reports. By synthesizing findings across disciplines, this review provided an overview of the prevalence of telescoping, along with its potential relationships to PLP, treatment response, psychosocial factors, other non-painful phantom sensations, cortical organization, prosthesis use, and sleep or dreaming.

4.3 Prevalence and Temporal Variability of Telescoping

This review highlights that telescoping is a common but highly variable phenomenon among individuals with limb loss. Prevalence estimates were wide-ranging, from as low as 3.8% to over 90%. Across studies, rates within the first year post-amputation ranged from 22.4% to 32.4% (Ahmed et al., 2017; Sin et al., 2013) with the largest studies based on hundreds or thousands of participants hovering around 22%, with a mean of 10 years or more since amputation (Diers et al., 2022; Griffin et al., 2022; Solonen, 1962). Longitudinal evidence demonstrates that the prevalence of telescoping can decrease or increase over time depending on the sample, with some authors suggesting that telescoping can occur very shortly after surgery and others after extended periods of time. Inconsistencies related to prevalence highlight the need to further investigate these trends in future research. Variability across studies reflects differences in sample size, time since amputation, assessment methods, and study design.

Together, these findings suggest that telescoping is neither a rare nor universal experience, but one that appears in a substantial proportion of individuals after limb loss.

4.4 Amputation-Related Factors Influencing Telescoping

The review also suggests that rates of telescoping likely vary depending on the reason for amputation. Individuals with trauma- and cancer-related amputations reported higher rates of telescoping in comparison to other causes of limb loss. Further, those with vascular- and diabetes-related amputations reported notably lower rates than those with other causes of limb loss. This distinction may reflect differences in the suddenness of sensory disruption, underlying neuropathology, or presurgical functional status, which together could impact cortical reorganization. One implication of this conclusion is that telescoping involves a use-dependent interaction between intact primary afferent fibers and somatosensory structures in the brain. For instance, sensory loss associated with peripheral vascular disease and diabetes typically progress gradually prior to limb loss, often due to peripheral neuropathy or functional impairment, whereas such sensory decline is typically more abrupt in traumatic or cancer-related limb loss. This suggests that nerve fibres that carry sensory information from the body towards the central nervous system (i.e., afferent fibres) may contribute to the emergence of telescoping, highlighting an important avenue for future research.

Telescoping appears to be associated with the extremity, level, and laterality of amputation. Across studies, telescoping was more frequently reported following upper-limb loss compared to lower-limb loss. This may reflect the fine-grained cortical representation of the upper extremities and the greater disruption of skilled motor function that arises after amputation. Evidence suggests that distal amputations (e.g., below elbow, below knee) are more often associated with completely telescoped phantoms, whereas proximal amputations (e.g.,

above elbow, above knee) tend to be associated with partial telescoping (Weiss & Fishman, 1963). These findings align with early theories of cortical reorganization (Katz, 1992; Katz & Melzack, 2003). In both proximal and distal amputations, it is the distal segment of the limb (i.e., the hand or foot) that is perceived to move closer to the residual limb. However, given that the distal segment must traverse a greater distance in proximal amputations, complete telescoping is less frequently reported. This may reflect limits in cortical remapping, where the brain's ability to reorganize somatosensory representation is constrained by the larger spatial shift required for more proximal amputations. Nevertheless, recent evidence from Schone et al. (2025) does not support this hypothesis.

Other studies reported differences associated with handedness, where all right-handed individuals who lost the left upper limb endorsed telescoping, compared to only half of those who lost the right upper limb (Shukla et al., 1982). This intriguing finding warrants replication and may suggest that differences related to fine motor experience associated with handedness influence aspects of body representation. Overall, these results suggest how factors such as time since amputation, reason for amputation, level and side of amputation, and possibly handedness should be considered in regard to their contribution to the prevalence of telescoping (Stankevicius et al., 2021).

Another important theme brought to light in this review is the variability and, in some cases, controllability of telescoping. Some individuals who reported telescoping also reported that the length of their phantom varied with time of day or prosthesis use. Notably, some participants described being able to intentionally alter the degree of telescoping in the moment, highlighting an underexplored dimension of agency in phantom experiences. These findings

underscore that telescoping is not a static phenomenon but may fluctuate in relation to sensory input, prosthetic embodiment, and individual differences in neuroplasticity.

4.6 Telescoping and Phantom Limb Pain

The investigation of the relationship between telescoping and PLP has yielded mixed findings, including positive, negative, and non-significant associations. Nevertheless, when weighted by sample size and methodological quality, the evidence suggests that telescoping is more likely to be associated with the presence of and/or greater intensity of PLP. Of the 39 studies that investigated this relationship, 12 supported a positive relationship between telescoping. These studies collectively comprised the largest sample size and demonstrated the strongest methodological quality overall. The findings support the hypothesis that telescoping may reflect maladaptive cortical reorganization, whereby overlapping or disrupted somatosensory representations contribute to the persistence or amplification of PLP (Flor, 2002; Flor et al., 2006). Conversely, 20 studies, the majority of which are case reports with higher risk of bias, reported a negative relationship, suggesting that telescoping may be linked with reduced PLP. These findings have been interpreted as evidence of adaptive neurological changes that decrease PLP (Aternali et al., 2024; Katz, 1992). This dichotomy raises questions about the underlying mechanisms of PLP and the role of individual differences in the occurrence of telescoping. The variability in findings may stem from methodological differences, including sample sizes and the nature of interventions employed. Notably, a substantial proportion of studies did not provide clear information regarding the timing of telescoping assessment, limiting interpretation and highlighting the need for research that explicitly examines the temporal relationship between telescoping and PLP to better determine the direction of this association. Although RCTs investigating the efficacy of PLP treatments have not consistently demonstrated

superiority over control conditions (Aternali & Katz, 2019b), interventions such as mirror therapy and virtual reality reviewed here have shown promise in alleviating PLP while simultaneously influencing the perception of telescoping (Ortiz-Catalan et al., 2014; Ramachandran & Rogers-Ramachandran, 1996). These therapeutic approaches suggest that altering somatosensory, visual, and motor feedback can modulate the experience of both telescoping and PLP. At present, while telescoping appears to be associated to the presence of PLP, the variability across studies warrants further exploration to illuminate the mechanisms at play.

4.7 Telescoping and PLP Treatment Response

There also appears to be a complex relationship between telescoping and PLP treatment response based on the 13 articles reviewed here that involved an intervention. Some evidence suggests that individuals with telescoped phantoms prior to the start of treatment may report no reduction in PLP from visual-motor interventions, such as mirror therapy. This contrasts sharply with findings from studies of participants with normal-length phantoms who reported significant pain relief. This negative association between telescoping and treatment response underscores the need for research into why commonly used treatments appear to be ineffective and suggests that tailored therapeutic approaches are required for this subgroup (Richardson & Kulkarni, 2017). Four studies provided no clear evidence supporting the possible influence of telescoping on treatment outcomes, suggesting that factors beyond phantom length may play a critical role in PLP management. Nevertheless, higher-quality studies with greater cumulative sample sizes indicate that individuals who report telescoped phantoms prior to treatment may derive greater benefits from PLP interventions, such as mirror therapy, augmented reality-based interventions, and tactile discrimination training. Together, these findings suggest that telescoping may

function as a meaningful moderator of PLP treatment response, and not a marker of poorer clinical prognosis. While this may appear to contradict the possible positive relationship between telescoping and PLP, both phenomena may be better understood as manifestations of cortical reorganization. For instance, telescoping may reflect altered somatosensory representations that increase pain, but this same plasticity that contributes to pain may also permit greater recalibration. Interventions that restore congruent multisensory and motor feedback may therefore directly target this reorganization. In this way, cortical reorganization may simultaneously increase vulnerability to PLP by disrupting body representations, while reflecting a state of heightened neural plasticity that renders pain-related representations more amenable to therapeutic change.

4.8 Biological and Psychosocial Correlates of Telescoping

The relationship between telescoping and various biological and psychosocial factors has been explored in several studies, revealing subtle insights. The evidence presented here suggests that demographic characteristics such as age, time since amputation, and sex are not related to phantom length. There may be an association between presurgical pain and telescoping experiences in which people who experienced pain before surgery are more likely to report telescoping of their phantom limb. This would align with other research that has found presurgical pain to be significantly predictive of the incidence and severity of PLP, suggesting that pain before amputation may contribute to altered neural representations that influence both pain and telescoping (Larbig et al., 2019). Psychiatric diagnoses do not appear to play a critical role in the experience of telescoping either. However, research thus far provides little detail on the role of positive and negative psychological states in relation to telescoping. How individuals' mood, resilience, anxiety, or stress may influence or be influenced by telescoping remains

largely unstudied. Given the well-established impact of mental health on post-amputation pain, functional recovery, and adjustment to limb loss, this aspect of the phantom limb experience warrants greater attention in both research and clinical care. Moreover, psychological and emotional states, such as stress and anxiety, have been hypothesized to alter phantom limb sensations, such as telescoping, through activation of the sympathetic nervous system (Katz, 2000). Collectively, these findings underscore the possible implications of biological and psychosocial factors on telescoping, suggesting that while certain trends exist, further research is necessary.

4.9 Telescoping and Non-Painful Phantom Sensations

The findings from Weiss and Fishman (1963) and Haber (1958) provide insights on the relationship between telescoping and non-painful phantom sensations. Weiss and Fishman (1963) found that a normal length phantom was associated with stronger non-painful phantom sensations in comparison to a shorter/telescoped phantom. This suggests a potential link between phantom limb length and sensory feedback mechanisms. Furthermore, the enhanced residual limb sensitivity and tactile discrimination in individuals with telescoped phantoms may indicate a unique neurophysiological adaptation (Haber, 1958). The experience that telescoped phantom limbs do not penetrate solid objects contrasts with the experiences of those with normal length phantoms, suggesting that those who report telescoping may have a more spatially constrained representation (obstacle tolerance) of their phantom limb (Saetta et al., 2018). These results contribute to our understanding of phantom limb phenomena and their implications for rehabilitation strategies. Telescoping also co-occurs with referred sensations, which are especially relevant because these additional sensations may further reinforce the perception of a shortened limb. Thus, telescoping can interfere with motor imagery, indicating functional

consequences beyond subjective perception (Bjorkman et al., 2016; Lyu et al., 2016). Taken together, these findings suggest that telescoping may be linked to distinct patterns of non-painful phantom sensations and altered perceptual experiences, though the precise nature of this relationship remains to be clarified.

4.10 Telescoping and Cortical Reorganization

The investigation of cortical reorganization in individuals experiencing telescoping remains a relatively underexplored area. Several studies have highlighted significant cortical reorganization associated with telescoping in the primary somatosensory cortex, an area known for its detailed body map. Findings also suggest that telescoping may be linked to alterations in brain regions beyond those typically associated with PLP, such as the posterior parietal cortex. Conversely, two studies have failed to find a significant association between telescoping and cortical reorganization. A recent study that examined three individuals before amputation through up to five years after amputation showed stable body representations in the primary somatosensory cortex in the individual who reported telescoping, suggesting no clear association between telescoping and primary somatosensory cortex body representation (Schone et al., 2025). Nevertheless, studies supporting an association between telescoping and cortical reorganization collectively comprise larger overall sample sizes and had lower overall risk of bias. There still however remains a need for further research with larger samples to clarify these relationships.

4.11 Prosthesis Use, Embodiment, and Telescoping

The relationship between prosthetic limb use and telescoping reveals a complex interplay between ownership, embodiment, and sensory feedback. Evidence suggests that embodiment can alter the experience of telescoping, highlighting its dynamic and potentially modifiable nature

(Schmalzl et al., 2014). Most studies indicate a negative correlation between prosthesis use and telescoping, suggesting that individuals who utilize prosthetics experience less telescoping of their phantom limbs. One possible interpretation of this association is the involvement of additional sensory modalities in shaping perceived phantom limb length. Prosthetic use may partially restore visual input lost following limb loss, providing an external input of the limb length and position. Prostheses also allow individuals to engage in touch-directed actions toward the phantom limb (e.g., contacting the prosthetic limb via other intact limbs or residual limb). Together, reinstatement of visual and tactile cues can contribute to a phantom limb resembling their prosthetic arm or leg, which is typically the same length as the intact arm or leg, thereby reducing telescoping. This would be consistent with accounts emphasizing multisensory basis of body representation (Katz, 2000; Katz & Melzack, 2003). Overall, the findings on the relationship between prosthesis use and underscore the importance of further researching prosthetic design and sensory integration in optimizing user experience and embodiment.

4.12 Telescoping Across Wakefulness, Sleep, and Dreaming

Telescoping in individuals with limb loss also presents a complex interplay between waking experiences and dream states, as highlighted by Frank and Lorenzoni (1989). Their findings indicate that while many participants perceive telescoping while awake, only a subset continues to experience this phenomenon in dreams. Schmitt et al. (2022) further elucidate the impact of telescoping on sleep quality, noting that it can lead to nightmares and sleep disruption. Interestingly, the use of sensory neuroprosthesis at lower levels mitigated these adverse effects, suggesting potential therapeutic avenues for managing sleep disturbances associated with the telescoping phenomenon in individuals with limb loss.

4.13 Clinical Relevance

These findings carry important clinical implications, as a clearer understanding of the factors influencing telescoping may guide both rehabilitation strategies and psychological support for individuals with limb loss. Telescoping is not a uniform phenomenon, and its variability across individual experience underscores the need for personalized care. For example, individuals with upper-limb amputations may be more likely to experience telescoping and could benefit from early screening so that clinicians can monitor adjustment to the loss of the limb, psychological distress, and possible development of post-amputation pain more closely. Similarly, recognizing that telescoping can fluctuate over time, or even be influenced by prosthesis use, highlights the importance of ongoing clinical assessment rather than one-time evaluation.

Integrating the assessment of telescoping into routine post-amputation care may help clinicians anticipate challenges related to PLP, prosthesis embodiment, and functional rehabilitation. Outcomes of interventions that aim to reduce PLP, such as mirror therapy, augmented reality, or tactile discrimination training, may vary depending on whether an individual experiences a telescoped or normal-length phantom, as these interventions may rely on feedback related to the perceived length of the phantom limb. This suggests that clinicians should consider the length of the phantom when selecting or adapting treatments. Beyond physical rehabilitation, psychological support can also be tailored: validating the diversity of phantom limb experiences and helping individuals make sense of their unique sensations may reduce distress and promote adjustment.

At the same time, the current evidence base is small and heterogeneous, and definitive conclusions cannot be drawn about which therapeutic approaches to managing PLP are most

effective for individuals with telescoping. The findings from this review highlight the importance of individualized assessment, the need for flexible treatment planning, and the potential value of developing targeted therapies that account for the wide variability in telescoping experiences. Continued research that links clinical interventions with detailed measures of phantom limb characteristics will be essential for translating these findings into practice.

4.14 Limitations and Future Research

Narrative reviews such as this one can provide valuable insights, however they also come with certain limitations. While the systematic search of the literature undertaken in this review was comprehensive, narrative reviews can be subjective in nature. Nevertheless, the authors aimed to objectively interpret and synthesize the findings of the various studies included. The studies included in this review also varied in their approach to reporting epidemiological data and post-amputation experiences. Methodological rigor in the included studies was generally low to moderate, the samples used were frequently selective, and many studies were either case reports and/or had small sample sizes. Given that approximately one third of the studies included in this review were case reports, the overall quality of the evidence is lower than that provided by well-powered studies employing rigorous methodological designs, such as RCTs. While the authors' conclusions have taken this into account, this limitation raises questions about the validity of the studies and the extent to which the findings reflect the population of individuals with limb loss. Another limitation of this review is that it only included studies published in English. It is possible that the search criteria were not comprehensive enough in this regard due to this language bias. Reviews like this one are time-consuming to conduct due to the need for an extensive review of the literature and synthesis of findings across multiple studies.

Future research should aim to standardize methodologies investigating telescoping. This would improve comparability of results across studies and enhance reproducibility of research findings. The web-based tool we developed (<https://demo.phantomlimbs.ca/>) represents a step towards this goal by providing a standardized platform for assessing and documenting telescoping phenomena (Aternali & Katz, 2019a). Telescoping may also be influenced by a variety of confounding factors, such as time since amputation, level of amputation, and design of the study. Without standardized methods, researchers may overlook or inadequately control for these confounding variables. In addition, given that telescoping is such a complex phenomenon, its underlying mechanisms may vary based on context. Thus, standardized methodologies would allow researchers to isolate and clarify these mechanisms more effectively. Future research should also explore the psychological and neurophysiological factors that contribute to the divergent findings described in this review. By elucidating these factors and mechanisms underlying telescoping, our understanding of telescoping will be engaged, and it can inform clinical interviews and/or optimize PLP treatment protocols.

Despite the valuable insights gained from the quantitative studies included in this review, it is important to note that only four qualitative studies have explored phantom limb telescoping. This is a limitation not only of this review, but of the field investigating the phenomenon of telescoping. Qualitative research is needed to fully capture the complexity and variability of the subjective experiences of individuals with telescoping. Such research could illuminate the personal, psychological, and emotional dimensions of telescoping that are often missed in quantitative studies, helping to inform more tailored and effective interventions for individuals affected by limb loss. Overall, as described by Stankevicius et al. (2021), future research should

be patient-focused, where health professionals consider factors that merit further investigation based on what aligns most with their patients.

5. CONCLUSIONS

This narrative review highlights the considerable variability in the experience of phantom limb telescoping. Despite this inconsistent evidence, the prevalence appears to be approximately 22%, with higher rates observed among individuals with upper limb loss, particularly following trauma-related etiologies. Telescoping does not appear to be related to biological factors such as age, sex, and time since amputation. Converging evidence instead implicates cortical reorganization as a key mechanism, which in turn may increase vulnerability to PLP while simultaneously facilitating greater responsiveness to PLP interventions. Telescoping does not appear to be related to psychosocial factors or non-painful phantom sensations and is more frequently reported among individuals who do not use a prosthesis arm or leg. Evidence further suggests that telescoping is not always maintained while asleep/dreaming. Collectively, these findings underscore the complex and multifaceted nature of telescoping. To gain a deeper understanding of the implications of telescoping and to identify individual characteristics that may predict favourable outcomes for individuals with limb loss, large-scale, multi-site studies with standardised methodologies are essential.

AUTHORS CONTRIBUTIONS

Andrea Aternali and Joel Katz developed the review protocol. Andrea Aternali conducted the database search to retrieve all articles, in consultation with a library scientist who provided

guidance on search strategy and database selection. Andrea Aternali and Heather Lumsden-Ruegg completed the title/abstract screening, risk of bias assessments, and data extraction. Andrea Aternali and Joel Katz completed data analysis and interpretation. Andrea Aternali, Heather Lumsden-Ruegg, and Joel Katz participated in the preparation of the manuscript. All authors discussed the results, reviewed the manuscript, and approved the final version.

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Author (year)	Selection bias: Demographic characteristics	Information bias: Patient history	Measurement bias: Description of condition	Detection bias: Description of tests	Performance bias: Description of procedures	Measurement bias: Post-intervention description	Reporting bias: Adverse events	Reporting bias: Takeaway lesions	Overall Appraisal
Aglioti et al. (1994)	✗	✗	—	✓	—	✗	✓	✓	✗
Belleggia and Birbaumer (2001)	✗	✗	✓	✓	✓	✓	N/A	✓	✓
Bradbrook (2004)	✗	✗	✓	✓	✓	✓	✓	✓	✓
Condes-Lara et al. (2000)	✗	✗	✓	✓	N/A	N/A	N/A	✓	—
Cuberovic et al. (2019)	✗	✗	✓	✓	✓	✓	✗	✓	—
Davies (2013)	✗	✗	✓	✓	✓	✓	✓	✓	✓
Desmond et al. (2006)	✗	✗	✓	✓	✓	✓	✓	✓	✓
Dietrich et al. (2018)	✗	✗	✓	✓	✓	✓	✗	✓	—
Fukui et al. (2002)	✗	✓	✓	✓	✓	✓	—	✓	✓
Giummarra et al. (2011)	✓	✓	✗	✓	N/A	N/A	N/A	✓	✓
Graczyk et al. (2018)	✗	✗	✗	✓	N/A	N/A	N/A	✓	—
Grüsser, Winter, Schaefer, et al. (2001)	✗	✗	✓	✓	N/A	N/A	N/A	✓	—
Grüsser et al. (2004)	✗	✗	✓	✓	N/A	N/A	N/A	✓	—
Halligan et al. (1994)	✗	✗	✓	✗	N/A	N/A	✓	✓	—
Iida et al. (2004)	✗	✓	✓	✓	✓	✓	✓	✓	✓
Katz and Melzack (1987)	✗	✗	✓	✗	—	—	✓	✓	—
Katz et al. (1989)	✗	✗	✓	✗	✓	—	✓	✓	—
Lee and Donovan (1995)	✗	✗	✓	✗	✓	✓	✓	✓	—
Liaw et al. (1998)	✗	✓	✓	✗	✗	✓	N/A	✓	—
McAvinue and Robertson (2011)	✗	✗	✓	—	✓	✓	✓	✓	✓

Morgenstern (1964)	✗	✓	✓	✗	✗	✓	✓	✓	—
Muraoka et al. (1996)	✗	✓	✓	✓	✗	✓	✗	✓	—
Ortiz-Catalan et al. (2014)	✗	✗	✓	✓	✓	✓	✓	✓	✓
Pascual-Leone et al. (1996)	✗	✗	✓	✓	N/A	N/A	N/A	✓	—
Ramachandran et al. (2009)	✗	✗	✓	✗	✗	—	✓	✓	—
Restrepo-Garces et al. (2011)	✗	✗	✓	✓	✓	✓	—	✓	✓
Rognini et al. (2019)	✗	✗	✗	✗	✗	—	✗	✓	✗
Rosen et al. (2001)	✗	✗	✓	✓	✗	✓	—	✓	—
Roux et al. (2001)	✗	✗	✗	✓	✓	✓	✓	✓	—
Schmalzl et al. (2014)	✗	✗	✓	✓	N/A	N/A	N/A	✓	—
Schmitt et al. (2022)	✗	✗	✗	✓	N/A	N/A	N/A	✓	—
Stannard and Porter (1993)	✗	✗	✓	✗	✓	✓	✓	✓	—
Stone (1950)	✗	✓	✓	✗	✓	✓	✗	✓	—
Topfner et al. (2001)	✗	✗	✗	✓	✓	✓	—	✓	—

Supplementary Table 1. Risk of bias assessment: Case report studies; KEY: Risk of bias: High ✗ Moderate — Low ✓

Author (year)	Selection bias: Target population	External validity	Measurement bias: Exposure	Measurement bias: Objective criteria	Confounding bias: Identified	Confounding bias: Addressed	Measurement bias: Outcomes	Analysis bias	Overall Appraisal
Bjorkman et al. (2016)	✗	✗	✗	✗	✓	✗	✓	✓	✗
De Graaf et al. (2016)	✓	✗	—	✗	✓	—	✗	✓	✗
Dettmers et al. (2001)	✗	✗	✓	✓	✗	✗	✓	✓	—
Diers et al. (2010)	✗	✗	✓	✓	✓	✓	—	✓	—
Draganski et al. (2006)	✗	✗	✓	✓	✓	✓	✓	✓	✓
Flor et al. (1998)	—	✗	✓	✓	✗	✗	✓	—	✗
Flor et al. (2000)	✗	✗	—	✓	✗	✗	—	✓	✗
Grüsser, Winter, Muhlnickel, et al. (2001)	✗	✗	✓	✓	✗	✗	—	✗	✗
Haber (1958)	✗	✗	✓	✓	✗	✗	✓	✓	—
Hunter et al. (2003)	✓	✓	✓	✓	✓	✓	✓	N/A	✓
Hunter et al. (2005)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Jalavisto (1950)	✗	✗	—	✓	✗	✗	✗	—	✗
Karl et al. (2004)	✗	✗	✓	✓	✗	✗	✓	✓	—
Kew et al. (1994)	✗	✗	—	✓	✓	✓	✓	✓	—
Kikkert et al. (2018)	—	✗	✓	✓	✗	✗	—	✓	—
Lyu et al. (2016)	✗	✓	✓	✓	✓	✓	—	✓	✓
Machin and Williams (1998)	—	✗	✓	—	✓	✓	—	✓	—
Makin et al. (2013)	—	✗	✓	✓	✓	✓	—	✓	—
Mall et al. (1997)	—	✗	—	✓	✗	✗	✗	—	✗
Montoya et al. (1997)	✓	✗	—	✓	✓	✓	✓	✓	✓

Price (1976)									
Trivedi et al. (1997)									

Supplementary Table 2. Risk of bias assessment: Analytical cross-sectional studies KEY: Risk of bias: High  Moderate  Low 

Author (year)	Selection bias: Target population	Selection bias: Sampling	Statistical bias	Reporting bias	Attrition bias	Detection bias: Identification of the condition	Detection bias: Measurement of the condition	Analysis bias	Non-response bias	Overall Appraisal
Ahmed et al. (2017)	—	—	—	✓	✗	—	—	✓	✓	—
Aldington et al. (2014)	✓	✓	—	✗	—	—	—	✓	—	—
Carlen et al. (1978)	✓	—	—	✓	—	✗	✗	✗	—	✗
Collins et al. (2018)	✓	—	✗	✓	✗	✗	—	✗	—	✗
Diers et al. (2022)	✓	✓	—	✓	—	✓	✓	✗	—	—
Giummarra et al. (2010)	—	—	—	✗	—	✓	—	✗	—	—
Griffin et al. (2022)	✗	✗	—	✓	✓	✓	✓	✓	—	—
Lacoux et al. (2002)	—	✗	—	✗	—	✓	—	✓	—	—
Mayer et al. (2008)	—	—	—	✗	—	✓	—	✗	—	—
Probstner et al. (2010)	—	—	—	✓	✓	✓	—	✗	—	—
Richardson et al. (2006)	—	✓	—	✗	✓	✓	—	✗	✓	—
Richardson et al. (2015)	—	—	—	✗	—	✓	✗	✗	—	✗
Richardson et al. (2018)	—	—	—	✗	—	✓	—	✗	—	—
Shukla et al. (1982)	—	—	—	✗	—	✓	—	—	—	—
Sin et al. (2013)	—	✓	—	✓	—	✓	—	✗	✗	—
Solonen (1962)	✓	—	—	✗	—	✗	✓	✗	—	✗
Weiss and Fishman (1963)	✗	✗	—	✗	—	—	—	✗	—	✗

Supplementary Table 3. Risk of bias assessment: Prevalence (descriptive cross-sectional) studies; KEY: Risk of bias: High ✗ Moderate — Low ✓

Author (year)	Study objectives	Selection bias: Eligibility criteria	Selection bias: Population of interest	Selection bias: enrollment	Statistical power	Performance bias	Measurement bias: outcome measures	Detection bias	Attrition bias	Statistical bias	Confounding bias	Clustering bias	Overall Appraisal
Bamford (2006)	✓	✗	✓	✓	✗	✗	✓	N/A	✓	✓	✓	✓	—
De Nunzio et al. (2018)	✓	✓	✓	—	✗	✓	✓	✓	N/A	✓	✓	✓	✓
Foell et al. (2014)	✓	—	✓	—	✗	✓	✓	—	✓	✓	✓	✓	—
Kulkarni et al. (2020)	✓	✓	—	—	✗	✓	✓	N/A	✓	✓	✓	N/A	—
Murray et al. (2006)	✓	✓	✗	—	✗	✗	✓	—	✗	✗	✓	N/A	✗
Osumi et al. (2019)	✓	✗	—	—	—	✗	✓	—	—	✓	✗	✓	✗
Thogersen et al. (2020)	✗	✓	✓	—	✗	✗	✓	N/A	—	✓	✓	N/A	—
Vaso et al. (2014)	✓	✓	✓	—	—	✗	✓	✗	N/A	✓	—	✓	—
Willoch et al. (2000)	✓	✗	—	—	—	✗	✓	—	N/A	✓	✗	N/A	✗
Yildirim and Kanan (2016)	✓	✓	✓	—	✗	✓	—	N/A	✓	✓	✓	N/A	—
Zheng et al. (2009)	✓	✗	✓	—	✗	✓	✗	N/A	✓	✗	✓	N/A	—

Supplementary Table 4. Risk of bias assessment: Before-after (pre-post) studies; KEY: Risk of bias: High ✗ Moderate — Low ✓

Author (year)	Selection bias: Exposed cohort	Selection bias: Non-exposed cohort	Detection bias	Baseline misclassification bias	Confounding bias	Assessment bias	Attrition bias: Adequate follow-up	Attrition bias: Dropout rate	Overall Appraisal
Giordano et al. (2021)	✗	N/A	✓	—	✓	—	✓	—	—
Hunter et al. (2008)	✗	N/A	✓	—	✓	—	✓	—	—
Jensen et al. (1983)	✗	N/A	✓	✓	N/A	—	✓	✓	—
Jensen et al. (1984)	✗	N/A	✓	✓	N/A	—	✓	—	—
Richardson et al. (2007)	✗	N/A	✓	✓	✓	—	✓	✓	—

Supplementary Table 5. Risk of bias assessment: Cohort studies; KEY: Risk of bias: High ✗ Moderate — Low ✓

Author (year)	Theoretical bias	Methodological bias: Objectives	Methodological bias: Methods	Methodological bias: Analysis	Methodological bias: Results interpretation	Contextual bias	Researcher bias	Interpretation bias: Participant voices	Ethical bias	Interpretation bias: Conclusions	Overall Appraisal
Bjorkman et al. (2010)	✓	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓
Frank and Lorenzoni (1989)	—	—	—	—	—	✗	✗	✓	—	✓	—
Middleton and Ortiz-Catalan (2020)	✓	✓	✓	✓	✓	✗	✗	✗	✓	✓	✓
Trevelyan et al. (2016)	✓	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓

Supplementary Table 6. Risk of bias assessment: Qualitative research; KEY: Risk of bias: High ✗ Moderate — Low ✓

Author (year)	Selection bias: Randomization	Selection bias: Concealment	Performance bias	Detection bias	Attrition bias	Reporting bias	Other bias	Overall Appraisal
Casale et al. (2009)	—	✓	✓	✓	✓	✓	—	✓
Rothgangel et al. (2018)	✓	✗	✗	✓	✓	✓	✓	✓

Supplementary Table 7. Risk of bias assessment: Randomized controlled trials; KEY: Risk of bias: High ✗ Moderate — Low ✓

Author (year)	Confounding bias	Selection bias: Participants	Classification bias	Implementation bias	Selection bias: Missing data	Measurement bias	Reporting bias	Overall Appraisal
Wakolbinger et al. (2018)	✗	✗	—	—	✓	✗	—	✗
Schmalzl et al. (2011)	—	—	✓	—	✓	—	—	—

Supplementary Table 8. Risk of bias assessment: Non-randomized controlled trials; KEY: Risk of bias: High ✗ Moderate — Low ✓

Author (year)	Misclassification bias	Selection bias	Selection bias (controls)	Misclassification bias (controls)	Confounding	Measurement bias	Differential misclassification	Non-response bias	Overall Appraisal
Kew et al. (1997)	✓	✓	✗	✓	✓	✓	✓	—	✓

Supplementary Table 9. Risk of bias assessment: Case control; KEY: Risk of bias: High ✗ Moderate — Low ✓

Author (year)	Study objectives	Selection bias	Consecutive cases	Comparable cases	Assessment bias: Intervention	Assessment bias: Outcome measures	Attrition bias: Adequate follow-up	Statistical bias	Reporting bias	Overall Appraisal
Ramachandran and Rogers-Ramachandran (1996)	✗	✗	—	—	✓	—	N/A	—	✓	—

Supplementary Table 10. Risk of bias assessment: Case series; KEY: Risk of bias: High ✗ Moderate — Low ✓

Author (year)	Development	Content validity	Structural validity	Internal consistency	Measurement bias	Reliability	Measurement error	Criterion validity	Hypothesis testing	Measurement bias: Responsiveness	Overall Appraisal
Kawashima and Mita (2016)	✗	—	N/A	N/A	✗	—	—	—	N/A	N/A	✗

Supplementary Table 11. Risk of bias assessment: Outcome measurement; KEY: Risk of bias: High ✗ Moderate — Low ✓

AUTHOR (YEAR)	WERE THE PATIENT'S DEMOGRAPHIC CHARACTERISTICS CLEARLY DESCRIBED?	WAS THE PATIENT'S HISTORY CLEARLY DESCRIBED AND PRESENTED AS A TIMELINE?	WAS THE CURRENT CLINICAL CONDITION OF THE PATIENT ON PRESENTATION CLEARLY DESCRIBED?	WERE DIAGNOSTIC TESTS OR METHODS AND THE RESULTS CLEARLY DESCRIBED?	WAS THE INTERVENTION(S) OR TREATMENT PROCEDURE(S) CLEARLY DESCRIBED?	WAS THE POST-INTERVENTION CLINICAL CONDITION CLEARLY DESCRIBED?	WERE ADVERSE EVENTS (HARMS) OR UNANTICIPATED EVENTS IDENTIFIED AND DESCRIBED?	DOES THE CASE REPORT PROVIDE TAKEAWAY LESSONS?	OVERALL APPRAISAL
AGLIOTI ET AL. (1994)	No; lacking demographic information	No; history not extensively reported	Unclear; minimal information on phantom limb experience provided	Yes; tests and methods adequately described	Unclear; limited information provided	No; did not report outcome	Yes; adverse events reported	Yes; areas for further investigation discussed	Low methodological quality; high risk of bias
BELLEGGIA AND BIRBAUMER (2001)	No; lacking demographic information	No; history not extensively reported	Yes; pain level and phantom experience well described	Yes; use of visual analogue scale described	Yes; treatment clearly described	Yes; outcomes at follow-up reported	N/A	Yes; areas for further investigation discussed	High methodological quality; low risk of bias
BRADBROOK (2004)	No; lacking demographic information	No; history not extensively reported	Yes; pain level and phantom experience well described, though did not report time since amputation	Yes; tests and methods adequately described	Yes; acupuncture procedure adequately described	Yes; outcome measures provided	Yes; intervention ineffective for one participant	Yes; clear summary with discussion of limitations	High methodological quality; low risk of bias
CONDES-LARA ET AL. (2000)	No; lacking demographic information	No; history not extensively reported	Yes; pain level and phantom experience well described, though did not explicitly report time since amputation	Yes; neuroimaging procedures adequately described	N/A	N/A	N/A	Yes; neuroimaging analyses and interpretations provided	Medium methodological quality; moderate risk of bias
CUBEROVIC ET AL. (2019)	No; lacking demographic information	No; history not extensively reported	Yes; current experience and intervention measures described	Yes; outcome measures and qualitative information presented	Yes; electrode and neurostimulator procedure adequately described	Yes; changes in phantom experience and psychosocial outcomes reported	No; no mention of adverse or unexpected events	Yes; areas for further investigation discussed	Medium methodological quality; moderate risk of bias
DAVIES (2013)	No; lacking demographic information	No; history not extensively reported	Yes; pain and phantom sensations described	Yes; use of visual analogue scale described	Yes; acupuncture procedure adequately described	Yes; changes in pain experience and phantom sensations reported	Yes; unanticipated events (telescoping) described	Yes; findings, limitations, and implications discussed	High methodological quality; low risk of bias

DESMOND ET AL. (2006)	No; lacking demographic information	No; history not extensively reported	Yes; pain and phantom sensations described	Yes; use of semi-structured interview and MPQ described	Yes; augmented mirror box and wireless glove adequately described	Yes; post-intervention experience reported	Yes; unanticipated events described	Yes; findings, limitations, and implications discussed	High methodological quality; low risk of bias
DIETRICH ET AL. (2018)	No; lacking demographic information	No; history not extensively reported	Yes; pain and phantom sensations described	Yes; use of visual analogue scale and neuroimaging process described	Yes; brachial plexus block procedure described	Yes; thorough description of sensations and brain activation pre-and post-block	No; no mention of adverse or unexpected events	Yes; findings, underlying mechanisms, and implications discussed	Medium methodological quality; moderate risk of bias
FUKUI ET AL. (2002)	No; lacking demographic information	Yes; history sufficiently reported	Yes; pain experience described	Yes; use of visual analogue scale and intervention procedures described	Yes; description of electroconvulsive therapy procedures described	Yes; follow-up information provided after 1.5 years	Unclear; briefly described adverse events	Yes; findings and implications discussed	High methodological quality; low risk of bias
GIUMMARRA ET AL. (2011)	Yes; demographic information provided	Yes; history sufficiently reported	No; pain experience described but details surrounding telescoping experience lacking	Yes; use of VAS, MPQ, etc. described	NA	NA	NA	Yes; describes reasons for late-onset PLP	High methodological quality; low risk of bias
GRACZYK ET AL. (2018)	No; lacking demographic information	No; history not extensively reported	No; lacking information regarding participants' experience	Yes; methods of assessment and prosthesis use well outlined	NA	NA	NA	Yes; describes how prosthesis can contribute to holistic experience	Medium methodological quality; moderate risk of bias
GRÜSSER, WINTER, SCHAEFER, ET AL. (2001)	No; lacking demographic information	No; history not extensively reported	Yes; pain and phantom sensations described	Yes; methods of assessment and imaging techniques well described	NA	NA	NA	Yes; describes experiences during the perioperative period	Medium methodological quality; moderate risk of bias
GRUSSER ET AL. (2004)	No; lacking demographic information	No; history not extensively reported	Yes; pain and phantom sensations described	Yes; methods of assessment and sites of stimulation well outlined	NA	NA	NA	Yes; describes possible implications for neural plasticity in the pain process	Medium methodological quality; moderate risk of bias
HALLIGAN ET AL. (1994)	No; lacking demographic information (may be reported elsewhere)	No; history not extensively reported (may be reported elsewhere)	Yes; pain and phantom sensations described	No; descriptions not provided on how phantom sensations were evaluated	NA	NA	Yes; unanticipated events (referred sensation from the phantom) described	Yes; underlying mechanisms and implications discussed	Medium methodological quality; moderate risk of bias

IIDA ET AL. (2004)	No; lacking demographic information	Yes; history sufficiently reported	Yes; pain and phantom sensations described	Yes; information related to spinal injury discussed	Yes; details of surgery, increase in PLP and PLP treatment discussed	Yes; post-intervention experience reported	Yes; unanticipated events (PLP) described	Yes; underlying mechanisms and implications discussed	High methodological quality; low risk of bias
KATZ AND MELZACK (1987)	No; lacking demographic information	No; history not extensively reported	Yes; pain experience extensively described	No; descriptions not provided	Unclear; procedure described for the larger sample but not clarified regarding case reports	Unclear; description provided for 2 of 3 participants	Yes; responses to stimulation described	Yes; findings and implications discussed	Medium methodological quality; moderate risk of bias
KATZ ET AL. (1989)	No; lacking demographic information	No; history not extensively reported	Yes; pain and phantom sensations described	No; descriptions not provided	Yes; TENS procedure adequately described	Unclear; no long-term effects discussed	Yes; unanticipated events (skin temperature increase) described	Yes; implications discussed	Medium methodological quality; moderate risk of bias
LEE AND DONOVAN (1995)	No; lacking demographic information	No; history not extensively reported	Yes; pain and health condition described	No; pain not measured using validated scales	Yes; procedure brachial plexus block and general anesthesia described	Yes; events following procedure described	Yes; unanticipated events (recurrence of PLP) described	Yes; implications discussed	Medium methodological quality; moderate risk of bias
LIAW ET AL. (1998)	No; lacking demographic information	Yes; history sufficiently described	Yes; pain experience extensively described	No; administration of validated scale not described	No; not all interventions (e.g., frequency of treatment) described	Yes; events following procedure described	NA	Yes; findings and implications discussed	Medium methodological quality; moderate risk of bias
MCAVINUE AND ROBERTSON (2011)	No; lacking demographic information	No; history not extensively reported	Yes; pain experience extensively described	Unclear; pain diary and various scales used but lacking information on how PLP was measured before/after intervention	Yes; movement imagery training adequately described	Yes; events following procedure described	Yes; one participant experienced the re-emergency of old pain and ceased therapy	Yes; findings and implications discussed	High methodological quality; low risk of bias
MORGENSTERN (1964)	No; lacking demographic information	Yes; history sufficiently described	Yes; pain experience and symptoms extensively described	No; limited description of assessments	No; limited description of procedures	Yes; events (pain and telescoping) following procedure described	Yes; unanticipated events (telescoping) described	Yes; findings and implications discussed	Medium methodological quality; moderate risk of bias
MURAOKA ET AL. (1996)	No; lacking demographic information	Yes; history sufficiently described	Yes; PLP experience and symptoms extensively described	Yes; use of VAS, MMPI, etc. described	No; limited description of hypnosis procedures	Yes; description of changes in phantom limb experience provided	No; no mention of adverse or unexpected events	Yes; findings and implications discussed	Medium methodological quality; moderate risk of bias

ORTIZ-CATALAN ET AL. (2014)	No; lacking demographic information	No; only limited information on past interventions	Yes; pain experience extensively described	Yes; MPQ administration described	Yes; augmented reality intervention well described	Yes; events during and following the procedure described	Yes; unanticipated events (increase in pain) described	Yes; findings and implications discussed	High methodological quality; low risk of bias
PASCUAL-LEONE ET AL. (1996)	No; lacking demographic information	No; history not extensively reported	Yes; phantom limb experience extensively described	Yes; TMS mapping adequately described	N/A	N/A	N/A	Yes; findings and implications discussed	Medium methodological quality; moderate risk of bias
RAMACHANDRAN ET AL. (2009)	No; lacking demographic information	No; history not extensively reported	Yes; PLP experience extensively described	No; how pain ratings were obtained was not described	No; minimal information about the equipment was used	Unclear; description of changes provided at one time point but not the other	Yes; unanticipated events (impact of magnifying lens) described	Yes; findings and implications discussed	Medium methodological quality; moderate risk of bias
RESTREPO-GARCES ET AL. (2011)	No; lacking demographic information	No; history not extensively reported	Yes; patient's RLP extensively described	Yes; ultrasound scan, nerve stimulation, etc. adequately described	Yes; lesioning process well described	Yes; pain following the procedure described	Unclear; no complications reported	Yes; findings and implications discussed	High methodological quality; low risk of bias
ROGNINI ET AL. (2019)	No; almost no demographic information provided	No; history not described	No; phantom limb experience not described	No; explanation of how nerve stimulation sites were identified not provided	No; information not adequately described in main text	Unclear; there is only mention of expected outcomes	No; no mention of adverse or unexpected events	Yes; findings and implications discussed	Low methodological quality; high risk of bias
ROSEN ET AL. (2001)	No; lacking demographic information	No; history not extensively reported	Yes; patients' PLP extensively described	Yes; use of VAS, MPQ and PET scans described	No; minimal information regarding hypnosis intervention provided	Yes; experience following the intervention described	Unclear; no mention of adverse events though described unexpected events	Yes; implications of hypnosis as treatment for PLP discussed	Medium methodological quality; moderate risk of bias
ROUX ET AL. (2001)	No; lacking demographic information	No; history not extensively reported	No; phantom sensations described but frequency not included	Yes; fMRI procedures clearly outlined	Yes; electrode placement and surgery well described	Yes; pain intensity described at multiple follow-ups	Yes; no adverse effects reported by authors	Yes; findings and implications discussed	Medium methodological quality; moderate risk of bias
SCHMALZL ET AL. (2014)	No; lacking demographic information	No; history not extensively reported	Yes; phantom experiences and pain described	Yes; fMRI and RHI procedures clearly outlined	N/A	N/A	N/A	Yes; research question worth further investigation identified	Medium methodological quality; moderate risk of bias

SCHMITT ET AL. (2022)	No; lacking demographic information	No; history not extensively reported	No; some phantom sensations described but pain not included	Yes; qualitative method described	N/A	N/A	N/A	Yes; implications for sensorimotor learning described	Medium methodological quality; moderate risk of bias
STANNARD AND PORTER (1993)	No; lacking demographic information	No; history not extensively reported	Yes; PLP well described for each patient	No; limited information about tests and measures used	Yes; administration of ketamine adequately described	Yes; outcomes following ketamine procedure described	Yes; adverse outcomes and side-effects described	Yes; findings and implications discussed	Medium methodological quality; moderate risk of bias
STONE (1950)	No; lacking demographic information	Yes; history sufficiently described where deemed relevant	Yes; PLP well described for each patient	No; limited information about tests and measures used	Yes; details of the craniotomy described	Yes; results of the surgery on PLP described	No; information on adverse and unforeseen outcomes not provided	Yes; findings and implications discussed	Medium methodological quality; moderate risk of bias
TOPFNER ET AL. (2001)	No; lacking demographic information	No; history not extensively reported	No; limited information on the quality and frequency of PLP	Yes; use of VAS and measure of cortical reorganization described	Yes; medication used, method of administration, frequency, and dose provided	Yes; 6-month follow-up provided information on PLP and psychosocial impacts	Unclear; did not provide reason why patient discontinued their medication	Yes; findings and implications discussed	Medium methodological quality; moderate risk of bias

Supplementary Table 12. Complete risk of bias assessment: Case report studies. Note: N/A; not applicable, VAS; Visual Analogue Scale, MPQ; McGill Pain Questionnaire (short form); MMPI; Minnesota Multiphasic Personality Inventory, PLP, phantom limb pain; TENS; transcutaneous electrical nerve stimulation, TMS; transcranial magnetic stimulation, RLP; residual limb pain; fMRI, functional magnetic resonance imaging; RHI, rubber hand illusion.

AUTHOR (YEAR)	WERE THE CRITERIA FOR INCLUSION IN THE SAMPLE CLEARLY DEFINED?	WERE THE STUDY SUBJECTS AND THE SETTING DESCRIBED IN DETAIL?	WAS THE EXPOSURE MEASURED IN A VALID AND RELIABLE WAY?	WERE OBJECTIVE, STANDARD CRITERIA USED FOR MEASUREMENT OF THE CONDITION?	WERE CONFOUNDING FACTORS IDENTIFIED?	WERE STRATEGIES TO DEAL WITH CONFOUNDING FACTORS STATED?	WERE THE OUTCOMES MEASURED IN A VALID AND RELIABLE WAY?	WAS APPROPRIATE STATISTICAL ANALYSIS USED?	
BJORKMAN ET AL. (2016)	No; phantom hand map alluded to as “one of” the inclusion criteria though no other described	No; demographic information and setting not adequately described	No; use of different assessors	No; phantom hand maps require subjective reports	Yes; PLP was identified as a possible confound	No; strategies not described	Yes; touch threshold and discriminative touch measured using microfilaments and 2-point discrimination test	Yes; statistical analyses appear appropriate	Low methodological quality; high risk of bias
DE GRAAF ET AL. (2016)	Yes; inclusion criteria defined	No; vague information about recruitment, time, and demographics	Unclear; cyberglove set up procedures uncertain	No; self-reported movement of phantom limb	Yes; incorrect mimicking of intact limb identified as a possible confound	Unclear; ambiguous explanation	No; reliance on participant’s phantom movement disclosure	Yes; statistical analyses appear appropriate	Low methodological quality; high risk of bias
DETMERS ET AL. (2001)	No; inclusion criteria not clearly defined	No; lacking information about recruitment and demographics	Yes; via fMRI procedure	Yes; amputation objectively measured	No; not presented nor discussed	No; strategies to deal with confounding not discussed	Yes; analysis of fMRI data appears valid and reliable	Yes; statistical analyses appear appropriate	Medium methodological quality; moderate risk of bias
DIERS ET AL. (2010)	No; inclusion criteria not clearly defined	No; lacking demographic information	Yes; via fMRI procedure	Yes; questionnaires used to measure PLP, imagery ability, etc.	Yes; side of amputation identified as confound	Yes; strategies discussed (scans flipped)	Unclear; questionnaires were modified for the purpose of the study	Yes; statistical analyses appear appropriate	Medium methodological quality; moderate risk of bias
DRAGANSKI ET AL. (2006)	No; inclusion criteria not clearly defined	No; lacking demographic information	Yes; via fMRI procedure, all using the same scanner	Yes; amputation objectively identified	Yes; discussion of scanner-specific bias	Yes; addressed via customized grey-matter anatomical map	Yes; discussed optimized parameters for fMRI	Yes; statistical analyses appear appropriate	High methodological quality; low risk of bias
FLOR ET AL. (1998)	Unclear; subsample acquisition not described	No; lacking demographic information	Yes; PLP and sensations measured via validated measures	Yes; amputation objectively identified	No; not presented nor discussed	No; strategies to deal with confounding not discussed	Yes; imaging outcome measures appear valid and reliable	Unclear; statistical approach not discussed in methods	Low methodological quality; high risk of bias
FLOR ET AL. (2000)	No; inclusion criteria not clearly defined	No; lacking demographic information	Unclear; measures modified	Yes; amputation objectively identified	No; not presented nor discussed	No; strategies to deal with confounding not discussed	Unclear; potential inconsistencies in data collection	Yes; statistical analyses appear appropriate	Low methodological quality; high risk of bias

GRÜSSER, WINTER, MUHLNICKEL, ET AL. (2001)	No; inclusion criteria not clearly defined	No; lacking demographic and recruitment information	Yes; via neuroimaging procedure	Yes; amputation objectively identified	No; not presented nor discussed	No; only controlled for PLP and RLP	Unclear; PLP and telescoping status measures may not all be reliable	No; small sample size and one-tailed levels of significance used	122 Low methodological quality; high risk of bias
HABER (1958)	No; inclusion criteria not clearly defined	No; lacking demographic and recruitment information	Yes; via two-point discrimination, point localization, etc.	Yes; amputation objectively identified	No; not presented nor discussed	No; strategies to deal with confounding not discussed	Yes; valid and reliable at the time of the publication	Yes; t-tests to compare group averages	Medium methodological quality; moderate risk of bias
HUNTER ET AL. (2003)	Yes; inclusion criteria defined	Yes; subjects and setting adequately described	Yes; experimental procedures described	Yes; amputation objectively identified	Yes; prosthetic training and other confounds identified	Yes; attempts made to evaluate participants before prosthetic training	Yes; validated measures used to evaluate pain (e.g., VAS, MPQ)	N/A	High methodological quality; low risk of bias
HUNTER ET AL. (2005)	Yes; inclusion criteria defined	Yes; subjects and setting adequately described	Yes; measures conducted multiple times to produce a consistent response	Yes; amputation objectively identified	Yes; vascular and neurological disease confounds identified	Yes; individuals with vascular or neurological disease excluded	Yes; validated measures (e.g., VAS) and single interviewer used	Yes; statistical analyses appear appropriate	High methodological quality; low risk of bias
JALAVISTO (1950)	No; inclusion criteria not clearly defined	No; lacking demographic information	Unclear; methods not clearly described	Yes; amputation objectively identified	No; not presented nor discussed	No; strategies to deal with confounding not discussed	No; reliance on self-report and one-time examination of participants	Unclear; Chi-square tests used but could have been more rigorous	Low methodological quality; high risk of bias
KARL ET AL. (2004)	No; inclusion criteria not clearly defined	No; lacking demographic information	Yes; standardized interview and standardized measures used	Yes; amputation objectively identified	No; not presented nor discussed	No; strategies to deal with confounding not discussed	Yes; validated neuroimaging techniques used	Yes; statistical analyses appear appropriate	Medium methodological quality; moderate risk of bias
KEW ET AL. (1994)	No; inclusion criteria not clearly defined	No; lacking demographic information	Unclear; data collection procedures not described	Yes; amputation objectively identified	Yes; reason for amputation identified as a confound	Yes; data analysed separately based on reason for amputation	Yes; neuroimaging techniques and protocol adequately described	Yes; statistical analyses appear appropriate	Medium methodological quality; moderate risk of bias
KIKKERT ET AL. (2018)	Unclear; participants part of larger studies, details not included in present publication	No; lacking demographic information	Yes; via fMRI procedure	Yes; amputation objectively identified	No; not presented nor discussed	No; strategies to deal with confounding not discussed	Unclear; measures not adequately described	Yes; statistical analyses appear appropriate	Low methodological quality; high risk of bias
LYU ET AL. (2016)	No; inclusion criteria not clearly defined	Yes; subjects and setting adequately described	Yes; visual and kinesthetic abilities measured reliably (e.g., MIQ-R)	Yes; amputation objectively identified	Yes; discussed age, education, handedness, etc. as confounds	Yes; control group matched on age and education and all participants were right-handed	Unclear; multiple data collectors	Yes; statistical analyses appear appropriate	High methodological quality; low risk of bias

MACHIN AND WILLIAMS (1998)	Unclear; inclusion criteria not specified	No; lacking demographic information	Yes; reliable measures used (e.g., MPQ)	Unclear; method of validating amputation not described	Yes; living situation	Yes; groups separated based on living situation	Unclear; qualitative outcomes assessed by the principal investigator	Yes; statistical analyses appear appropriate	Medium methodological quality; moderate risk of bias
MAKIN ET AL. (2013)	Unclear; inclusion criteria not specified	No; lacking demographic information	Yes; PLP ratings acquired via standardized measures	Yes; amputation objectively identified	Yes; discussed age, education, and limb loss as confounds	Yes; control and comparison groups included	Unclear; MRI results collected by multiple individuals	Yes; statistical analyses appear appropriate	Medium methodological quality; moderate risk of bias
MALL ET AL. (1997)	Unclear; inclusion criteria not specified	No; lacking information on “sick” vs. “non-sick” participants	Unclear; only described how psychiatric illness was assessed (not pain)	Yes; amputation objectively identified	No; not presented nor discussed	No; strategies to deal with confounding not discussed	Unclear; scales for measuring factors other than psychiatric illness (DSM-III) not described	Unclear; analyses appear simplistic and do not account for multiple outcomes measured	Low methodological quality; high risk of bias
MONTOYA ET AL. (1997)	Yes; inclusion criteria defined	No; limited information about location and period	Unclear; not all scales used have been clearly validated	Yes; amputation objectively identified	Yes; discussed age, time since amputation, site of amputation, and education	Yes; verified significant differences between groups on confounds	Yes; PLP evaluated via self-report measures	Yes; statistical analyses appear appropriate	High methodological quality; low risk of bias
PRICE (1976)	Yes; inclusion criteria defined	No; lacking demographic information	Unclear; distinction between shortening vs. amputation	Yes; amputation objectively identified	No; not presented nor discussed	No; strategies to deal with confounding not discussed	No; unstructured interview, methods changed part way through the study	Unclear; statistical approach not clearly described	Low methodological quality; high risk of bias
TRIVEDI ET AL. (1997)	Yes; inclusion criteria defined	No; lacking demographic information	Unclear; did not describe how phantom phenomena were measured	Yes; amputation objectively identified	Yes; sociodemographic factors identified	No; strategies to deal with confounding not discussed	Yes; use of DSM-III and other standardized measures	Unclear; no mention of small sample sizes used	Medium methodological quality; moderate risk of bias

Supplementary Table 13. Complete risk of bias assessment: Analytical cross-sectional studies. Note: N/A; not applicable, fMRI; functional magnetic resonance imaging, PLP; phantom limb pain, RLP; residual limb pain, VAS; Visual Analogue Scale, MPQ; McGill Pain Questionnaire, MIQ-R; Movement Imagery Questionnaire, DSM-III; Diagnostic and Statistical Manual of Mental Disorders.

AUTHOR (YEAR)	WAS THE SAMPLE FRAME APPROPRIATE TO ADDRESS THE TARGET POPULATION?	WERE STUDY PARTICIPANTS SAMPLED IN AN APPROPRIATE WAY?	WAS THE SAMPLE SIZE ADEQUATE?	WERE THE STUDY SUBJECTS AND THE SETTING DESCRIBED IN DETAIL?	WAS THE DATA ANALYSIS CONDUCTED WITH SUFFICIENT COVERAGE OF THE IDENTIFIED SAMPLE?	WERE VALID METHODS USED FOR THE IDENTIFICATION OF THE CONDITION?	WAS THE CONDITION MEASURED IN A STANDARD, RELIABLE WAY FOR ALL PARTICIPANTS?	WAS THERE APPROPRIATE STATISTICAL ANALYSIS?	WAS THE RESPONSE RATE ADEQUATE, AND IF NOT, WAS THE LOW RESPONSE RATE MANAGED APPROPRIATELY?	OVERALL APPRAISAL
AHMED ET AL. (2017)	Unclear; small standard deviation for age.	Unclear; possible convenience sample	Unclear; sample size calculation not provided	Yes; sociodemographic details included though lacking age range	No; low female response rate	Unclear; validation of the measures not discussed	Unclear; limited information about testing administration	Yes; analyses appear appropriate (denominators missing)	Yes; reasons for attrition provided.	Medium methodological quality; moderate risk of bias
ALDINGTO N ET AL. (2014)	Yes; target population was addressed	Yes; all individuals were approached	Unclear; sample size calculation not provided	No; sociodemographic details not included	Unclear; no information on if men and women were both adequately represented	Unclear; validation of the measures not discussed	Unclear; limited information about questionnaire administration	Yes; percentage and number of participants provided (denominators missing)	Unclear; limited information about response rate provided	Medium methodological quality; moderate risk of bias
CARLEN ET AL. (1978)	Yes; target population was addressed	Unclear; recruitment strategy not described	Unclear; sample size calculation not provided	Yes; sociodemographic details included	Unclear; subgroups not clearly identified or discussed	No; no measures or their validation were discussed	No; methods were modified after several participants	No; denominators and confidence intervals not provided	Unclear; response rate not discussed	Low methodological quality; high risk of bias
COLLINS ET AL. (2018)	Yes; target population was addressed	Unclear; recruited from a previous study	No; small sample size	Yes; sociodemographic details included	No; low response rate from specific populations	No; state of participant could not be validated	Unclear; inconsistencies between interviewers	No; only percentages provided	Unclear; response rate not discussed	Low methodological quality; high risk of bias
DIERS ET AL. (2022)	Yes, broad sample	Yes, all individuals who met inclusion criteria were included	Unclear; sample size calculation not provided	Yes; sociodemographic details included	Unclear; higher rate of male respondents	Yes; majority of measures used were validated	Yes; standardized self-report survey	No; denominators and confidence intervals not provided	Unclear; low response rate not adequately explained	Medium methodological quality; moderate risk of bias
GIUMMAR RA ET AL. (2010)	Unclear; potential issues with recruitment and response bias	Unclear; part of the sample was asked to participate whereas others volunteered	Unclear; sample size calculation not provided	No; lacking sociodemographic information	Unclear; possible response bias	Yes; majority of measures used were validated	Unclear; limited information on if amputation status was verified	No; denominators and confidence intervals not provided	Unclear; low response rate not adequately explained	Medium methodological quality; moderate risk of bias

GRIFFIN ET AL. (2022)	No; certain groups underrepresented	No; convenience sample used	Unclear; sample size calculation not provided	Yes; sociodemographic details included	Yes; large subgroups	Yes; majority of measures used were validated	Yes; standardized self-report survey	Yes; skewness and kurtosis assessed, confidence intervals reported (denominators missing)	Unclear; response rate not described	Medium methodological quality; moderate risk of bias
LACOUX ET AL. (2002)	Unclear; does not appear to be a broad sample	No; convenience sample used	Unclear; sample size calculation not provided	No; lacking sociodemographic information	Unclear; possible response bias	Yes; valid method of measurement	Unclear; use of different interpreters	Yes; percentage and denominators provided	Unclear; response rate not described	Medium methodological quality; moderate risk of bias
MAYER ET AL. (2008)	Unclear; not enough information on participant characteristics provided	Unclear; method of sampling not described	Unclear; sample size calculation not provided	No; lacking sociodemographic information	Unclear; lacking participant information to determine	Yes; valid method of measurement	Unclear; possible inconsistencies in measurement across participants	No; results only provided for certain outcomes	Unclear; response rate not described	Medium methodological quality; moderate risk of bias
PROBSTNER ET AL. (2010)	Unclear; comparison to target population not discussed	Unclear; method of sampling not described	Unclear; sample size calculation not provided	Yes; sociodemographic details included	Yes; wide range of responses collected	Yes; valid method of measurement	Unclear; use of different research assistants	No; denominators and confidence intervals not always provided	Unclear; response rate not described	Medium methodological quality; moderate risk of bias
RICHARDSON ET AL. (2006)	Unclear; missing sociodemographic information to determine appropriateness	Yes, all individuals who met inclusion criteria were approached	Unclear; sample size calculation not provided	No; lacking sociodemographic information	Yes; participation completed for all those able	Yes; valid method of measurement	Unclear; potential use of different interviewers	No; numerators and denominators missing	Yes; describes reasons for exclusion	Medium methodological quality; moderate risk of bias
RICHARDSON ET AL. (2015)	Unclear; missing sociodemographic information to determine appropriateness	Unclear; method of sampling not described	Unclear; sample size calculation not provided	No; lacking sociodemographic information	Unclear; possible response bias	Yes; valid method of measurement	No; inconsistencies in patient evaluation	No; inconsistencies in reporting, numerators, denominators, and confidence intervals missing	Unclear; response rate not described	Low methodological quality; high risk of bias
RICHARDSON ET AL. (2018)	Unclear; missing sociodemographic information to determine appropriateness	Unclear; recruitment strategy not described	Unclear; sample size estimate provided though multiple statistical tests conducted (type II error)	No; lacking sociodemographic information	Unclear; possible response bias	Yes; valid method of measurement of limb loss	Unclear; potential use of different interviewers	No; numerators and denominators missing	Unclear; relatively low response rate not discussed by authors	Medium methodological quality; moderate risk of bias

SHUKLA ET AL. (1982)	Unclear; information not included	Unclear; sampling method not described	Unclear; sample size calculation not provided	No; lacking sociodemographic information	Unclear; unable to determine due to lacking participant information	Yes; valid method of measurement	Unclear; limited information about methodology provided	Unclear; limited information on analytical strategy	Unclear; response rate not described	126 Medium methodological quality; moderate risk of bias
SIN ET AL. (2013)	Unclear; generalization of sample	Yes, all individuals who met inclusion criteria were approached	Unclear; sample size calculation not provided	Yes; sociodemographic details included	Unclear; overrepresentation of Malaysian individuals	Yes; valid method of measurement	Unclear; interviews conducted in English with different dialects and translator used	No; confidence intervals not provided	No; low response rate	Medium methodological quality; moderate risk of bias
SOLOMON (1962)	Yes; large male sample	Unclear; sampling method not described	Unclear; sample size calculation not provided	No; lacking sociodemographic information	Unclear; first 1000 respondents used	No; scales used were not described	Yes; same measures completed by all participants	No; results ambiguously described	Unclear; total number of surveys completed not described	Low methodological quality; high risk of bias
WEISS AND FISHMAN (1963)	No; certain groups underrepresented	No; convenience sample used	Unclear; sample size calculation not provided	No; lacking sociodemographic information	Unclear; response rates for different ethnic groups not provided	Unclear; method of measurement not adequately described	Unclear; limited information about interviews and measures provided	No; inconsistencies in reporting numerators and denominators, and confidence intervals missing	Unclear; response rate not described	Low methodological quality; high risk of bias

Supplementary Table 14. Complete risk of bias assessment: Prevalence studies.

AUTHOR (YEAR)	WAS THE STUDY QUESTION OR OBJECTIVE CLEARLY STATED?	WERE ELIGIBILITY/SELECTION CRITERIA FOR THE STUDY POPULATION PRESPECIFIED AND CLEARLY DESCRIBED?	WERE THE PARTICIPANTS IN THE STUDY REPRESENTATIVE OF THOSE WHO WOULD BE ELIGIBLE FOR THE TEST/ SERVICE/ INTERVENTION IN THE GENERAL OR CLINICAL POPULATION OF INTEREST	WERE ALL ELIGIBLE PARTICIPANTS THAT MET THE PRESPECIFIED ENTRY CRITERIA ENROLLED?	WAS THE SAMPLE SIZE SUFFICIENTLY LARGE TO PROVIDE CONFIDENCE IN THE FINDINGS?	WAS THE TEST/ SERVICE/ INTERVENTION CLEARLY DESCRIBED AND DELIVERED CONSISTENTLY ACROSS THE STUDY POPULATION?	WERE THE OUTCOME MEASURES PRESPECIFIED, CLEARLY DEFINED, VALID, RELIABLE, AND ASSESSED CONSISTENTLY ACROSS ALL STUDY PARTICIPANTS?	WERE THE PEOPLE ASSESSING THE OUTCOMES BLINDED TO THE PARTICIPANTS' EXPOSURES/ INTERVENTIONS?	WAS THE LOSS TO FOLLOW-UP AFTER BASELINE 20% OR LESS? WERE THOSE LOST TO FOLLOW- UP ACCOUNTED FOR IN THE ANALYSIS?	DID THE STATISTICAL METHODS EXAMINE CHANGES IN OUTCOME MEASURES FROM BEFORE TO AFTER THE INTERVENTION? WERE STATISTICAL TESTS DONE THAT PROVIDED P VALUES FOR THE PRE-TO-POST CHANGES?	WERE OUTCOME MEASURES OF INTEREST TAKEN MULTIPLE TIMES BEFORE THE INTERVENTION AND MULTIPLE TIMES AFTER THE INTERVENTION (I.E., DID THEY USE AN INTERRUPTED TIME-SERIES DESIGN)?	IF THE INTERVENTION WAS CONDUCTED AT A GROUP LEVEL (E.G., A WHOLE HOSPITAL, A COMMUNITY, ETC.) DID THE STATISTICAL ANALYSIS TAKE INTO ACCOUNT THE USE OF INDIVIDUAL-LEVEL DATA TO DETERMINE EFFECTS AT THE GROUP LEVEL?	QUALITY RATING (GOOD, FAIR, OR POOR)
BAMFORD (2006)	Yes; study objectives clearly stated	No; eligibility and selection criteria not described	Yes; various individuals with PLP included	Yes; explanation of why participants were not enrolled was provided	No; small sample size	No; unclear description of hypnosis procedure and working “pool”	Yes; VAS used pre- and post-treatment	NA; same intervention used for all participants	Yes; 12% of questionnaires not returned at follow-up	Yes; all p-values provided in tables	Yes; VAS scores obtained before, during, and after the intervention	Yes; individual level data was examined	Fair; moderate risk of bias
DE NUNZIO ET AL. (2018)	Yes; study objectives clearly stated	Yes; time since amputation, pain level, etc. described	Yes; various individuals with PLP included	CD; no description of how participants were “selected”	No; small sample size	Yes; protocol administered consistently	Yes; VAS used pre- and post-treatment	Yes; evaluators who completed the baseline interview did not take part in the training process	NA; no loss of follow-up	Yes; p-values reported	Yes; VAS scores obtained before, during, and after the intervention	Yes; individual level data was examined	Good; low risk of bias
FOELL ET AL. (2014)	Yes; study objectives clearly stated	CD; unclear if criteria were pre-specified	Yes; various individuals with PLP included	CD; sampling method and number of eligible participants not described	No; small sample size	Yes; protocol administered consistently	Yes; VAS used pre- and post-treatment	NR; who assessed the outcomes not described	Yes; no drop out, minimal non-compliance, missing data replaced with average scores	Yes; p-values reported	Yes; VAS scores obtained before, during, and after the intervention	Yes; telescoping and use of pain medication considered	Fair; moderate risk of bias
KULKARNI ET AL. (2020)	Yes; study objectives clearly stated	Yes; inclusion and exclusion criteria clearly described	CD; insufficient information provided about the study sample	CD; sampling method and number of eligible participants not described	No; pilot study with small sample size	Yes; VR protocol administered consistently	Yes; NRS used to measure pain on multiple occasions	NA; same intervention used for all participants	Yes; all participants completed follow-up	Yes; p-values reported	Yes; NRS of PLP measures before, during, and after the VR sessions in addition to one year follow-up	NA; not group level	Fair; moderate risk of bias
MURRAY ET AL. (2006)	Yes; study objectives clearly stated	Yes; inclusion and exclusion criteria clearly described	No; small sample and narrow age range	CD; number of eligible participants not described	No; small sample size	No; intervention altered based on amputation site	Yes; MPQ and pain diary used to measure pain on multiple occasions	CD; unlikely given qualitative data obtained	No; 40% loss at follow-up for MPQ	No; sample size too small	Yes; MPQ scores obtained before, during, and after the intervention	NA; not group level	Poor; high risk of bias

AUTHOR (YEAR)	Was the study question or objective clearly stated?	Were eligibility/selection criteria for the study population prespecified and clearly described?	Were the participants in the study representative of those who would be eligible for the test/ service/ intervention in the general or clinical population of interest	Were all eligible participants that met the prespecified entry criteria enrolled?	Was the sample size sufficiently large to provide confidence in the findings?	Was the test/ service/ intervention clearly described and delivered consistently across the study population?	Were the outcome measures prespecified, clearly defined, valid, reliable, and assessed consistently across all study participants?	Were the people assessing the outcomes blinded to the participants' exposures/ interventions?	Was the loss to follow-up after baseline 20% or less? Were those lost to follow-up accounted for in the analysis?	Did the statistical methods examine changes in outcome measures from before to after the intervention? Were statistical tests done that provided p values for the pre-to-post changes?	Were outcome measures of interest taken multiple times before the intervention and multiple times after the intervention (i.e., did they use an interrupted time-series design)?	If the intervention was conducted at a group level (e.g., a whole hospital, a community, etc.) did the statistical analysis take into account the use of individual-level data to determine effects at the group level?	Quality Rating (Good, Fair, or Poor)
OSUMI ET AL. (2019)	Yes; study objectives clearly stated	No; eligibility and selection criteria not described	CD; unclear if participants were systematically different	CD; recruitment strategy and enrollment not described	CD; no discussion of power	No; VR procedures were not clearly described	Yes; valid and reliable measures used (e.g., MPQ)	NR; who assessed the outcomes not described	NR; no details provided on loss to follow-up	Yes; p-values reported	No; outcomes measured taking before and after intervention only	Yes; researchers examined differences in quality of PLP	Poor; high risk of bias
THOGERSEN ET AL. (2020)	No; objective not clearly stated	Yes; inclusion and exclusion criteria clearly described	Yes; representative of individuals with a telescoped phantom	CD; sampling method and number of eligible participants not described	No; small sample size	No; one participant used a virtual reality background due to nausea	Yes; valid and reliable measures used (e.g., VAS, MPQ, etc.)	NA; all participants experienced the same intervention	CD; not all participants were compliant with the pain journal	Yes; p-values reported	Yes; measures obtained before, during, and after the intervention	NA; not group level	Fair; moderate risk of bias
VASO ET AL. (2014)	Yes; study objectives clearly stated	Yes; inclusion and exclusion criteria clearly described	Yes; representative of individuals with limb loss with ongoing PLP	CD; recruitment strategy and enrollment not described	CD; no discussion of power	No; differences between groups due to variability in PLP location	Yes; valid and reliable measures used (e.g., VAS)	No; those administering the blocks were aware of the exposure condition	NA; follow-up occurred immediately after intervention	Yes; p-values reported	CD; inconsistently reported follow-up one day after the intervention	Yes; individual differences reported	Fair; moderate risk of bias
WILLOCH ET AL. (2000)	Yes; study objectives clearly stated	No; eligibility and selection criteria not described	CD; results possibly only relevant to individuals who are "hypnotizable"	CD; recruitment strategy and enrollment not described	CD; no discussion of power	No; "natural approach" hypnotic technique used but not described	Yes; outcome measures included neuroimaging results, VAS, etc.	NR; who assessed the outcomes not described	NA; no loss to follow-up given all outcomes measures at one time	Yes; p-values reported	No; outcome measure obtained before and during the interventions	NA; not group level	Poor; high risk of bias
YILDIRIM AND KANAN (2016)	Yes; study objectives clearly stated	Yes; inclusion and exclusion criteria clearly described	Yes; various individuals with PLP included	CD; recruitment strategy not described	No; small sample size	Yes; training procedure clearly outlined and delivered consistently	CD; Mirror therapy practice booklet used	NA; all participants experienced the same intervention	Yes; >20% drop out, individuals removed from final analyses	Yes; p-values reported	Yes; measures obtained before, during, and after the intervention	NA; not group level	Fair; moderate risk of bias
ZHENG ET AL. (2009)	Yes; study objectives clearly stated	No; eligibility and selection criteria not described	Yes; representative of individuals with severe PLP	CD; recruitment strategy not described	No; small sample size	Yes, DREZ procedure adequately described and delivered consistently	No; participants asked to rate % pain relief (not via a validated scale)	NA; all participants experienced the same intervention	Yes, few lost to follow-up (death), individual excluded	No; p-values not reported	Yes; measures obtained before, and after the intervention (2 weeks and last follow-up)	NA; not group level	Fair; moderate risk of bias

Supplementary Table 15. Complete risk of bias assessment: Before-after (pre-post) studies. Note: CD; Cannot determine, VAS; Visual Analogue Scale, PLP; phantom limb pain, NA; not applicable; NRS; Numerical Rating Scale, MPQ; McGill Pain Questionnaire

AUTHOR (YEAR)	REPRESENTATIVENESS OF THE EXPOSED COHORT	SELECTION OF THE NON-EXPOSED COHORT	ASCERTAINMENT OF EXPOSURE	DEMONSTRATION THAT OUTCOME OF INTEREST WAS NOT PRESENT AT START OF STUDY	COMPARABILITY OF COHORTS ON THE BASIS OF THE DESIGN OR ANALYSIS	ASSESSMENT OF OUTCOME	WAS FOLLOW-UP LONG ENOUGH FOR OUTCOMES TO OCCUR	ADEQUACY OF FOLLOW UP OF COHORTS	QUALITY RATING (GOOD, FAIR, OR POOR)
GIORDANO ET AL. (2021)	d) no description of the derivation of the cohort	NA	a) secure record (e.g., surgical records)	b) no; dream content was not analysed prior to amputation	a) study controls for gender	c) self report	a) yes (4-6 months after amputation)	c) follow up rate <80% and minimal description of those lost	Fair; moderate risk of bias
HUNTER ET AL. (2008)	d) no description of the derivation of the cohort	NA	a) secure record (e.g., surgical records)	b) no; skin temperature before amputation was not obtained (but contralateral arm was used as comparison)	a) study controls for baseline pain intensity	c) self report	a) yes (1-3 years after amputation)	c) follow up rate <80% and minimal description of those lost	Fair; moderate risk of bias
JENSEN ET AL. (1983)	d) no description of the derivation of the cohort	NA	a) secure record (e.g., surgical records)	a) yes; phantom limb phenomena not present before amputation	NA; study does not control for important factors	c) self report	a) yes (6 months after amputation)	b) subjects lost to follow up unlikely to introduce bias (small number lost, >20%)	Fair; moderate risk of bias
JENSEN ET AL. (1984)	d) no description of the derivation of the cohort	NA	a) secure record (e.g., surgical records)	a) yes; phantom limb phenomena not present before amputation	NA; study does not control for important factors	c) self report	a) yes (2 years after amputation)	c) follow up rate <80% and minimal description of those lost	Fair; moderate risk of bias
RICHARDSON ET AL. (2007)	d) no description of the derivation of the cohort	NA	a) secure record (e.g., surgical records)	a) yes; phantom limb not present before amputation	a) study controls for pre-amputation pain	c) self report	a) yes (6 months after amputation)	b) subjects lost to follow up unlikely to introduce bias (small number lost, >20%)	Fair; moderate risk of bias

Supplementary Table 16. Complete risk of bias assessment: Cohort Studies. Note: NA; not applicable.

AUTHOR (YEAR)	IS THERE CONGRUITY BETWEEN THE STATED PHILOSOPHICAL PERSPECTIVE AND THE RESEARCH METHODOLOGY?	IS THERE CONGRUITY BETWEEN THE RESEARCH METHODOLOGY AND THE RESEARCH QUESTION OR OBJECTIVES?	IS THERE CONGRUITY BETWEEN THE RESEARCH METHODOLOGY AND THE METHODS USED TO COLLECT DATA?	IS THERE CONGRUITY BETWEEN THE RESEARCH METHODOLOGY AND THE REPRESENTATION AND ANALYSIS OF DATA?	IS THERE CONGRUITY BETWEEN THE RESEARCH METHODOLOGY AND THE INTERPRETATION OF RESULTS?	IS THERE A STATEMENT LOCATING THE RESEARCHER CULTURALLY OR THEORETICALLY?	IS THE INFLUENCE OF THE RESEARCHER ON THE RESEARCH, AND VICE- VERSA, ADDRESSED?	ARE PARTICIPANTS, AND THEIR VOICES, ADEQUATELY REPRESENTED?	IS THE RESEARCH ETHICAL ACCORDING TO CURRENT CRITERIA OR, FOR RECENT STUDIES, AND IS THERE EVIDENCE OF ETHICAL APPROVAL BY AN APPROPRIATE BODY?	DO THE CONCLUSIONS DRAWN IN THE RESEARCH REPORT FLOW FROM THE ANALYSIS, OR INTERPRETATION, OF THE DATA?	
BJORKMAN ET AL. (2010)	Yes; narrative study	Yes; researchers investigated how patients understand and experience their phantom sensations and pain	Yes; use of semi-structured interviews	Yes; discourse analysis and narrative analysis used	Yes; results consistent with methods and appear to have been interpreted appropriately	No; theoretical or cultural perspective not clearly described	No; relationship between researcher and participants not addressed	Yes; examples and quotes from participants were included	Yes; ethics board approval and verbal informed consent obtained	Yes; conclusions summarize findings	High methodological quality; low risk of bias
FRANK AND LORENZONI (1989)	Unclear; philosophical perspective and research methodology not described	Unclear; research question not clearly stated	Unclear; no information regarding weather information was collected via written reports or oral interviews	Unclear; methodology not sufficiently described	Unclear; methodology not sufficiently described	No; theoretical or cultural perspective not clearly described	No; relationship between researcher and participants not addressed	Yes; several cases are reported and described	Unclear; ethics statement and informed consent procedures not provided	Yes; conclusions extend from findings	Moderate methodological quality; moderate risk of bias
MIDDLETON AND ORTIZ- CATALAN (2020)	Yes; grounded theory methodology	Yes; researchers explored experience of using the prosthesis	Yes; use of semi-structured interviews	Yes; thematic content analysis and discourse analysis	Yes; results consistent with methods and appear to have been interpreted appropriately	No; theoretical or cultural perspective not clearly described	No; relationship between researcher and participants not addressed	No; only three participants included in the study	Yes; ethics board approval and verbal informed consent obtained	Yes; conclusions summarize findings	High methodological quality; low risk of bias
TREVELYAN ET AL. (2016)	Yes; constructivist paradigm	Yes; researchers investigated living with PLP in individuals with lower limb loss	Yes; face-to-face semi-structured interviews	Yes; framework analysis used	Yes; results consistent with methods and appear to have been interpreted appropriately	No; cultural perspective not clearly described	No; relationship between researcher and participants not addressed	Yes; examples and quotes from participants were included	Yes; ethics board approval and informed consent obtained	Yes; conclusions summarize findings	High methodological quality; low risk of bias

Supplementary Table 17. Complete risk of bias assessment: Qualitative research.

AUTHOR (YEAR)	<u>SELECTION BIAS</u> (BIASED ALLOCATION TO INTERVENTIONS) DUE TO INADEQUATE GENERATION OF A RANDOMISED SEQUENCE	<u>SELECTION BIAS</u> (BIASED ALLOCATION TO INTERVENTIONS) DUE TO INADEQUATE CONCEALMENT OF ALLOCATIONS BEFORE ASSIGNMENT	<u>PERFORMANCE BIAS</u> DUE TO KNOWLEDGE OF THE ALLOCATED INTERVENTIONS BY PARTICIPANTS AND PERSONNEL DURING THE STUDY	<u>DETECTION BIAS</u> DUE TO KNOWLEDGE OF THE ALLOCATED INTERVENTIONS BY OUTCOME ASSESSMENT	<u>ATTRITION BIAS</u> DUE TO AMOUNT, NATURE, OR HANDLING OF INCOMPLETE OUTCOME DATA	<u>REPORTING BIAS</u> DUE TO SELECTIVE OUTCOME REPORTING	OTHER BIAS	OVERALL RATING
CASALE ET AL. (2009)	Unclear risk; not specified how treatment condition was determined	Low risk; treatment condition was concealed as syringes were prepared in a separate room by a nurse and administered by a physician blinded to the condition	Low risk; physicians and participants unaware of treatment condition (syringes made to look the same)	Low risk; assessment conducted by a physician blind to the treatment condition	Low risk; no attrition reported	Low risk; selective reporting not evident	Unclear risk; unknown if participants were aware of placebo condition beforehand	Low risk of bias
ROTHGANGEL ET AL. (2018)	Low risk; the principal investigator concealed and block-randomized assignment	High risk; single-blind	High risk; participants have knowledge of allocated condition	Low risk; outcomes evaluated by individuals unaware of treatment conditions	Low risk; reasons for drop-out included	Low risk; selective reporting not evident	Low risk; no significant other biases noted	Low risk of bias

Supplementary Table 18. Complete risk of bias assessment: Randomized controlled trials.

AUTHOR (YEAR)	RISK OF BIAS DUE TO CONFOUNDING	BIAS IN SELECTION OF PARTICIPANTS INTO THE STUDY	BIAS IN CLASSIFICATION OF INTERVENTIONS	BIAS DUE TO DEVIATIONS FROM INTENDED INTERVENTIONS	BIAS DUE TO MISSING DATA	BIAS IN MEASUREMENT OF OUTCOMES	BIAS IN SELECTION OF THE REPORTED RESULT	OVERALL BIAS (LOW, MODERATE, SERIOUS, NI)
WAKOLBINGE R ET AL. (2018)	Serious risk; potential confounding (e.g., controls not matched, family members responsible for delivering intervention, subjective measures, etc.)	Serious risk; no information on the selection of participants provided, two participants refused to be allocated by the research team	Moderate risk; classification of intervention status could have been affected by knowledge of the outcome	Moderate risk; NI on if interventions deviated from the intended plan	Low risk; outcome date provided for all participants	Serious risk; knowledge of intervention group not masked to assessors	Moderate risk; no indication of selection of reported analysis from among multiple analyses	Serious risk; no critical risk in any domain, some important issues across domains
SCHMALZL ET AL. (2011)	Moderate risk; serious residual confounding not expected but small sample size make it difficult to fully address confounds	Moderate risk; selection may have been related to intervention and outcome, though it was not clear if other factors contributed	Low risk; intervention status was well defined	Moderate risk; deviations were apparent but expected to have slight impact	Low risk; data were reasonably complete	Moderate risk; methods were comparable across conditions but minimally influenced by knowledge of the intervention	Moderate risk; no apparent preregistration, though analyses appear consistent with a priori plan	Moderate risk

Supplementary Table 19. Complete risk of bias assessment: Non-randomized controlled trials. Note: NI; No information, PN; probably no, PY; probably yes .

AUTHOR (YEAR)	IS THE CASE DEFINITION ADEQUATE?	REPRESENTATIVENESS OF THE CASES	SELECTION OF CONTROLS	DEFINITION OF CONTROLS	COMPARABILITY OF CASES AND CONTROLS ON THE BASIS OF THE DESIGN OR ANALYSIS	ASCERTAINMENT OF EXPOSURE	SAME METHOD OF ASCERTAINMENT FOR CASES AND CONTROLS	NON-RESPONSE RATE	QUALITY RATING (GOOD, FAIR, OR POOR)
KEW ET AL. (1997)	a) yes, with independent validation *	a) Yes - likely representative of individuals with multiple cervical root avulsions resulting from trauma *	c) no description	a) no history of disease	a) study controls for cervical root avulsion	a) secure record (e.g., surgical records)	a) yes	a) same rate for both groups	Good; low risk of bias

Supplementary Table 20. Complete risk of bias assessment: Case control.

AUTHOR (YEAR)	WAS THE STUDY QUESTION OR OBJECTIVE CLEARLY STATED?	WAS THE STUDY POPULATION CLEARLY AND FULLY DESCRIBED, INCLUDING A CASE DEFINITION?	WERE THE CASES CONSECUTIVE?	WERE THE SUBJECTS COMPARABLE?	WAS THE INTERVENTION CLEARLY DESCRIBED?	WERE THE OUTCOME MEASURES CLEARLY DEFINED, VALID, RELIABLE, AND IMPLEMENTED CONSISTENTLY ACROSS ALL STUDY PARTICIPANTS?	WAS THE LENGTH OF FOLLOW-UP ADEQUATE?	WERE THE STATISTICAL METHODS WELL-DESCRIBED?	WERE THE RESULTS WELL-DESCRIBED?	QUALITY RATING (GOOD, FAIR, OR POOR)
RAMACHANDRAN AND ROGERS-RAMACHANDRAN (1996)	No; objective not clearly stated	No; case definition not provided	CD; how participants were evaluated in relation to each other not described	CD; lacking information describing participants and control subjects	Yes; mirror therapy described	CD; protocol may have been modified based on the participants	NA	CD; statistical methods not clearly described	Yes; outcomes well described	Fair; moderate risk of bias

Supplementary Table 21. Complete risk of bias assessment: Case series. Note: CD; Cannot determine.

Box 1. PROM Development	Was the concept elicitation study performed in a sample representing the target population for which the PROM was developed?	Was an appropriate qualitative data collection method used to identify relevant items for the new PROM?	Were skilled group moderators/interviewers used? Were the group meetings or interviews based on an appropriate topic or interview guide? Were the group meetings or interviews recorded and transcribed verbatim?	Was an appropriate approach used to analyse the data?	Was at least part of the data coded independently? Was data collection continued until saturation was reached?	For quantitative studies (surveys): was the sample size appropriate?	Were there any other important flaws in the design or methods of the study?	Was the pilot study performed in a sample representing the target population for which the PROM was developed?	Was the comprehensibility assessed of the PROM instructions, items, response options, and recall period?	Were all items tested in their final form?	Was an appropriate qualitative method used?	Were skilled interviewers used? Were the interviews based on an appropriate interview guide? Were the interviews recorded and transcribed?	Were there any other important flaws in the design or methods of the study?	Overall
	Doubtful whether the study was performed in a sample representing the target population	Doubtful; only qualitative methods used	N/A	Very good; a widely recognized approach was used	N/A	Inadequate; less than 30	Inadequate; Other important methodological flaws (e.g., gaps in explanation and justifications, missing rational, etc.)	Doubtful whether the study was performed in a sample representing the target population	Doubtful; not clear if patients were asked about the comprehensibility of all items, response options, instructions, and recall period	Inadequate; items were not tested in their final form	Doubtful; only quantitative measure used	N/A	Inadequate; methodological flaws	High risk of bias
Box 2. Content Validity	Was an appropriate method used to ask patients whether each item is relevant for their experience with the condition?	Was each item tested in an appropriate number of patients?	Were skilled group moderators/interviewers used? Were the group meetings or interviews based on an appropriate topic or interview guide? Were the group meetings or interviews recorded and transcribed verbatim?	Was an appropriate approach used to analyse the data?	Were at least two researchers involved in the analysis?	Were there any other important flaws in the design or methods of the study?	Was an appropriate method used for assessing the comprehensiveness of the PROM?	Was the PROM tested in an appropriate number of patients?	Were skilled group moderators/interviewers used? Were the group meetings or interviews based on an appropriate topic or interview guide?	Were the group meetings or interviews recorded and transcribed verbatim?	Was an appropriate approach used to analyse the data?	Were at least two researchers involved in the analysis?	Were there any other important flaws in the design or methods of the study?	Overall
	Doubtful; not clear if participants were asked whether each item is relevant	Doubtful; less than 30	N/A	Very good; a widely recognized approach was used	Doubtful; not clear if two researchers were included in the analysis	Inadequate; other methodological flaws	Adequate; only quantitative method used	Doubtful; less than 30	N/A	N/A	Very good; a widely recognized approach was used	Doubtful; not clear what approach was used	Inadequate; important methodological flaws	Moderate risk of bias
	Was an appropriate qualitative method used for assessing the comprehensibility of	Was the PROM tested in an appropriate number of patients?	Were skilled group moderators/interviewers used?	Were the group meetings or interviews based on an appropriate topic or	Were the group meetings or interviews recorded and transcribed verbatim?	Was an appropriate approach used to analyse the data?	Were at least two researchers involved in the analysis?	Were there any other important flaws in the design or methods of the study?	Was an appropriate method used to ask professionals whether each item is relevant for the construct of interest?	Were professionals from all relevant disciplines included?	Was each item tested in an appropriate number of professionals?			

	group variable?								
	Inadequate; the sample was not similar for relevant characteristics	Very good; a widely recognized approach was used	Inadequate; small sample size used	Inadequate; other important methodological flaws					High risk of bias
Box 6. Reliability	Were patients stable on the construct to be measured in the time between the repeated measurements?	Was the time interval between the repeated measurements appropriate?	Were the measurement conditions similar for the repeated measurements – except for the condition being evaluated?	Statistical methods (4-7)	Were there any other important flaws in the design or statistical methods of the study?				Overall
	Doubtful; unclear if participants were stable	Doubtful; time interval not stated	Doubtful; not clear if the measurement conditions were similar	N/A	Inadequate; other methodological flaws given only one individual was measured twice				Moderate risk of bias
Box 7. Measurement Error	Were patients stable on the construct to be measured in the time between the repeated measurements?	Was the time interval between the repeated measurements appropriate?	Were the measurement conditions similar for the measurements except for the condition being evaluated as a source of variation?	Statistical methods (4 & 5)	Were there any other important flaws in the design or statistical methods of the study?				Overall
	Doubtful; unclear if participants were stable	Doubtful if time interval was appropriate	Doubtful; unclear if the measurement conditions were similar	N/A	Other important methodological flaws; only one individual was measured twice				Moderate risk of bias

Box 8. Criterion validity	For continuous scores: were correlations, or the AUC calculated?	For dichotomous scores: were sensitivity and specificity determined?	Were there any other important flaws in the design or statistical methods of the study?											Overall
	N/A	N/A	Doubtful; other methodological flaws (e.g., the criterion they want to measure against)											Moderate risk of bias
Box 9. Construct validity	Is it clear what the comparator instrument(s) measure(s)?	Were the measurement properties of the comparator instrument(s) sufficient?	Were statistical methods adequate for the comparisons made?	Were there any other important flaws in the design or statistical methods of the study?	Was an adequate description provided of important characteristics of the subgroups?	Were statistical methods appropriate for the subgroups being compared?	Were there any other important flaws in the design or statistical methods of the study?							Overall
	N/A (no comparator)	N/A	N/A	N/A	N/A	N/A	N/A							N/A
Box 10. Responsiveness	Statistical methods (1&2)	Were there any other important flaws in the design or statistical methods of the study?	Is it clear what the comparator instrument(s) measure(s)?	Were the measurement properties of the comparator instrument(s) sufficient?	Were statistical methods appropriate for the comparisons being made?	Were there any other important flaws in the design or statistical methods of the study?	Was an adequate description provided of important characteristics of the subgroups?	Were statistical methods appropriate for the subgroups being compared?	Were statistical methods appropriate for the subgroups being compared?	Were there any other important flaws in the design or statistical methods of the study?	Was an adequate description provided of the intervention given?	Were statistical methods appropriate for the before-after comparison being made?	Were there any other important flaws in the design or statistical methods of the study?	Overall
	N/A (no comparator)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Moderate risk of bias

Supplementary Table 22. Complete risk of bias assessment: Outcome measurement. Note. PROM, patient reported outcome measure; N/A, not applicable.

Section 3: Summary of Study 1 and Rationale for Study 2

The results from the narrative review indicate that phantom limb telescoping is a relatively common but highly variable phenomenon among individuals with limb loss, occurring in approximately 22% of cases. Prevalence appears higher among individuals with upper limb loss and those with trauma-related etiologies. In contrast, telescoping does not appear to be associated with demographic or biological factors such as age, sex, or time since amputation, suggesting that it is not simply a function of chronicity or individual difference variables.

Evidence from the reviewed studies implicates central mechanisms, particularly cortical reorganization, as a key contributor to telescoping, though the precise nature of this process remains unresolved. Telescoping also appears to be linked to the presence and greater intensity of PLP. At the same time, it appears to be related to better outcomes when undergoing PLP-related treatment. Telescoping does not appear to be consistently associated with psychosocial variables or with the presence of non-painful phantom limb sensations, although these relationships have rarely been examined systematically. Telescoping is more frequently reported among individuals who do not use a prosthetic limb, and available evidence suggests that it is not always maintained during sleep or dreaming, underscoring its dynamic and context-dependent nature.

Collectively, these findings underscore the need to move beyond prevalence estimates and isolated correlational findings toward a more nuanced, person-centered, and methodologically rigorous examination of telescoping. The variability and contradictions identified in the review point to the importance of standardized measurement, larger and more diverse samples, and designs capable of capturing both mechanistic and experiential dimensions of this phenomenon. These gaps directly informed the rationale and design of the subsequent studies in this dissertation.

Study 2, a detailed case report described in the next chapter of this dissertation, was undertaken to address the lack of fine-grained clinical observation within the literature and to explore the timing of the relationship between telescoping and changes in PLP intensity. By closely examining the possible relationship between telescoping and pain within a single individual, this study aimed to challenge the assumption that telescoping is uniformly maladaptive and to generate clinically meaningful hypotheses regarding its potential role in pain modulation.

Chapter 3: Case Report (Study 2)

Section 1: Objective and Hypotheses

Objective

The present study reports on a research participant with limb loss who experienced post-amputation pain and phantom limb telescoping. The objective was to explore the association between the extent of telescoping and ongoing PLP and RLP, as well as their relationships with relevant psychosocial factors, including emotional functioning and pain-related coping.

Hypotheses

Although Study 1 indicates that telescoping is associated with PLP based on findings from large-scale studies, many case reports suggest the opposite, highlighting the potential for more detailed insights into this relationship. Building on this, the present case report hypothesized that higher levels of PLP and/or RLP would be associated with reduced telescoping, lower levels of optimism and resilience, and decreased acceptance of chronic pain. In addition, greater pain severity was expected to be associated with higher levels of pain catastrophizing and increased symptoms of depression and anxiety.

Section 2: Published Article

The following study has been published in an evidence-based, open-access journal distributed under the Creative Commons Attribution License, which permits its reproduction in the present dissertation. The full reference is pasted below.

Aternali, A., Lumsden-Ruegg, H., Appel, L., Hitzig, S. L., Mayo, A. L., & Katz, J. (2024). Case Report: Reduction in post-amputation phantom limb pain intensity accompanying the onset of phantom limb telescoping. *Frontiers in Pain Research*, 5, 1409352.



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Case Report: Reduction in post-amputation phantom limb pain intensity accompanying the onset of phantom limb telescoping

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Introduction: Individuals with limb loss frequently report post-amputation phenomena, including nonpainful phantom sensations, phantom limb pain (PLP), and residual limb pain (RLP). Although post-amputation pain is common, not all patients benefit from widely accepted treatments. A greater understanding of phantom limb "telescoping", the experience of one's phantom hand or foot gradually approaching the residual limb, may assist in developing more effective interventions for reducing post-amputation pain. This case report explores the relationships between PLP, RLP, telescoping, and psychosocial experience in one person with a lower limb amputation. The aim of this case is to illustrate one possible relationship between telescoping and PLP as the mechanisms linking the two remain equivocal.

Methods: The participant is a 35-year-old male who underwent a transfemoral amputation due to a traumatic injury to his right leg approximately 4 years prior. He responded to questionnaires evaluating demographic and health-related information (e.g., age, sex, marital status, reason for amputation), pain and psychological variables via the Brief Pain Inventory (BPI-SF), ID Pain Questionnaire (IDPQ), Pain Catastrophizing Scale (PSC-4), Patient Health Questionnaire-4 (PHQ-4), Life Orientation Test-Revised (LOT-R), Connor-Davidson Resilience Scale (CD-RISC2), and Chronic Pain Acceptance Questionnaire (CPAQ-8) and telescoping, measured by a newly developed app. The participant completed a semi-structured interview that was designed to ascertain patterns in the overlapping experience of phantom limb telescoping and post-amputation pain.

Results: The participant rated his average PLP as 10 on a Numeric Rating Scale (NRS) from 0 ("no pain") to 10 ("worst pain imaginable") shortly after amputation. Approximately 12 months later, the participant noticed a shortening of his phantom limb, with a concurrent decrease in PLP. At present, his average NRS pain intensity is a 5/10. The participant described how the daily, debilitating PLP intensity diminished to weekly, manageable pain over time. Most notably, his responses on questionnaires were consistent with neuropathic PLP, mild to moderate levels of pain interference, a high level of catastrophic thinking about pain, low optimism, and mild symptoms of anxiety and depression.

Discussion: In this report, telescoping appeared to be preceded by an initial reduction in PLP intensity but these findings are based on a single case report and must be replicated with a large sample size before we have a clearer idea of the relationship between telescoping and PLP. This study provides insight into factors that may maintain PLP, generating targets for further investigation.

KEYWORDS

case report, phantom limb pain, residual limb pain, post-amputation pain, telescoping, phantom sensations

1 Introduction

Individuals with limb loss commonly report post-amputation phenomena, including nonpainful phantom sensations, phantom limb pain (PLP), and residual limb pain (RLP) (1–3). PLP refers to pain that is perceived in part of the limb that has been amputated, whereas RLP refers to pain that is perceived in the remaining part of the limb after amputation. Recent meta-analyses have estimated that 60%–87% of individuals who have sustained limb loss experience PLP and approximately 50%–60% experience RLP (1, 4–8). Several studies have found these two phenomena to co-occur, however, there is disagreement surrounding the relationship between post-amputation pain and nonpainful phantom sensations (6, 9, 10). This is likely due to fluctuations in several factors, including amputation etiology, post amputation complications (e.g., presence of neuromas, infection, etc.), level of amputation (e.g., upper/lower limb), and variability in research methods (e.g., survey, semi-structured interview, chart review, etc.).

One understudied nonpainful phantom sensation is known as telescoping, which is the experience of the phantom limb gradually retracting towards the residual limb and gives the impression of a shorter-than-normal phantom. Telescoping is estimated to occur in approximately one-quarter to one-third of individuals who have had an amputation (5, 11), with rates as high as 67% in persons with lower limb loss (2). Researchers have theorized that cortical reorganization is the primary mechanism underlying phantom limb telescoping (12). As the distal portion of a limb is more strongly represented at the cortical level than the proximal areas of a limb, a hand or foot may remain in perceptual awareness while other areas of the missing limb fade over time. This loss of proximal limb sensation combined with new perceptual feedback (such as a change in sensation at the level of the residual limb) may lead to cortical remapping associated with the experience of a telescoped phantom (11). It has been hypothesized that length of the phantom is a perceptual marker of the extent to which residual limb inputs have expanded into cortical areas once subserving parts of the lost limb (13, 14). Others have proposed that telescoping involves a “maladaptive” remapping process at the cortical level (12), although there are inconsistencies in research investigating the relationship between PLP and telescoping. Presently, the link between post-amputation pain and telescoping remains equivocal as it has been associated with both painful and nonpainful phantom limbs. Some studies have found telescoping is a significant predictor of lower levels of PLP

in people with limb loss (14), while other studies have found the opposite (12), or no support for either relationship (2, 15). Clinicians and researchers have drawn attention to a gap in current research as it relates to better understanding the association between telescoping and PLP (16).

To the best of our knowledge, there are no descriptive reports of the course of post-amputation pain as it relates to telescoping of the phantom limb. To address this gap in research, we report the case of a research participant who experienced post-amputation pain and phantom limb telescoping with the aim of exploring the association between telescoping and ongoing PLP and RLP, in addition to other relevant psychosocial factors. We hypothesized that high levels of PLP and/or RLP would be associated with decreased telescoping, optimism, resilience, and chronic pain acceptance. Moreover, we hypothesized that greater pain levels would be associated with high pain catastrophizing, and greater symptoms of depression and anxiety.

2 Methods

2.1 Case presentation

A 35-year-old Caucasian male who underwent a traumatic transfemoral amputation was studied for the purpose of this case review. The participant provided informed consent to participate as part of a larger project (see Ethics Statement below) investigating the relationship between post-amputation pain and telescoping. On August 15, 2023, he was asked to respond to questionnaires evaluating demographic and health-related information, pain experience, and psychological factors. He also responded to questions on a computer app that evaluates telescoping experience. One month later, the participant completed a semi-structured interview, which asked him questions regarding his experiences with amputation and his phantom limb.

The participant lost his right leg in a motor vehicle collision (MVC) approximately 4.5 years prior to his participation in this study. He noted that his leg was completely severed during the collision, and he was conscious as it occurred. At the time he participated in the study, he was married and living with his wife. The participant reported that his highest level of education attainment was completing his post-secondary education. At the time of the study, he was working for a non-profit corporation in a role he held before the collision, and that he resumed approximately 2 years after the amputation. The participant

reported ongoing pain problems including PLP and RLP in his right lower limb.

2.2 Qualitative interview

During the qualitative interview, the participant was asked a series of questions regarding his experience of PLP, RLP, and non-painful phantom sensations. The questions asked are listed in Table 1. The qualitative information was coded by two members of the research team (AA and HLR) and coded according to previously identified coding schemes (e.g., pain experience, non-painful phantom sensations, psychological impact, etc.).

2.3 Questionnaires

One-month prior to the interview, the participant completed the questionnaires described below, results of which are listed in Table 2. The Brief Pain Inventory (Short Form) (BPI-SF) pain

TABLE 2 Participant questionnaire results.

Measure	Subscale	Score	Severity/interpretation
BPI-SF	Pain interference	4.29	Mild to moderate pain interference
PCS-4	Total score	16	High pain catastrophizing
IDPQ	Total score	3	Above cut-off, high likelihood of neuropathic pain
PHQ-4	Anxiety	2	Below cut-off, mild anxiety symptoms
	Depression	2	Below cut-off, mild depression symptoms
	Total score	4	Mild anxiety and depression symptoms
LOT-R	Total score	5	Low optimism (high pessimism)
CD-RISC2	Total score	5	Below general population mean
CPAQ-8	Activity engagement	14	High
	Pain willingness	7	Low
	Total score	21	

BPI-SF, Brief Pain Inventory Short Form; PCS-4, The 4-Item Pain Catastrophizing Scale; IDPQ, Identification Pain Questionnaire; PHQ-4, The 4-Item Patient Health Questionnaire; LOT-R, Revised Life Orientation Test; CD-RISC2, The 2-Item Connor-Davidson Resilience Scale; CPAQ-8, The 8-Item Chronic Pain Acceptance Questionnaire.

interference items were used to measure pain interference (17) across seven domains, including general activity, mood, work, sleep, and enjoyment of life. Items are scored on a scale from 0 (“does not interfere”) to 10 (“completely interferes”). The average obtained across these items has been shown to have high reliability and validity across diverse pain conditions, including phantom limb pain (18).

The ID Pain Questionnaire (IDPQ) is a 6-item self-administered screening tool with “yes” or “no” as response options used to identify neuropathic pain (19). The six items address different characteristics of neuropathic pain, such as burning, numbness, and electrical shocks. Scores range from −1 to 5, with higher scores indicative of pain with a neuropathic component. Scores between 3 and 5 are estimated to have a 69% probability of neuropathic pain (19). The IDPQ has been demonstrated to accurately indicate the presence of a neuropathic component of pain (19).

Catastrophic thinking about pain was measured with the abbreviated measure of the Pain Catastrophizing Scale (PCS-4) (20). The PCS-4 is rated on a 5-point Likert scale from 0 (“not at all”) to 4 (“all the time”). Total scores range from 0 to 16, where higher scores are indicative of greater catastrophic thinking related to pain. The short form of the questionnaire has good internal consistency and correlates highly with scores from the original PCS (20, 21).

The 4-item Patient Health Questionnaire-4 (PHQ-4) was used as a composite measure of depression and anxiety (22). Total scores greater than or equal to 3 on the first two and last two items suggest symptoms of anxiety and depression, respectively. Overall scores range from 0 to 12 and are rated as normal (0–2), mild (3–4), moderate (6–8), and severe (9–12). The questionnaire demonstrates high reliability and validity as a measure of depression and anxiety (23). The 10-item Life Orientation Test-Revised (LOT-R) was used to evaluate dispositional optimism (24). The participant was asked to indicate the degree to which

TABLE 1 The list of interview questions.

No.	Questions
1.	How would you describe your phantom limb, and any pain associated with it?
a.	When have you experienced it?
b.	Has it only been in the past or also presently?
c.	When did it first start?
d.	Had it ever gone away and then came back?
e.	How would you describe the type of pain, if any?
f.	Has the feeling changed over time?
2.	How would you describe your residual limb pain, if any, which is the pain that you feel in the part of your remaining limb after your amputation?
a.	When have you experienced it?
b.	Has it only been in the past or also presently?
c.	When did it first start?
d.	Had it ever gone away and then came back?
e.	How would you describe the type of pain, if any?
f.	Has the feeling changed over time?
3.	Have you experienced phantom limb “telescoping”?
a.	When did it first happen?
b.	What were your initial reactions?
c.	How have others reacted when you have tried to explain it?
d.	What have been your experiences with it?
e.	Is it a constant length?
4.	Have you experienced any shrinkage of the phantom limb?
a.	When did it first happen?
b.	What were your initial reactions?
c.	What have been your experiences with it?
d.	Is it a constant size?
e.	How has it influenced areas of your life negatively or positively?
5.	When thinking about the different types of sensations associated with your amputation (e.g., phantom limb, telescoping, residual limb, etc.), how have any of these affected your day to day life?
a.	Impact on ability to maintain your physical health?
b.	Impact on your mental wellbeing?
c.	Impact on your relationships with others?
6.	Is there anything else about your phantom limb that you would like to discuss that we did not touch upon?

he agrees with each of the ten statements about positive and negative expectations on a scale from 0 ("strongly disagree") to 4 ("strongly agree"). Four of the items are filler items only and do not contribute to the total score. Total scores range from 0 to 24, where a higher score is indicative of greater dispositional optimism. Scores ranging from 0 to 13 suggest low optimism (high pessimism), 14–18 suggest moderate optimism, and 19–24 suggest high optimism (low pessimism) (25). The measure contains both positively and negatively worded items which demonstrate good internal consistency and reliability across populations, including those with chronic pain (26).

The 2-item Connor-Davidson Resilience Scale (CD-RISC2) was used to measure resilience, the ability to "bounce back" and successfully adapt to change (27). Respondents are required to respond to the two items on a scale from 0 ("not at all true") to 4 ("true nearly all the time"). Total scores range from 0 to 8, with higher scores indicative of greater resilience. Mean CD-RISC2 score in the general North American population is approximately 6.91 (27). The self-rated measure has been demonstrated to display good internal consistency, convergent validity, divergent validity, and test-retest reliability (27).

The Chronic Pain Acceptance Questionnaire (CPAQ-8) is an 8-item scale to evaluate acceptance of chronic pain (28). Respondents rate the extent to which each statement is true for them on a scale from 0 ("never true") to 6 ("always true"). The questionnaire is comprised of pain willingness and activity engagement scales, which are combined to provide a total score ranging from 0 to 48. Higher scores are indicative of greater chronic pain acceptance. The questionnaire also has the capacity to identify four different clusters of patients with distinct functional levels (e.g., high activity engagement and pain willingness, low activity engagement and pain willingness, high activity engagement and low pain willingness, and low activity engagement and high pain willingness) (29). The CPAQ-8 has demonstrated high validity and good psychometric properties related to rehabilitation (30).

2.4 Telescoping app

When completing the questionnaires, the participant was also asked to respond to questions on a recent web-based/mobile application (<https://demo.phantomlimbs.ca/>), developed by our team to assess the extent of phantom limb telescoping and associated factors. The application allows the participant to identify the limb and level of amputation, the nature of the phantom limb, and the extent of telescoping (from normal length to completely telescoped) measured visually and as percentage (normal length phantom = 0% to completely telescoped phantom inside the residual limb = 100%) (31). This app is similar to other developed measures of phantom limb sensations (32), while requiring less time to complete and measuring other amputation-related information. The app also collects information related to participants' age, sex, date of amputation(s), and intensity of their PLP and/or RLP on average on a numeric rating scale using a slider that moves from 0 to 10.

The tool was designed as a systematic, consistent, and precise measure of telescoping that can be used to document its prevalence and understand its relationship to post-amputation pain (31).

3 Results

3.1 Qualitative interview

During the qualitative interview, the participant provided a detailed account of his phantom limb and pain experiences since the amputation. He explained that shortly after the amputation, he vividly experienced his phantom foot at the same level as his intact foot (i.e., normal length) with what he described as "intense" painful and non-painful sensations. He reported experiencing daily "extreme nerve pain" in his phantom foot for more than 1 year after his amputation. He described how it felt as though his phantom foot was "encased in cement" and painfully "compressed from all sides". He explained that this compression feeling increased during the day, thereby increasing his pain experience. In thinking back to this period in his life, the participant rated this PLP on average as a 10 on a Numeric Rating Scale (NRS) from 0 ("no pain") to 10 ("worst pain imaginable"). During the first year after the amputation surgery, he reported that the pain experience was a "struggle" that made him "very irritable", and negatively impacted his relationships with others. He reported that he was not significantly impacted, emotionally or psychologically, by the loss of his leg as he was glad to have survived the MVC. Nevertheless, the PLP he experienced was "debilitating to [his] mental health". In addition, approximately 6 months after the amputation, the participant reported that he developed a problem with the healing of the residual limb (i.e., heterotopic ossification), which delayed the use of his prosthesis and increased his discomfort until the problem was successfully treated.

The participant recalled how over time, his painful and non-painful phantom experiences "shifted". As his pain experience changed, the participant recalled also experiencing changes to his phantom limb. He explained that approximately 1 year after the amputation, coinciding with the use of his prosthetic leg, he noticed that his phantom foot began to move up towards his residual limb. He explained that there was further shortening of the phantom limb from week-to-week, as he concurrently experienced a reduction in the intensity of his PLP.

Approximately 2 years after the amputation, he described his PLP experience as somewhat "comfortable". At the time of the interview, approximately 4 years after the amputation, he reported his phantom foot to be attached to and partially inside the residual limb at the level of his upper thigh. The participant described how his phantom limb does not vary in length any longer, nor is it impacted by wearing his prosthetic. He described his phantom foot as the same size as the contralateral intact foot and denied experiencing any shrinkage of his phantom foot. When asked about his reaction to the telescoping experience, the participant responded: "*My biggest thing was if I just have to get*

over how uncomfortable phantom limbs—like pain and sensation is, then like, anything beyond discomfort, I'm going to train myself to be comfortable with. [...] So, I wasn't really bothered—like, I wasn't bothered too much by having the feeling up there. It was more so just like, make it—please make it comfortable.”

The participant explained that he now experiences a variety of different painful and non-painful phantom sensations that he can more easily cope with. While he currently continues to feel his phantom foot and ankle, he experiences “light pressure” around the foot, as if it were “under water”. He rated this frequent pressure as a 1 out of 10 on the NRS and said that it does not interfere with his daily activities. On days when he is more physically active, he reported that he will experience greater PLP intensity (increasing to 3 or 4 on 10 on the NRS), which he likened to the feeling of having an open “blister” on the lateral aspect of his phantom foot that is continuously being rubbed. He reported that this pain does not deter him from engaging in physical activity. Lastly, the participant described experiencing monthly debilitating pain which typically lasts for a period of approximately 24 h. He described the sensation as an “electric zapper” at a high intensity that is being applied to his phantom foot every 30–60 s. The participant rated this pain as 9 or 10 on the NRS and results in no sleep, “peak frustration” and “peak discomfort”. He also commented that this monthly pain is especially difficult to cope with as it often increases his feelings of frustration, which increases his pain intensity in turn. The participant explained that he started massage therapy to his residual limb approximately 1 year ago and that it “significantly helped” manage his PLP pain. Overall, he rated the average intensity of his overall pain at a 6 on the 11-point NRS. He reported that he has not experienced significant levels of RLP since his leg healed after surgery, though does occasionally experience pain when using his prosthetic leg, which he feels can be easily addressed.

3.2 Questionnaires

The participant scored a 3 on the IDPQ, suggesting that he experiences symptoms of neuropathic pain. His overall score on the CPAQ-8 was 21, with subscales of pain willingness and activity engagement scoring 7 and 21 respectively. He had an average score of 4.29 on the BPI-SF and a total score of 16 out of a possible 16 on the PCS-4. His total score on the PHQ-4 was 4, with scores of 2 for both the depression and anxiety subscales. He attained total scores of 5 on the LOT-R and CD-RISC2.

3.3 Telescoping app

On the web-based/mobile application evaluating post-amputation pain and telescoping, the participant indicated that his phantom experience consisted mainly of his phantom foot and ankle, which were telescoped to 76% (Figures 1, 2). Using the sliders, he rated the intensity of his RLP and PLP over the past week as both 5 out of 10 on the 11-point NRS.

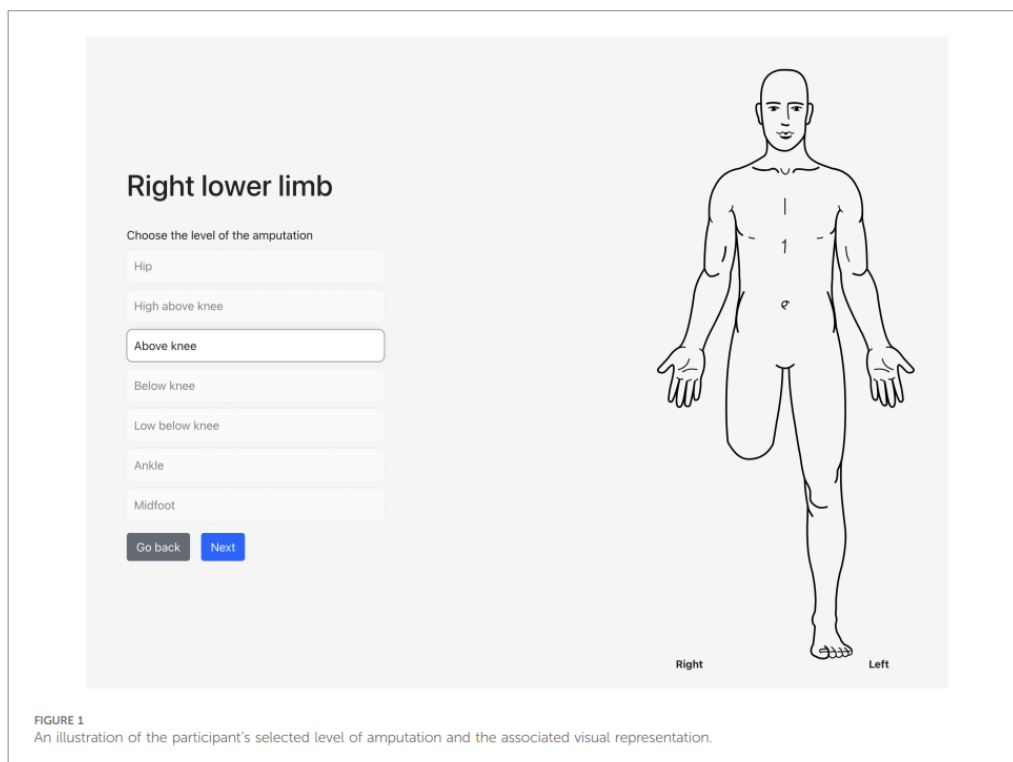
4 Discussion and future directions

This case provides information on the possible relationship between telescoping and post-amputation pain, notably PLP. To the best of our knowledge, this study is the first to thoroughly describe the onset and progression of telescoping alongside reductions in PLP and RLP intensity. The participant described in this case report experienced the onset of telescoping of his phantom limb followed by a reduction in his PLP intensity. This is consistent with our hypothesis and other studies that have found an inverse relationship between telescoping and PLP experience (13, 14). It is not possible to determine whether PLP decreased as a result of telescoping or other rehabilitation-related factors. Nevertheless, based on the present participant's experience, it is possible that telescoping is a perceptual marker of an adaptive form of plasticity reflecting a process of cortical reorganization that is accompanied by a reduction in PLP severity (13, 14). The cortical remapping that occurred as the participant's phantom foot remained in perpetual awareness and the other areas of his missing limb faded over time may have resulted in cortical reorganization that reduced his PLP.

The current case may clarify why other researchers have found PLP to be as likely to be present in a telescoped phantom as in a full-length phantom (2) and why others have considered telescoping a “maladaptive” process (12). It may not be the absolute value of the PLP intensity that is associated with telescoping but rather its reduced intensity relative to earlier levels. Thus, while telescoping and PLP can both be present, others may not have considered that a critical factor involved in telescoping is a reduction in the intensity of PLP which still could leave the individual with a significant level of PLP intensity. This possibility is best tested with a longitudinal design that observes the course of telescoping and PLP concurrently.

There are several other notable factors about this case. First, 4 years after amputation, the participant still experiences PLP, consistent with an estimated 63% of individuals after an approximate equivalent period of time (33). As well, he reported RLP at various times after amputation and at least three different qualities of PLP including a feeling of pressure as if his phantom foot were encased in cement or underwater, the sensation of a blister-like pain on his phantom foot that occurred during bouts of exercise, and monthly, intense electric-shock-like pain that lasts 24 h. This is consistent with published studies indicating that people with amputation-related pain report multiple kinds of PLP (33, 34). For example, on average, participants with PLP used a median of 13 different PLP descriptors, including shock, burning, pressure, and pins and needles (34). Moreover, PLP and RLP are strongly correlated (35–37), suggesting that many individuals with limb loss also experience a variety of RLP-related sensations, in addition to PLP. This diversity in pain experience within any given individual is partly why PLP has been so intractable with multiple mechanisms responsible for the pain (38, 39).

The finding that the participant continued to experience a shortened phantom even when wearing his prosthesis is unusual.

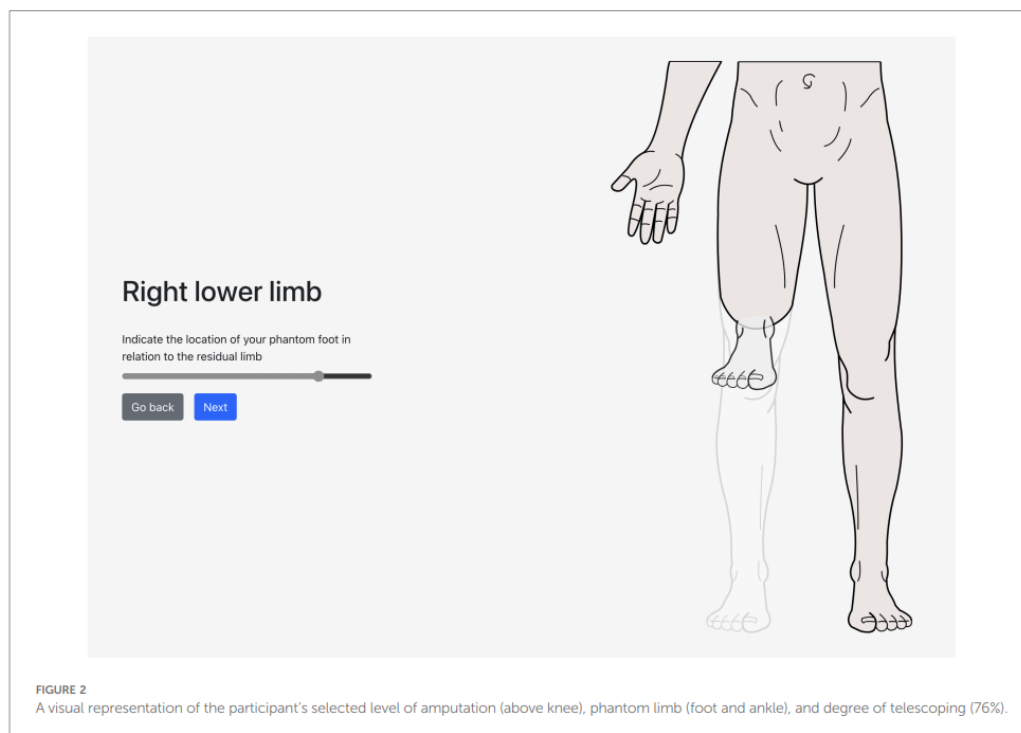


Typically, individuals with a shortened or telescoped phantom limb report that when they are wearing a prosthesis, the phantom limb extends to normal length to match the length of the prosthetic limb as appreciated by vision, a phenomenon referred to as “embodiment” (40). Prosthesis embodiment was reported to occur significantly more often in those with a normal length phantom than in those with a telescoped phantom (40), but other cases in which the two do not coincide have been reported, including a 10-year-old boy with bilateral below-the-knee amputations performed 10 months earlier who felt his “toes at [the] stumps, not in [the] tips of [his] prosthetic shoes” (41).

The participant's responses to questionnaires suggest other factors may be contributing to his PLP. Consistent with our hypotheses, the participant endorsed moderate post-amputation pain while endorsing questionnaire items consistent with high levels of catastrophic thinking about pain, low optimism, below average resilience, and low pain willingness. Catastrophic thinking about pain has been demonstrated in several studies to be positively correlated with the severity of PLP and disability in individuals with limb loss (42–45). Contrary to our hypotheses, the participant endorsed mild symptoms of anxiety and depression and high activity engagement. Provided the participant endorsed moderate daily PLP, we would have predicted higher symptoms of anxiety and depression and lower activity engagement.

While the current case report suggests there is a link between telescoping and a reduction in PLP from a previously higher level, future large-scale studies are needed to determine whether this is in fact the case. There are several limitations to this study. Given this is a single case report, our findings likely do not reflect most limb loss patients. Additionally, all information regarding the participant's amputation experience was collected retrospectively. As a result, various biases, including recall bias, may have influenced the results. Moreover, physical and neurological examinations were not completed, limiting the information gathered from this participant. In addition, to ensure the interview was reasonable in duration, not all information about the participant's experience could be gathered. As such, the participant was not asked if he can move his phantom limb nor was he asked to list the medication he has used and if they have been helpful/unhelpful. Following the patient longitudinally through the various stages of his rehabilitation would have been advantageous. The inclusion of a variety of different individuals with limb loss in future studies will be necessary to confirm the validity of a possible association between telescoping and PLP.

Using the valuable insights offered by this case report, we are exploring the use of targeted, customizable interventions, such as virtual reality (VR), to further evaluate the relationship between telescoping and PLP. Immersive VR environments can simulate



telescoping experiences, measure associated changes in PLP intensity and frequency, and have demonstrated efficacy in pain management (46). Such an innovative approach holds potential for uncovering and better understanding the underlying mechanisms linking telescoping and PLP (47). Through rigorous evaluation in clinical settings, the efficacy of this novel VR tool can be assessed, offering a promising avenue for addressing the complex interplay between post-amputation phenomena and improving the quality of life for individuals with limb loss (48).

5 Conclusions

This case report describes the experiences of a person with a lower limb amputation focusing mainly on PLP and phantom limb telescoping. The participant described the onset of telescoping followed shortly by a reduction in PLP intensity. Future adequately powered longitudinal studies are needed to fully explore this relationship. In addition, mechanism-based interventions are needed to determine the temporal and potential causal relationships between the two. It is hoped that this case report will contribute to better understanding the factors that influence post-amputation experience and rehabilitation for individuals with limb loss.

Participant perspective

The participant read this case report and agreed with the content. He provided written informed consent to have the case report published.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Research Ethics Boards of Sunnybrook Health Sciences Centre (REB #3071) and York University (HPRC #e2019-138). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

AA: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing, Visualization. HL-R: Data curation, Formal Analysis, Investigation, Visualization, Writing – original draft. LA: Supervision, Validation, Writing – review & editing. SH: Conceptualization, Investigation, Resources, Supervision, Validation, Writing – review & editing. AM: Conceptualization, Investigation, Resources, Supervision, Validation, Writing – review & editing. JK: Conceptualization, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Section 3: Summary of Study 2 and Rationale for Study 3

Study 2 provided an in-depth examination of the co-occurrence of phantom limb telescoping, PLP, RLP, and psychosocial functioning in a single individual with limb loss. Consistent with the aims of this case report, the findings offer a detailed illustration of one possible temporal relationship between telescoping and post-amputation pain. Specifically, the participant described the emergence of telescoping approximately one year following amputation, coinciding with a marked reduction in the intensity and frequency of PLP. Although pain remained present, it shifted from a daily, debilitating experience to a more intermittent and manageable pattern. This change occurred alongside enduring features of neuropathic pain, elevated pain catastrophizing, low optimism, and mild symptoms of anxiety and depression, highlighting the multifaceted nature of post-amputation adjustment.

When considered in the context of the findings from Study 1, the present case report highlights important variability in the relationship between telescoping and PLP. The narrative review identified that, across the literature, the most well-supported pattern suggests that telescoping is associated with increased PLP intensity. Nevertheless, this pattern was not observed in the present case. Despite clear and pronounced telescoping, the participant did not demonstrate the elevated PLP intensity that might have been expected based on the dominant trend identified in Study 1. This divergence underscores the complexity of telescoping as a perceptual phenomenon that cannot be fully understood through pain metrics alone.

Rather than contradicting the broader literature, the case report may illustrate the range of possible relationships between perceptual changes in phantom limb length and pain. The participant's experience suggests that telescoping may intersect with sensory, emotional, and cognitive processes in ways that shape both pain experience and broader quality of life after limb loss. At the same time, the findings illustrate the limits of interpretation inherent in single-case

designs. While the temporal association between the onset of telescoping and reduced PLP is clinically intriguing, the mechanisms linking these experiences remain unclear. It is not possible to determine whether telescoping contributed to pain reduction, reflected an underlying process of neural or perceptual reorganization, or emerged alongside other adaptive changes occurring over time.

These limitations highlight the need to move beyond isolated case reports toward research designs that can capture variability across individuals and contexts. Telescoping is likely not a uniform phenomenon; rather, it may differ in form, meaning, and clinical relevance depending on factors such as amputation level, time since limb loss, pain history, emotional functioning, and coping strategies. Larger samples are therefore essential to determine how commonly telescoping occurs, how it is experienced across individuals, and whether distinct patterns of telescoping are differentially associated with PLP, RLP, or psychosocial outcomes. At the same time, the richness of the participant's narrative in Study 2 underscores the value of qualitative approaches for advancing understanding of telescoping. Standardized questionnaires captured important aspects of pain and psychological functioning, but the semi-structured interview provided critical insight into how telescoping was interpreted, monitored, and integrated into daily life. This qualitative data revealed nuances that would likely be missed by quantitative measures alone, including how changes in phantom limb perception shaped the participant's sense of bodily awareness and adaptation following limb loss.

In sum, Study 2 serves as an important exploratory step, illustrating the potential significance of telescoping while simultaneously revealing the need for broader, more inclusive investigation. The findings reinforce the necessity of larger studies to clarify the role of

telescoping within the spectrum of post-amputation experiences and to better understand its implications for pain, adaptation, and well-being following limb loss.

Together, these observations provide a clear rationale for the subsequent study in this dissertation. Study 3 builds directly on the insights generated by this case report by employing a quantitative methodology with a larger sample of individuals with limb loss. By increasing sample size, Study 3 seeks to clarify the relationship between telescoping and post-amputation pain that cannot be discerned from single cases alone.

Chapter 4: Quantitative Data (Study 3)

Section 1: Objective and Analytic Focus

Objective

While PLP and RLP have been extensively studied, the role of phantom limb telescoping in shaping these experiences and related psychosocial outcomes remain poorly understood. Existing research has largely focused on post-amputation pain in general or on neurophysiological mechanisms, with very few studies directly comparing individuals who report telescoping with those who do not. This represents a critical gap in the literature, particularly in relation to pain intensity, pain interference, and psychosocial dimensions such as pain catastrophizing, anxiety, depression, optimism, and resilience.

The primary objective of the present study was to examine whether individuals with and without telescoping differ systematically in their experiences of post-amputation pain and psychosocial functioning. By exploring these relationships, this study aims to clarify the potential significance of telescoping as a factor in the broader post-amputation experience and to inform future research and clinical approaches that consider both perceptual phenomena and psychosocial adaptation. Findings from this study can provide foundational knowledge about the potential role of telescoping in post-amputation adjustment and help identify targets for future mechanistic and interventional research.

Analytic focus

Given the limited prior evidence, the study was exploratory in nature. No a priori hypotheses were formulated regarding the direction of associations between telescoping and post-amputation pain or psychosocial variables. Instead, the analytic focus was to compare groups based on the presence or absence of telescoping across a range of outcome variables,

including: pain intensity and pain interference, pain catastrophizing, symptoms of anxiety and depression, optimism, and resilience. This approach allows for a systematic assessment of whether telescoping is associated with measurable differences in pain and psychosocial functioning, without imposing assumptions about causality or directional effects.

Section 2: Published Article

The following study has been published in an evidence-based, open-access journal distributed under the Creative Commons Attribution License, which permits its reproduction in the present dissertation. The full reference is pasted below.

Aternali, A., Lumsden-Ruegg, H., Appel, L., Hitzig, S. L., Mayo, A., & Katz, J. Phantom Limb Telescoping in Individuals with Limb Loss: Links to Anxiety, Depression, and Pain-Related Measures. *Frontiers in Pain Research*, 7, 1755884.



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Phantom limb telescoping in individuals with limb loss: links to anxiety, depression, and pain-related measures

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Phantom limb pain (PLP) and residual limb pain (RLP) have been widely studied following limb loss; however, the role of telescoping, the perceived shortening of the phantom limb, remains poorly understood in pain and psychosocial outcomes. Using a cross-sectional observational design, this study examined whether PLP and RLP intensity, pain interference, and psychosocial functioning differ between individuals who report telescoping and those who do not. Fifty-one adults with limb loss (mean age = 49.5 years, SD = 15.4) completed measures of PLP and RLP intensity (0–10 numeric rating scale), telescoping (presence and percent), pain interference (Brief Pain Inventory–Short Form), pain catastrophizing (Pain Catastrophizing Scale–4), neuropathic pain (ID Pain Questionnaire), pain acceptance (Chronic Pain Acceptance Questionnaire–8), anxiety and depression symptoms (Patient Health Questionnaire–4), optimism (Life Orientation Test–Revised), and resilience (Connor–Davidson Resilience Scale–2). Twenty-three participants (45.1%) reported telescoping, while 28 (54.9%) did not. Telescoping was more common among younger participants and those with upper-limb loss, particularly right-sided below-elbow loss (all $ps < .05$). No significant between-group differences were observed for PLP intensity, RLP intensity, or pain interference (all $ps > .05$). However, greater percent telescoping was associated with lower pain interference ($r = -.43$, $p = .040$) and lower PLP intensity ($r = -.49$, $p = .018$). Participants reporting telescoping also endorsed higher symptoms of anxiety ($p = .022$) and depression ($p = .029$) relative to those with normal length phantoms. These findings suggest that telescoping may reflect distress linked to symptom monitoring and potentially adaptive cortical reorganization associated with reduced PLP.

KEYWORDS

limb loss, phantom limb pain, post-amputation pain, residual limb pain, telescoping

1 Introduction

Limb loss is a major life-altering event that is frequently accompanied by acute and chronic pain conditions (1, 2). Among these, two of the most common and distressing consequences reported by individuals with limb loss are phantom limb pain (PLP), referring to painful sensations perceived as originating from the amputated or missing limb, and residual limb pain (RLP), pain localized to the remaining portion of the limb (3, 4). The majority of individuals with an amputation will experience one or both types of pain, often at clinically significant levels and for years after their amputation (1). Pain interference, defined as the extent to which pain disrupts daily activities, social roles, sleep, and mood, is also elevated following limb loss (5). Both PLP and RLP have been associated with greater interference in everyday functioning (6, 7). Importantly, amputation has been identified as the surgical procedure with the highest incidence of chronic post-surgical pain in comparison to other surgeries including thoracotomy, mastectomy, inguinal hernia, caesarian section, etc. (8). This underscores the need for continued investigation into the mechanisms and predictors of pain following limb loss (9).

Some individuals with limb loss also report other phantom limb phenomena, including telescoping, a phenomenon in which the phantom limb is perceived to progressively shorten and even retract completely into the residual limb. It was first described by Guéniot (10) and has since been examined in greater detail by others (11, 12). Telescoping is estimated to occur in approximately 22% of individuals with limb loss (13) but estimates vary considerably, ranging from 14%–32% in large samples (14–16).

The extent to which telescoping is linked to variations in pain intensity or psychosocial outcomes is not well established (17). Several studies have examined the relationship between telescoping and PLP, but findings have been inconsistent, with some studies reporting positive associations with PLP intensity, others reporting negative associations, and still others finding no significant relationship. Larger-sample size investigations have reported that telescoping may be linked to the presence of PLP (13, 18), whereas several smaller studies (19, 20) and case reports (21, 22) described the absence of PLP to be associated with telescoping. Other research, including both longitudinal (23) and experimental studies (24), have indicated that telescoping may coincide with lower levels of PLP intensity or even remission of pain. Taken together, these mixed findings highlight the uncertainty regarding whether telescoping is a risk factor for PLP, a protective mechanism against PLP, or a causally-unrelated correlate of PLP. Clarifying the nature of this relationship is important, as it may determine whether telescoping is a process that facilitates adaptation after amputation or one that hinders it. Furthermore, if telescoping can be shaped through targeted interventions, it raises important questions about whether therapeutic strategies, such as immersive virtual reality experiences, could be designed to encourage adaptive forms of telescoping and support post-amputation adjustment.

Psychosocial factors such as pain catastrophizing, characterized by heightened negative thinking and worry about pain, as well as anxiety and depression have been consistently associated with poorer outcomes in the broader chronic pain literature, including conditions such as low back pain, fibromyalgia, and arthritis (25). In these conditions, the above psychosocial factors have been associated with increased pain intensity, greater disability, and diminished quality of life (26–32). Similarly, anxiety and depression have been linked to poor adjustment, greater pain, and less successful rehabilitation outcomes after limb loss (33, 34). These negative affective and cognitive processes may exacerbate pain perception and interfere with adaptive coping, highlighting the importance of examining psychological contributors to post-amputation pain experiences. In contrast, positive constructs such as optimism, resilience, and acceptance may serve as protective factors, potentially buffering individuals against pain-related distress and facilitating more effective coping strategies (35–37). Together, these constructs allow for a comprehensive investigation of both vulnerability and resilience factors in the context of chronic post-amputation pain.

While PLP and RLP have been extensively studied, the role of telescoping remains less understood in shaping these pain experiences and associated psychosocial outcomes. Very few investigations have directly compared individuals who report telescoping with those who do not, particularly in relation to pain intensity and psychosocial dimensions such as pain catastrophizing, anxiety, and resilience. This lack of direct comparison represents a critical gap in the literature. As such, the present study aims to examine how telescoping is associated with psychosocial aspects of post-amputation pain. Specifically, the goal was to establish whether pain intensity and interference, as well as psychosocial functioning, including pain catastrophizing, anxiety, depression, optimism, and resilience, differ between those who endorse telescoping and those who do not. Given the current lack of evidence regarding whether telescoping is a risk factor, a protective factor, or is causally unrelated to PLP, we did not make specific hypotheses about the direction of the relationships. Instead, our primary objective was to examine whether individuals with and without telescoping differ systematically in pain-related factors and psychosocial variables.

2 Methods

2.1 Recruitment

Eligible participants were adults over the age of 18 years old, fluent in English, who had undergone one or more upper and/or lower limb amputations of any etiology at least three months prior to recruitment. Individuals were excluded if they had significant cognitive impairment, a diagnosis of severe psychopathology (e.g., active psychotic disorder, dementia), or significant issues in visual impairment that would interfere with study participation.

The study team implemented multiple recruitment strategies from June 1, 2019 to December 16, 2024 to reach eligible individuals. (1) Treating clinicians at participating hospital sites in Toronto, Ontario introduced the study to eligible patients and provided preliminary information. (2) Flyers outlining the study purpose, eligibility criteria, compensation, and research team contact information were posted in hospital areas serving individuals with limb loss. (3) The same flyer was disseminated electronically via websites, forums, and social media platforms to increase study visibility. (4) Finally, individuals who had previously consented to be contacted for research participation through the St. John's Rehab Research Database received an email invitation containing a brief study description and eligibility criteria.

Interested individuals were asked to contact the research team by phone or email. Upon expressing interest, potential participants received a unique, anonymous study ID and a secure link to the online consent form. Those who provided consent were directed to online questionnaires and a web-based app, which in total required approximately 45 min to complete. Individuals who declined consent were thanked for their time and exited from the study platform.

The online consent form also provided participants the option to take part in a qualitative interview regarding their experiences of phantom limb pain and telescoping. Only participants who both expressed interest and endorsed telescoping on the online measures were invited to complete the optional interview. The results of the qualitative interview study will be published in a separate article. Ethics for this study was provided through the Research Ethics Boards at the Sunnybrook Health Sciences Centre (REB# 3071) and York University (HPRC #e2019-138).

2.2 Questionnaires

Pain interference was assessed using the Brief Pain Inventory—Short Form (BPI-SF) (38), which evaluates the impact of pain on seven domains, including general activity, mood, work, sleep, and enjoyment of life. Each item is rated on a scale from 0 (“does not interfere”) to 10 (“completely interferes”), and the average score across items provides a reliable and valid measure of pain interference across a range of conditions, including phantom limb pain (34).

Neuropathic pain was screened for using the 6-item ID Pain Questionnaire (IDPQ), a self-administered tool with “yes” or “no” response options (39). The items assess neuropathic pain characteristics such as burning, numbness, and electric-like sensations. Scores range from −1 to 5, with higher scores reflecting a greater likelihood of neuropathic pain; scores between 3 and 5 are associated with an estimated 69% probability of neuropathic pain (39). The IDPQ has been shown to effectively identify pain with a neuropathic component (39).

Pain-related catastrophic thinking was measured with the four-item version of the Pain Catastrophizing Scale (PCS-4), which uses a 5-point Likert scale from 0 (“not at all”) to 4 (“all the time”) (40). Total scores range from 0 to 16, with higher

scores indicating greater catastrophic thinking about pain. The PCS-4 demonstrates strong internal consistency and correlates highly with the full PCS (40, 41).

Depression and anxiety symptoms were assessed using the Patient Health Questionnaire-4 (PHQ-4) (42). Scores on the first two items contribute to the anxiety symptoms subscale, and scores on the last two items contribute to the depression symptoms subscale. Total scores range from 0 to 12, with categories of normal (0–2), mild (3–4), moderate (6–8), and severe (9–12). Subscale scores ≥ 3 are considered indicative of clinically relevant symptoms. The PHQ-4 is a brief measure of these affective symptoms that has previously demonstrated good reliability and validity (43).

Dispositional optimism was measured using the 10-item Life Orientation Test—Revised (LOT-R) (44). Participants rate statements about positive and negative expectations on a 5-point scale from 0 (“strongly disagree”) to 4 (“strongly agree”), with four items serving as fillers. Total scores range from 0 to 24, with higher scores indicating greater optimism. The LOT-R includes positively and negatively worded items and shows good reliability and validity in both general and chronic pain populations (45).

Resilience, defined as the ability to recover and adapt to change, was assessed using the 2-item Connor-Davidson Resilience Scale (CD-RISC2) (46). Items are rated from 0 (“not at all true”) to 4 (“true nearly all the time”), producing a total score from 0 to 8, with higher scores reflecting greater resilience. The CD-RISC2 demonstrates strong internal consistency, convergent and divergent validity, and test-retest reliability, with a mean score of approximately 6.91 in North American populations (46).

Acceptance of chronic pain was evaluated with the 8-item Chronic Pain Acceptance Questionnaire (CPAQ-8) (47). Participants rate each item from 0 (“never true”) to 6 (“always true”). The measure includes subscales of pain willingness and activity engagement, which combine to produce a total score from 0 to 48, where higher scores indicate greater pain acceptance. The measure has demonstrated strong validity and psychometric reliability in rehabilitation contexts (48).

2.3 Telescoping app

Participants used a web-based/mobile application (<https://demo.phantomlimbs.ca/>) developed by our team to assess the presence and extent of phantom limb telescoping and related factors. Users enter basic demographic and clinical information (e.g., sex, month and year of birth, month and year of amputation), indicate the affected side, limb and level of amputation, select the posture of their phantom limb hand or foot from among four common exemplars, and visually quantify the degree of telescoping using a slider that moves the phantom limb from normal length to fully telescoped within the residual limb (49). Figure 1 depicts the participant's view while using the app, illustrated with a right upper limb example. The app was designed to be quick to complete while also capturing amputation-related information not

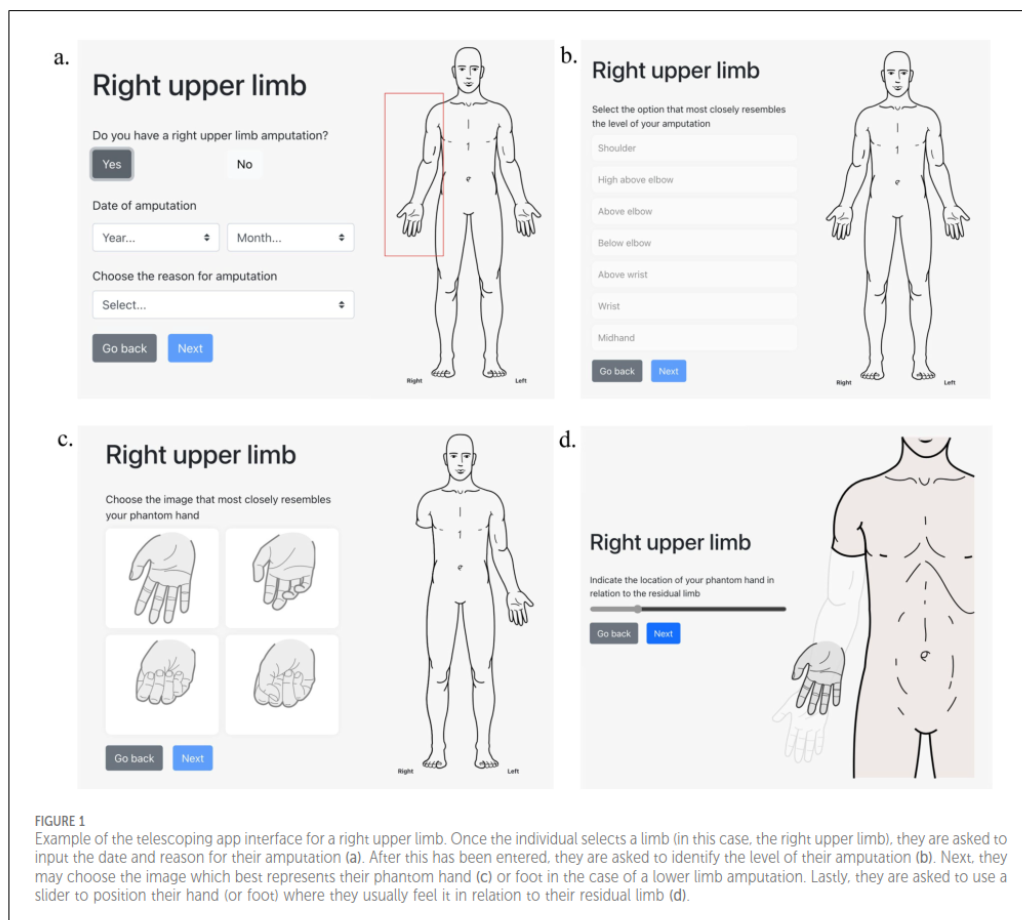


FIGURE 1

Example of the telescoping app interface for a right upper limb. Once the individual selects a limb (in this case, the right upper limb), they are asked to input the date and reason for their amputation (a). After this has been entered, they are asked to identify the level of their amputation (b). Next, they may choose the image which best represents their phantom hand (c) or foot in the case of a lower limb amputation. Lastly, they are asked to use a slider to position their hand (or foot) where they usually feel it in relation to their residual limb (d).

captured by other similar tools (50). Participants were asked to rate the intensity of the PLP and RLP they experienced several times a week or more over the past 3 months using a 0–10 numeric rating scale slider, where 0 refers to “no pain” and 10 to “worst possible pain”. The app calculates the percentage of telescoping relative to the length of a normal limb (0%) to fully telescoped into the residual limb (100%). The application was developed to provide a consistent, precise, and systematic method for documenting telescoping and investigating its association with post-amputation pain.

2.4 Analyses

Descriptive statistics were used to summarize participant demographic and clinical characteristics. Means and standard deviations were calculated for continuous variables, and frequencies and percentages were calculated for categorical variables.

Between-group comparisons were conducted to examine differences between participants who reported telescoping and those who reported normal phantom limb length. Independent-samples *t* tests were used to compare continuous demographic, clinical, and psychosocial variables (e.g., age, pain intensity ratings, pain interference, catastrophizing, optimism, resilience, depression, anxiety, and pain acceptance). For all *t* tests, Levene’s test for equality of variances was conducted; results are reported using the equal variances assumed statistic when Levene’s test was non-significant and the equal variances not assumed statistic when Levene’s test was significant. Chi-square tests of independence were conducted to compare categorical variables (e.g., sex, ethnicity, marital status, education, living situation, amputation etiology, and amputation level). In addition, within the subgroup of participants who endorsed telescoping, Pearson correlations were conducted to examine associations between the percentage of telescoping reported and continuous pain (intensity, interference) and psychosocial

variables (e.g., age, catastrophizing, resilience, depression, anxiety, pain acceptance, etc.).

Analyses of amputation type (upper/lower limb), side (left/right), and level (above/below elbow/knee) were performed at the limb level rather than the individual level, given that two participants had multiple amputations.

When chi-square tests indicated significant group differences, *post hoc* comparisons were performed with Bonferroni correction to control for multiple comparisons. All tests were two-tailed with a significance threshold of $p < .05$. Missing data were handled by listwise deletion, such that participants who did not complete an entire questionnaire, such as the telescoping app, were not included in the final analytic sample. For participants who completed a questionnaire but had one missing item, the missing value was replaced with the individual's average response on that questionnaire (51). All analyses were conducted using IBM SPSS Statistics, Version 31 (IBM Corp., Armonk, NY).

3 Results

3.1 Participant characteristics

A total of 86 individuals expressed interest in participating in the study. Eighteen were excluded because their email addresses appeared suspicious (e.g., random strings of letters followed by numbers followed by an email service address) and they declined to provide relevant information necessary for participation (e.g., responses to inclusion/exclusion criteria, full name, or contact information). Eleven individuals provided their contact information but did not respond to subsequent outreach from the research assistant, who had attempted to provide them with additional study details. Six individuals provided consent but did not complete all online questionnaires.

Fifty-one participants comprised the final sample size for data analysis. Thirty-three individuals (64.7%) identified as male and 18 (35.3%) identified as female. Participants had a mean age of 49.5 years ($SD = 15.4$, range = 18–79). Most participants identified as White (76.5%), were married or in a domestic partnership (52.9%), and lived with a spouse or significant other (62.7%). The majority had reported obtaining either an associate degree or college diploma/certificate (33.3%) or bachelor's degree (29.4%) as their highest level of education.

Nearly all participants (96.1%) had undergone amputation of one limb, with the exception of two participants (i.e., one who lost both lower extremities and another who lost all four limbs). Accordingly, limb-level analyses included 55 limbs rather than 51 participants. Of the 55 limbs, 11 were upper limbs and 44 were lower limbs. The most common cause of amputation was trauma (49.0%), followed by diabetes and/or vascular disease (21.6%), malignancy (5.9%), and non-diabetic/vascular-related infection (2.0%). The remaining 21.5% of participants reported another cause of amputation. Time since amputation averaged 5.7 years ($SD = 7.3$, range = 3.8 months to 38.1 years). A majority of participants (70.6%) reported experiencing ongoing pain. Ratings of PLP and RLP intensity were 3.6 ($SD = 3.1$) and

4.3 ($SD = 3.0$), respectively, on a 0–10 numerical rating scale. At the participant level, 23 individuals (45.1%) endorsed telescoping and 28 (54.9%) did not. At the limb level, 24 of 55 limbs (43.6%) were reported to be telescoped to some degree, and 31 (56.4%) did not. Among cases endorsing telescoping, the mean percent telescoping was 23.5% ($SD = 31.5$; range = 0–100).

3.2 Group comparisons

Table 1 presents the demographic and clinical characteristics of participants who endorsed telescoping and those who did not. Chi-square analyses revealed that the two groups did not significantly differ in sex distribution, highest education completed, ethnicity, marital status, living situation, presence of ongoing pain problems, amputation etiology or side of amputation (e.g., left or right). Independent-samples *t*-tests revealed no significant differences between the two groups on the number of ongoing pain problems, number of limbs amputated, or time since amputation. Individuals who reported telescoping were significantly younger ($M = 42.2$ years, $SD = 15.5$) than those who did not ($M = 55.5$ years, $SD = 12.7$), $t(49) = 3.37$, $p = .001$.

Analyses did show a significant difference between groups for type of amputation (e.g., upper or lower), $\chi^2(1, N = 55) = 4.73$, $p = .030$. Specifically, telescoping was reported in 33.3% of individuals with an upper limb amputation, compared to 9.7% of individuals with a lower limb amputation. Similarly, there was a significantly greater proportion of individuals with lower limb amputations who did not report telescoping (90.3%) than those who reported telescoping (66.7%). There were also significant group differences when type of amputation (e.g., upper or lower) and side of amputation (e.g., left or right) were evaluated together, $\chi^2(1, N = 55) = 9.56$, $p = .023$. Bonferroni-adjusted *post hoc* analyses revealed a significantly greater proportion of individuals with a right upper limb amputation in the telescoping group than the normal length phantom group. All other group comparisons were not significant. Further, there were significant differences between groups for level of amputation (e.g., above/below elbow/knee), $\chi^2(1, N = 55) = 9.46$, $p = .024$. Bonferroni-adjusted *post hoc* analyses revealed a significantly greater proportion of individuals with a below-elbow amputation endorsed telescoping than those who did not report telescoping. Fewer individuals with a below-knee amputation who endorsed telescoping than those who did not report telescoping. All other group comparisons were not significant.

Pain (intensity and interference) ratings and psychosocial variables were compared between individuals with telescoping and those without (see Table 2). Independent samples *t* tests did not reveal significant group differences in RLP intensity, $t(49) = -0.553$, $p = .583$, or PLP intensity, $t(49) = 0.245$, $p = .808$. Similarly, there were no group differences for pain interference (BPI-SF), $t(49) = -.288$, $p = .775$, pain catastrophizing (PCS-4), $t(49) = -.724$, $p = .473$, optimism (LOT-R), $t(49) = 0.973$, $p = .335$, or resilience (CD-RISC 2), $t(49) = 0.567$, $p = .573$. Conversely, differences were observed for anxiety and depression, whereby participants with telescoping reported higher anxiety symptoms

TABLE 1 Demographic and clinical characteristics for individuals with vs. without telescoping.

Variable	Telescoping (<i>n</i> = 23)	Normal length (<i>n</i> = 28)	<i>P</i>
Sex, <i>n</i> (%)			.066
Male	18 (78.3)	15 (53.6)	
Female	5 (21.7)	13 (46.4)	
Age (y), mean, SD (range)	42.2, 15.5 (18–72)	55.5, 12.7 (28–79)	.001*
Highest education completed, <i>n</i> (%)			.498
High school	1 (4.3)	2 (7.1)	
High school/GED	3 (13.1)	4 (14.3)	
College/Associate degree	6 (26.1)	11 (39.3)	
Bachelor's degree	10 (43.5)	5 (17.9)	
Graduate degree	1 (4.3)	3 (10.7)	
Professional degree	2 (8.7)	3 (10.7)	
Ethnicity, <i>n</i> (%)			.117
White	16 (69.6)	23 (82.1)	
African Canadian/ Caribbean	4 (17.5)	0 (0.0)	
East Asian	1 (4.3)	0 (0.0)	
Hispanic/Latino/a	0 (0.0)	1 (3.7)	
Middle Eastern/North African	1 (4.3)	0 (0.0)	
South Asian	1 (4.3)	2 (7.1)	
Other	0 (0.0)	2 (7.1)	
Marital status, <i>n</i> (%)			.435
Single/Never married	6 (26.2)	6 (21.4)	
In a relationship	5 (21.7)	2 (7.1)	
Married/Domestic partnership	9 (39.2)	18 (64.3)	
Widowed	1 (4.3)	1 (3.6)	
Divorced	1 (4.3)	1 (3.6)	
Separated	1 (4.3)	0 (0.0)	
Living situation, <i>n</i> (%)			.225
Living alone	2 (8.7)	3 (10.7)	
With roommate (s)	1 (4.3)	2 (7.1)	
With relative(s)	8 (34.8)	3 (10.7)	
With spouse/significant other	12 (52.2)	20 (71.5)	
Amputation etiology, <i>n</i> (%)			.362
Accident/Trauma	14 (60.9)	11 (39.3)	
Cancer/Tumor	1 (4.3)	2 (7.1)	
Diabetes/Vascular disease	3 (13.1)	8 (28.6)	
Non-diabetic vascular infection	1 (4.3)	0 (0.0)	
Other	4 (17.4)	7 (25.0)	
Any ongoing pain problems, <i>n</i> (%)			.884
Yes	16 (69.6)	20 (71.4)	
No	7 (30.4)	8 (28.6)	
Number of ongoing pain problems, mean, SD (range)	1.3, 1.4 (0–5)	1.1, 1.0 (0–3)	.482
Number of limbs amputated, mean, SD (range)	1.1, 0.6 (1–4)	1.0, 0.2 (1–2)	.450
Type of amputation ^a , <i>n</i> (%)			.030*
Upper limb	8 (33.3)	3 (9.7)	
Lower limb	16 (66.7)	28 (90.3)	

(Continued)

TABLE 1 Continued

Variable	Telescoping (<i>n</i> = 23)	Normal length (<i>n</i> = 28)	<i>P</i>
Side of amputation ^a , <i>n</i> (%)			.739
Right	15 (62.5)	18 (58.1)	
Left	9 (37.5)	13 (41.9)	
Side and type of amputation ^a , <i>n</i> (%)			.023*
Right upper limb	5 (20.8)	0 (0.0)	
Right lower limb	9 (37.5)	16 (51.6)	
Left upper limb	3 (12.5)	1 (3.2)	
Left lower limb	7 (29.2)	14 (45.2)	
Level of amputation ^a , <i>n</i> (%)			.024*
Below-elbow	4 (16.7)	0 (0.0)	
Above-elbow	4 (16.7)	1 (3.2)	
Below-knee	12 (49.9)	24 (77.4)	
Above-knee	4 (16.7)	6 (19.4)	
Time since amputation (y), mean, SD (range)	5.5, 6.4 (0.3–26.8)	5.9, 8.0 (0.3–38.1)	.838

y; years, SD; standard deviation.

^aVariables assessed at the limb level (*n* = 55, where 24 limbs were reported to experience telescoping and 31 were normal length phantoms).**p* < .05.

(PHQ-4), $t(49) = -2.385$, $p = .022$, as well as higher symptoms of depression (PHQ-4), $t(49) = -2.252$, $p = .029$.

Among the 36 participants who endorsed ongoing pain problems, pain acceptance scores (CPAQ) were compared between those with telescoping (*n* = 16) and those with normal length perception (*n* = 20), as shown in Table 2. Independent samples *t* tests did not reveal group differences for the willingness, $t(34) = -.781$, $p = .440$, or activity engagement, $t(34) = .283$, $p = .779$, subscales. Similarly, no differences were detected between groups on the total CPAQ score, $t(34) = -.326$, $p = .747$. No other group differences on other measures were detected.

3.3 Correlational analyses

A greater degree of telescoping was associated with lower pain interference (BPI-SF), $r(21) = -.431$, 95% CI $[-.716, -.022]$, $p = .040$, and lower PLP intensity, $r(21) = -.490$, 95% CI $[-.751, -.098]$, $p = .018$. No other significant correlations were observed with any other variable (all *ps* > .05; see Table 3).

4 Discussion

This study examined demographic, clinical, and psychosocial differences between individuals who reported telescoping of their phantom limb and those who did not, with the aim of clarifying the relationship between telescoping and phantom limb sensations, including pain. In this sample, 23 individuals (45.1%) reported experiencing telescoping of the phantom limb, while 28 (54.9%) did not. This rate is markedly higher than the 14%–33% estimate reported in large-scale studies (13–16). There are several plausible reasons for this discrepancy. First, the sample size is relatively

TABLE 2 Pain ratings and psychosocial variables for individuals with vs. without telescoping.

Variable	Telescoping (<i>n</i> = 23)	Normal length (<i>n</i> = 28)	<i>P</i>
Residual limb pain, mean, SD	3.9, 3.0	3.4, 3.3	.583
Phantom limb pain, mean, SD	4.2, 2.8	4.4, 3.3	.808
BPI-SF pain interference, mean, SD	3.7, 2.6	3.5, 2.8	.775
PCS-4, mean, SD	7.6, 5.4	6.6, 3.9	.473
PHQ-4, mean, SD			
Anxiety	2.7, 2.2	1.3, 1.7	.022*
Depression	2.5, 2.2	1.3, 1.6	.029*
LOT-R, mean, SD	14.7, 5.2	16.0, 4.4	.335
CD-RISC2	6.3, 1.5	6.6, 1.3	.573
CPAQ-8*, mean, SD			
Willingness	13.1, 4.7	12.0, 3.5	.440
Activity engagement	16.5, 4.2	16.9, 4.2	.779
Total	29.6, 7.4	28.9, 4.7	.747
ID Pain*, mean, SD	2.9, 1.1	2.7, 1.4	.599

SD, standard deviation; BPI-SF, brief pain inventory—short form; PCS-4, pain catastrophizing scale; PHQ-4, patient health questionnaire-4; LOT-R, life orientation test—revised; CD-RISC2, connor-davidson resilience scale; CPAQ-8, chronic pain acceptance questionnaire.

*Variables assessed using those who endorsed ongoing pain problems (*n* = 36, where 16 reported telescoping and 20 had normal length phantoms).

**p* < .05.

TABLE 3 Correlations between percent of telescoping and psychosocial variables among participants who endorsed telescoping.

Variable	Pearson correlation	<i>P</i>
Age	-.316	.142
Time since amputation	.347	.104
RLP (NRS)	-.298	.168
PLP (NRS)	-.490	.018*
BPI-SF	-.431	.040*
PCS-4	-.134	.542
PHQ-4		
Anxiety	-.089	.688
Depression	-.157	.475
LOT-R	-.173	.429
CD-RISC2	.055	.801
CPAQ-8*		
Willingness	-.178	.510
Activity engagement	-.405	.119
Total	-.342	.195
ID Pain*	.092	.736

RLP, residual limb pain; PLP, phantom limb pain; BPI-SF, brief pain inventory—short form; PCS-4, pain catastrophizing scale; PHQ-4, patient health questionnaire-4; LOT-R, life orientation test—revised; CD-RISC2, connor-davidson resilience scale; CPAQ-8, chronic pain acceptance questionnaire.

*Variables assessed using those who endorsed ongoing pain problems (*n* = 16).

**p* < .05.

small, which increases the likelihood of sampling variation and possibly overestimation of prevalence compared to those large-scale investigations. Second, the composition of our sample may differ in keyways. Most notably, a large proportion of participants had a traumatic amputation etiology, which prior work has suggested is associated with higher rates of phantom phenomena such as telescoping (17). Thus, the elevated rate of telescoping in our

cohort may reflect greater risk factors (trauma etiology) in the sample, rather than indicating a fundamentally higher population rate. Finally, other sample-specific factors (e.g., time since amputation, level of amputation, prosthesis use, and pre-amputation pain) may also play a role in the difference. Thus, while the higher observed prevalence of telescoping highlights a meaningful occurrence in this cohort, caution is warranted in generalizing this rate to the broader population of individuals with limb loss. Future studies with larger, more heterogenous samples will help clarify the true prevalence of the telescoping phenomenon.

The findings of this study provide greater insights on the telescoping phenomenon by highlighting factors related to age, amputation location, and psycho-social profiles. For instance, those who reported telescoping tended to be younger than those who did not. This may reflect greater neuroplasticity earlier in adulthood, which could increase susceptibility to perceptual phenomena like telescoping (52). Younger individuals may also engage in higher activity levels and adopt prostheses more quickly, amplifying sensory input that may impact perceived limb length (53, 54). Nevertheless, evidence from prior studies suggests that reduced prosthesis use may be associated with shorter phantom limbs (55), while meaningful sensorimotor engagement through prosthesis use can lengthen previously shortened phantoms through use-dependent cortical reorganization (12, 56), highlighting the complexity of the relationship between sensory engagement and telescoping. In addition, the complicating role of vision when wearing a prosthesis may affect telescoping irrespective of use-dependent changes in brain reorganization since telescoped phantoms often lengthen to assume the proportions of the prosthesis as appreciated by sight (57). Younger individuals may also be more likely to notice and report phantom-related changes, whereas older adults may have more stable somatosensory maps and less pronounced distortions. In terms of other demographic or clinical characteristics, including sex, marital status, education, or time since amputation, no significant findings were detected, which may suggest that underlying neurocognitive or perceptual mechanisms related to body representation following limb loss play a larger role in telescoping.

Telescoping was more frequently reported among individuals with upper limb amputations compared to those with lower limb amputations, especially those who lost a right upper limb below the elbow. This finding suggests that limb type and dominance may influence the occurrence of this phenomenon. One possible explanation lies in differences in cortical representation, as upper limbs, and especially the dominant right hand, occupy greater sensory and motor cortical areas, which may make body image distortions such as telescoping more likely (58–60). Although hand dominance was not measured in this sample, population base rates suggest that most participants were likely right-handed. This pattern may align with some prior reports indicating higher prevalence of telescoping in upper than lower limb amputees (24, 61, 62). Future studies should include hand dominance as a variable to better account for this factor.

Although the present study did not find significant group differences in ratings of PLP intensity, RLP intensity, or pain interference, there was a negative association between PLP intensity and percent telescoping. One interpretation is that greater

telescoping may reflect adaptive cortical reorganization that, for some individuals, co-occur with lower PLP intensity (11). Conversely, higher pain may disrupt embodiment and reduce telescoping. It is also plausible that effects are non-linear or moderated by factors such as age, level of amputation, or time since amputation, which could attenuate simple between-group contrasts but still yield within-group correlations (63). In line with this, recent work indicates that primary somatosensory hand representations can remain *stable* before and up to five years after upper-limb amputation (64). This individual variability in cortical reorganization may dilute differences between those who do and do not endorse telescoping, even as associations within a single group (e.g., those who endorse telescoping) still emerge. Ultimately, such factors would have to be investigated in larger samples.

In terms of psychological variables, participants who reported telescoping also endorsed significantly higher levels of anxiety and depression, which may reflect maladaptive coping or increased vigilance toward altered body perceptions such as a shorter than normal phantom limb. It is also possible that higher levels of anxiety or depression may contribute to increased attention to bodily sensations or perceptual distortions, which could influence the experience or reporting of telescoping. Further research is needed to clarify the direction of this relationship, though we hypothesize that the perceptual changes associated with telescoping may contribute to elevated anxiety and depressive symptoms rather than the reverse. The broader research evidence might therefore suggest that individuals who experience telescoping could be more vulnerable to increased pain. At the same time, between-group differences were not found between telescoping and PLP intensity, RLP intensity, or pain interference. Further, within the telescoping subgroup, greater percentage of telescoping was associated with lower PLP intensity. Group differences also were not found in optimism or resilience, suggesting that telescoping is not uniformly associated with either protective or harmful psychosocial factors. Taken together, these findings suggest that telescoping should not be interpreted as a marker of greater pain intensity or interference. A dual-process interpretation may explain the results whereby: (a) the presence of telescoping may be distressing for some individuals, contributing to elevated symptoms of anxiety and depression via uncertainty and increased symptom monitoring, while (b) the degree of telescoping, once present, may be indicative of adaptive cortical reorganization that co-occurs with lower PLP intensity for a subset of participants. Clinically, this pattern points to a mixture of affective responses to an unusual sensation and, in some cases, potentially beneficial neuroplastic change.

These findings underscore the importance of incorporating psychosocial assessment into the care of individuals who report phantom limb telescoping, with particular attention to screening for anxiety and depression. The observed associations with anxiety and depression suggest that, for some individuals, telescoping may be accompanied by negative affective responses (e.g., uncertainty, heightened monitoring of bodily sensations, difficulty coping, etc.). Tailored interventions, such as acceptance and commitment therapy to address unhelpful coping strategies or cognitive-behavioral therapy to reduce symptoms of anxiety

and depression, may help alleviate distress and support better psychological adjustment (65–67). Theoretically, the results contribute to ongoing debates regarding whether telescoping should be considered solely a perceptual phenomenon or one that is also intertwined with psychosocial outcomes.

5 Strengths and limitations

A notable strength of this study is its inclusion of both clinical and psychosocial variables, allowing for a more comprehensive understanding of the factors associated with telescoping beyond pain intensity alone. The use of standardized and validated measures for constructs such as pain, catastrophizing, anxiety, depression, and resilience further enhances the reliability and comparability of the findings. Likewise, the measure of telescoping used in the present study provides a more in-depth and precise way to quantify what has been a difficult phenomenon to assess. Despite these strengths, several limitations should be acknowledged. First, the relatively small final sample size ($N = 51$) reduced the statistical power to detect more subtle group differences and may limit the robustness of the observed effects. Second, because recruitment was conducted online, the sample may not be representative of the broader population of individuals with limb loss; in particular, the overrepresentation of telescoping and White participants raises concerns about generalizability across diverse demographic groups. Third, all measures relied on self-report, which introduces the possibility of recall bias and variability in how participants understood and reported telescoping. Fourth, participation bias may have occurred, as individuals experiencing higher levels of distress, depression, or limited social support may have been less likely to enroll, potentially influencing the generalizability of our findings. Finally, the cross-sectional design does not establish the temporal relationship between variables, preventing us from determining whether changes in telescoping preceded or followed the development of pain, and/or the psychosocial factors.

6 Conclusions and future directions

This study demonstrated that telescoping was more common among younger individuals with upper limb amputations, particularly on the right side, below the elbow, and was associated with higher levels of anxiety and depression. Percent telescoping was negatively associated with PLP intensity in correlational analyses. Nevertheless, no associations were present between telescoping and RLP intensity, pain interference, and most other psychosocial variables, including optimism and resilience. Taken together, these findings suggest that telescoping is not a stand-alone marker of overall pain burden and may reflect a mix of affective responses (e.g., anxiety/depression) and, for some individuals, adaptive reorganization. Clinically, the results highlight the value of routine screening for anxiety and depression, and they point to the potential utility of supportive

interventions aimed at improving adjustment among individuals who report telescoping.

Future research should extend these findings by examining the longitudinal course of telescoping and its relationship with psychosocial adjustment over time. Prospective studies could help determine whether telescoping precedes or follows psychological distress, thereby clarifying its causal role. Neuroimaging approaches may also provide important insights into the cortical reorganization and sensorimotor mechanisms underlying telescoping. Intervention studies are needed to test whether strategies such as cognitive-behavioral therapy for catastrophizing or mindfulness-based approaches for anxiety can reduce distress linked to telescoping. Additionally, recruiting larger and more diverse samples will improve the generalizability of results, while incorporating rich qualitative approaches is essential to capture the lived experience of telescoping, deepen understanding of the phenomenon, and inform the design of meaningful and sustainable interventions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Research Ethics Boards at the Sunnybrook Health Sciences Centre (REB# 3071) and York University (HPRC #e2019-138). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AA: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. HL-R: Formal analysis, Project administration, Writing – review & editing. LA: Writing – review & editing. SH: Conceptualization, Methodology, Resources, Supervision, Writing – review & editing. AM: Methodology, Writing – review & editing. JK: Conceptualization, Funding acquisition, Methodology, Resources, Writing – original draft, Writing – review & editing.

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Section 3: Summary of Study 3 and Rationale for Study 4

Study 3 examined demographic, clinical, and psychosocial differences between individuals with limb loss who reported phantom limb telescoping and those who did not, with the goal of clarifying the role of telescoping in post-amputation pain and adjustment. In this sample, nearly half of participants reported telescoping, a prevalence notably higher than rates reported in large-scale studies. Several demographic and clinical patterns emerged. Individuals who reported telescoping tended to be younger, suggesting that age-related factors such as neuroplasticity, sensory engagement, or attentiveness to bodily changes may influence susceptibility to perceptual alterations following limb loss. Telescoping was also more frequently reported among individuals with upper limb amputations, particularly those with right-sided limb loss. No significant differences were observed for other demographic or clinical variables, including sex, marital status, education, or time since amputation, suggesting that telescoping may be more closely tied to perceptual and neurocognitive mechanisms than to general demographic factors.

With respect to pain, the presence of telescoping was not associated with higher or lower levels of PLP, RLP, or pain interference. However, within the subgroup of individuals who endorsed telescoping, greater degree of telescoping was associated with lower PLP intensity. This finding suggests a more nuanced relationship between telescoping and pain than simple group comparisons can capture. One possible interpretation is that the extent of telescoping, once present, may reflect adaptive cortical reorganization that co-occurs with reduced pain for some individuals. These patterns highlight the likelihood of non-linear or moderated relationships between telescoping and pain, which may be obscured in between-group analyses but detectable within subgroups.

In contrast, psychosocial differences were more pronounced. Individuals who reported telescoping endorsed significantly higher symptoms of anxiety and depression compared to those who did not. These findings suggest that telescoping may be accompanied by emotional distress for some individuals, potentially due to uncertainty, increased vigilance toward bodily sensations, or difficulty integrating altered phantom perceptions. At the same time, no group differences were observed in optimism or resilience, indicating that telescoping is not uniformly associated with either protective or maladaptive psychosocial profiles. Taken together, these results suggest a dual-process interpretation: the presence of telescoping may be emotionally distressing for some individuals, contributing to elevated anxiety and depressive symptoms, while the degree of telescoping, once present, may reflect adaptive perceptual or neuroplastic changes associated with lower PLP intensity in a subset of individuals.

Overall, the findings from Study 3 indicate that phantom limb telescoping should not be interpreted as a simple marker of greater pain severity or poorer clinical prognosis. Instead, telescoping appears to reflect a complex interplay between perceptual reorganization and psychosocial response. Clinically, these results underscore the importance of screening for anxiety and depression among individuals who report telescoping, while avoiding assumptions that telescoping necessarily signals worsening pain. Conceptually, the study supports viewing telescoping as a multifaceted post-amputation phenomenon that encompasses sensory, emotional, and adaptive dimensions, reinforcing the need for integrative, biopsychosocial models of post-amputation experience.

Building on these findings, Study 4 was designed to further examine the lived experience of phantom limb telescoping using a qualitative approach. Although Study 3 did not support telescoping as a straightforward indicator of pain severity or clinical deterioration, the observed

associations with anxiety and depression suggest that psychological factors may shape how telescoping is experienced and interpreted by individuals. Interviewing a subset of participants allowed for a more nuanced exploration of the subjective impact of telescoping, including its emotional meaning, perceived consequences, and potential links with mental health. This qualitative inquiry aimed to deepen understanding of whether, and how, anxiety and depressive symptoms intersect with telescoping experiences, complementing the quantitative findings and informing more integrative biopsychosocial models of post-amputation adjustment.

Chapter 5: Qualitative Data (Study 4)

Section 1: Objective and Research Approach

Objective

The present study aims to develop a comprehensive understanding of the post-amputation experience by eliciting rich, first-person accounts of phantom limb telescoping. By centering the voices of individuals with limb loss, this study emphasizes the value of patient-centered narratives for advancing both clinical knowledge and research practice. This approach acknowledges the complexity, variability, and individuality of post-amputation experiences, many aspects of which are difficult to capture through quantitative methods alone. By attending to the full spectrum of lived experience, including perceptual, emotional, and contextual dimensions that are often overlooked. This study contributes to a growing body of work seeking to align clinical and research agendas more closely with the needs, priorities, and realities of individuals living with limb loss.

Research approach

Consistent with the exploratory and inductive aims of this study, no a priori hypotheses were specified. Data collection and analysis were conducted through an iterative and reflexive process, allowing participants' accounts to guide analytic decisions as themes were identified. An inductive thematic analysis approach was employed to identify patterns and meanings grounded directly in participants' lived experiences, rather than imposing predefined categories based on existing theoretical models or expectations. A constructionist epistemological perspective informed this approach, recognizing that experiences of phantom limb telescoping are shaped through dynamic interactions among perceptual, psychological, social, and emotional contexts. This orientation was intentionally adopted to remain open to unanticipated insights and to

capture the diversity and complexity of how telescoping is experienced and understood following limb loss.

Section 2: Manuscript (Under Editorial Review)

This manuscript has been submitted to a peer-reviewed journal and is currently under editorial review. The text that follows reflects the version submitted.



The Lived Complexity of Phantom Limb Telescoping: Insights from a Qualitative Study

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17 **Keywords: phantom limb, telescoping, qualitative research, lived experience, amputation.**

18 Abstract

19 Phantom limb telescoping, the perceived shortening of a missing limb, remains an underexplored
20 phenomenon despite its relatively frequent occurrence after limb loss. Existing literature has
21 primarily emphasized quantitative or neurophysiological approaches, leaving the lived experience of
22 telescoping largely unexamined. This study aimed to develop a richer, more comprehensive
23 understanding of phantom limb telescoping by prioritizing the first-person accounts of individuals
24 with limb loss. Twelve participants (11 men, one woman; M age = 50.1 years, SD = 12.2) who
25 endorsed telescoping participated in semi-structured interviews. These interviews explored
26 participants' perceptions, interpretations, and adaptations to their phantom limb and telescoping
27 experience. Data analysis was carried out through an iterative and reflexive process using an
28 inductive thematic analysis approach, within a constructionist epistemological perspective. Analysis
29 generated four overarching themes: (1) *A Personal and Evolving Experience*, (2) *Neither Right Nor*
30 *Wrong, Just Strange*, (3) *Carrying the Phantom Alone*, and (4) *Resilient Adaptation to an Altered*
31 *Phantom Limb*. Participants described telescoping as a dynamic and individualized process shaped by
32 emotional, social, and contextual factors. These findings illustrate how telescoping extends beyond
33 sensory change to encompass meaning, adaptation, and identity. Clinically, early education and open

discussion of telescoping may normalize the experience, reduce uncertainty, and strengthen rapport with health care professionals. These insights underscore the value of integrating patient-centered qualitative research into rehabilitation practice to better address the full spectrum of post-amputation experiences.

1 Introduction

Limb loss, whether due to trauma, disease, or infection, often gives rise to a range of phantom sensations (1). The most common of these include pain, tingling, cramping, temperature changes, pressure, and a sense of movement, all referred to the missing, or phantom limb (2). Many phantom sensations, especially phantom limb pain (PLP), have been extensively documented in the clinical and psychological literatures (3). However, one of the strangest post-amputation phenomena to occur, known as phantom limb telescoping, remains relatively underexplored. Telescoping refers to the sensation in which the phantom hand or foot is perceived to gradually move closer to the residual limb. The phantom extremity may eventually even retract completely into the residual limb where it is also perceived to be much smaller in proportion to the original size of the hand or foot (2, 4). Although telescoping is estimated to occur in approximately 14-32% of individuals with limb loss, it remains a puzzling and overlooked sequela of amputation that is infrequently described in the limb loss literature (5-8). Like PLP, telescoping reflects a complex interplay of sensory, cognitive, and emotional processes (9). Its presence profoundly alters an individual's perception of their phantom limb and represents one of many unfamiliar and often disorienting sensations that individuals must navigate following amputation.

Despite increasing attention to phantom limb phenomena, limited research has examined telescoping through a qualitative lens. Notably, Björkman, Arnér (10) employed qualitative interviews to better understand the experiences of individuals with PLP, and while some participants described telescoping sensations, the study was not designed to explore this phenomenon in detail. Similarly, Trevelyan, Turner (11) investigated the impact of PLP on quality of life, noting instances of telescoping among participants, yet without examining how this specific sensation was perceived to affect psychosocial outcomes. Early work by Frank and Lorenzoni (12) considered the influence of waking versus sleeping states on the experience of telescoping in individuals with both full-length and shortened phantom limbs. However, their study did not address how these variations shaped the individual's subjective or emotional experience, leaving the affective dimensions of telescoping underexplored.

More recently, Middleton and Ortiz-Catalan (13) examined telescoping in the context of neuromusculoskeletal prosthesis use, and observed that all three participants included in their study experienced phantom limb shortening in the absence of their prosthesis and lengthening to align with the seen position of the prosthetic hand when it was worn. Yet, the study did not delve into the psychological or emotional implications of this phenomenon. Collectively, these gaps highlight the need for further qualitative research centered on the lived experiences of individuals with limb loss, particularly regarding how telescoping influences their daily lives, mental health, and adaptation to limb loss.

To address this gap in the literature, the present study aims to develop a more nuanced and comprehensive understanding of the post-amputation experience by eliciting rich, first-person accounts of phantom limb telescoping. By centering the voices of individuals with limb loss, this study highlights the value of patient-centered narratives in enhancing both clinical knowledge and research practice. Such an approach acknowledges the complexity and individuality of post-

78 amputation experiences, which are often difficult to capture through quantitative methods alone. By
 79 attending to the full spectrum of the post-amputation experience, including aspects that are often
 80 overlooked, this study contributes to a growing body of work that seeks to align clinical and research
 81 agendas more closely with the needs, challenges, and priorities of individuals living with limb loss.

82 **2 Methods**

83 **2.1 Study Design**

84 This study used a qualitative research design and thematic analysis (14). The study is part of a
 85 broader research project exploring the relationship between telescoping and PLP. It was approved by
 86 the Research Ethics Boards of Sunnybrook Health Sciences Centre (REB #3071) and York
 87 University (HPRC #e2019-138). The participants provided written and verbal informed consent to
 88 participate in this study. The study, methods, and description of one participant's experience have
 89 also been published elsewhere (15). The Consolidated Criteria for Reporting Qualitative Studies
 90 guidelines for reporting qualitative research was followed (16), and the Joanna Briggs Institute (JBI)
 91 critical appraisal checklist for qualitative research was followed to minimize risk of bias (17).

92 **2.2 Reflexivity Statement**

93 The first author (A.A.) conducted the semi-structured interviews and data analysis after
 94 obtaining graduate-level training in qualitative methods. At the time of the study, A.A. was a full-
 95 time clinical psychology doctoral student; she did not provide clinical care to the participants. Prior
 96 to study commencement, A.A. had no relationship with any of the study participants. She limited
 97 reporting any characteristics about herself (e.g., biases, assumptions, reasons for exploring the
 98 research topic) to participants. Prior to their participation, participants were informed that the study
 99 aimed to better understand the factors that contribute to the development of post-amputation pain.
 100 They were not made aware that the study would be contributing to the first author's doctoral thesis,
 101 though this information was not withheld in a deliberate manner.

102 **2.3 Participants and Data Collection**

103 Eligible individuals were recruited using advertisements posted in the clinical area of St.
 104 John's Rehab, a rehabilitation centre in Toronto, Canada. In addition, advertisements were shared by
 105 the authors and organizations for individuals with limb loss (e.g., Amputee Coalition of Toronto) on
 106 social media. Interested individuals who saw the advertisement were asked to contact the study
 107 coordinator (AA), who determined eligibility. Individuals were included if they were at least 18 years
 108 old with the ability to read and speak English fluently. They also were required to have had an upper
 109 and/or lower limb amputated more than three months prior to recruitment. Participants who were
 110 cognitively impaired, diagnosed with severe psychopathology (e.g. active psychotic disorder,
 111 dementia, etc.), or had significant issues in visual impairment were excluded from the study. All
 112 participants were first provided a link to an online consent form, where they provided written
 113 informed consent.

114 Once consent was obtained, participants were then asked to complete a series of patient-
 115 reported outcome measures via online questionnaires. If participants endorsed telescoping when
 116 filling out the questionnaires, they were invited to an optional interview, which took place either in
 117 person (prior to the COVID-19 pandemic) at a rehabilitation hospital (St. John's Rehab, Toronto,
 118 Canada) or virtually via secure videoconferencing. The interviewer used a semi-structured interview
 119 guide, consisting of a series of open-ended questions and probes to elicit a deeper understanding of

the participant's perceptions and experiences with their phantom limb. Individual interviews were estimated to take approximately 45 minutes.

After several initial interviews, the first author (A.A.) consulted with a senior-member of the team trained in qualitative methods (S.L.H.) to evaluate the effectiveness of the semi-structured interview guide and identify areas for refinement. Changes were not made to the interview guide given the progress made using the initial questions. To minimize the risk of error and investigator recall bias, the interviewer took notes during the interview when the participant responded to specific experiential questions. All interviews were digitally recorded and later transcribed verbatim. H.L.R. took a leading role and transcribed the majority of the interviews, while N.D. transcribed several and assisted A.A. during the analysis phase. Transcripts were not returned to participants for comment and/or correction, nor were participants consulted for feedback on the findings. Data saturation was determined to occur when new information (e.g., new codes) related to the research question was not forthcoming (18).

2.4 Measures

The semi-structured interviews began with the investigator obtaining verbal consent. The interviewer then introduced the purpose of the study and invited the participants to share a description of their phantom limb(s). Participants were asked to describe their phantom limb and any associated pain, including onset, duration, quality, and changes over time. Residual limb pain (RLP) was similarly examined. A substantial portion of the interview focused on phantom limb telescoping, including when it was first noticed, how it was experienced, and how it may have changed in relation to emotional states, prosthesis use, or other contextual factors. Participants were also asked how various post-amputation sensations, such as telescoping, impacted their physical health, mental wellbeing, and relationships. The interview concluded with an open-ended invitation for participants to share any further reflections on their phantom limb experience. The semi-structured interview guide is listed in Table 1.

2.5 Analysis

Data collection and analyses were carried out through an iterative and reflexive process, allowing the data to inform ongoing analytic decisions. The inductive thematic analysis approach enabled the authors to identify patterns and themes that were grounded directly in the participants' experiences rather than imposing preconceived categories based on theoretical interest (14). A constructionist epistemological perspective was adopted, given the study's focus on lived experience and the multifaceted ways in which telescoping can be shaped by psychological, social, and emotional contexts (19). To support the organization and interpretation of the qualitative data, NVivo 15, a qualitative data analysis software, was used for managing, coding, and retrieving interview transcripts. The initial coding framework was developed by A.A. through repeated close readings of the interview transcripts. Her prior knowledge of chronic pain and phantom limb sensations informed her interpretive lens during analysis. Further, her immersive engagement with the data facilitated the generation of preliminary codes that captured salient concepts and patterns emerging from the participants' narratives. To enhance the credibility and reliability of the coding process, a second researcher (N.D.) independently coded a subset of the transcripts. This step served to check for consistency in code application and to identify potential areas of divergence in interpretation. Reflexive memos were also used throughout analysis to track how the researcher's perspectives might have shaped theme development. Debriefing and consultation with co-authors were used to ensure analytic transparency and credibility.

The research team discussed individual coding outcomes to ensure consistency and reliability in the analytical process. Any discrepancies in coding were addressed collaboratively and resolved as a team. Once coding agreement was established, the final codes were systematically analyzed to identify recurring patterns, relationships, and salient concepts within the dataset. Detailed notes were developed for each code to articulate its meaning, significance, and contextual relevance to the broader investigation. To substantiate and illustrate the identified codes, exemplary quotations were carefully selected from the dataset. These quotations were chosen based on their clarity and their capacity to exemplify the key features of each code, thereby grounding the analysis in participants' narratives and enhancing the transparency of the interpretive process.

Drawing on the coded data and supporting quotations, the research team developed preliminary thematic categories to synthesize the central findings. These themes and subthemes were iteratively refined through discussion involving the research team. This structured creative process of theme development aimed to enhance the analytical depth and ensure that the themes accurately reflected the complexity of the data. Throughout the data analysis process, the team engaged in reflexive dialogue, critically examining their assumptions and actively exploring alternative interpretations. This commitment to reflexivity and methodological rigor contributed to the credibility and overall quality of the qualitative analysis.

3 Results

Twelve individuals who endorsed telescoping participated in this study, including 11 men and one woman. No participants who expressed interest subsequently declined or withdrew from the study. Participants had a mean age of 50.1 years ($SD = 12.2$; range = 35–67 years). All participants had one limb amputated with the exception of one participant (P012) who had undergone quadruple limb amputations. The average time since amputation was 3.9 years ($SD = 3.5$; range = 0.5–12 years). On average, interviews lasted 47.1 minutes ($SD = 13.7$; range = 26.2–78.2 minutes). Only the investigator and participant were present during each interview. Participants rated PLP and RLP using a 0–10 Numeric Rating Scale, where 0 indicated no pain and 10 indicated the worst pain imaginable. The mean PLP and RLP scores were 4.6 ($SD = 3.6$) and 4.9 ($SD = 3.4$), respectively. For the participant with four limb amputations (P012), PLP and RLP ratings were averaged across both upper limbs as those were the limbs in which he experienced telescoping. This participant reported that he did not experience PLP in either upper limb. Additional demographic and amputation-related details, including side, level, and etiology, are presented in Table 2.

The inductive thematic analysis resulted in a total of 56 codes, which were subsequently organized into themes and subthemes. Four main themes and 10 subthemes were developed to characterize individuals' experience of phantom limb telescoping (Figure 1). Despite individual differences, every participant's experience of telescoping included at least one element of the following four main categories: (1) *A Personal and Evolving Experience*, in which participants described phantom limb telescoping not as a uniform or predictable process, but as one that was both uniquely experienced and unfolded across time in different ways; (2) *Neither Right Nor Wrong, Just Strange*, where participants described telescoping as an unusual sensation which gave rise to potential concerns and/or was overshadowed by larger concerns; (3) *Carrying the Phantom Alone*, which represents how participants felt isolated and invalidated as they grappled with their new reality after amputation; and (4) *Resilient Adaptation to an Altered Phantom Limb*, which describes the ways participants adapted to the experience of living with an amputated limb(s) and the experience of telescoping. The following sections report the findings using participant quotations to illustrate the subthemes within each main theme. Quotations have been labelled in brackets with the individual's unique ID number and age.

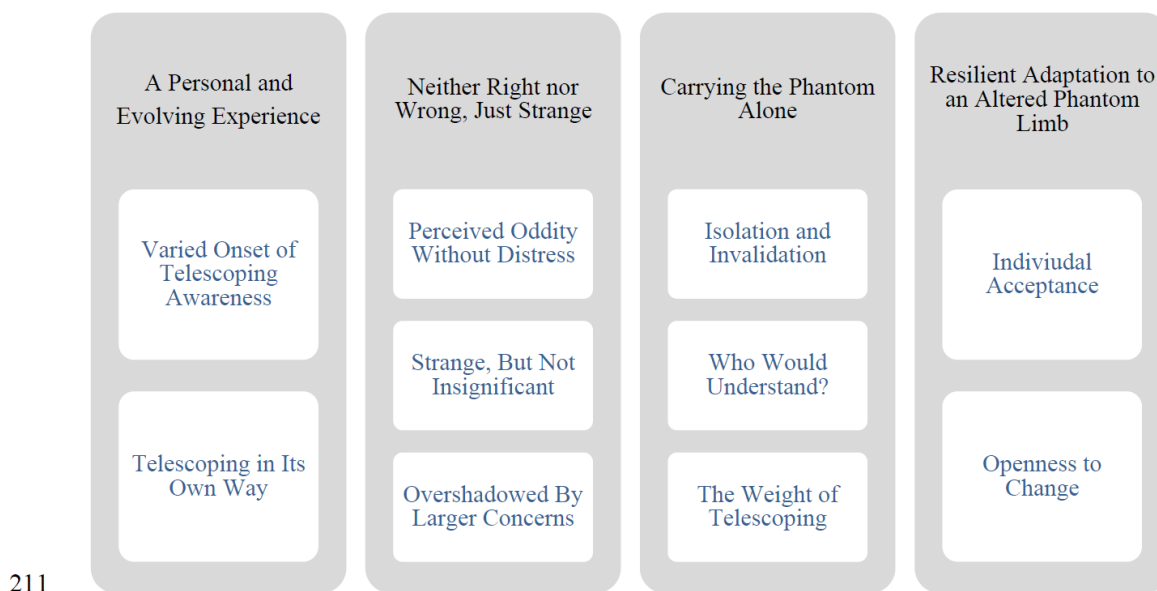


Figure 1. The four main themes and their subthemes.

3.1 A Personal and Evolving Experience

3.1.1 *Varied Onset of Telescoping Awareness*

Participants differed widely in when they first became aware of their phantom limb telescoping. Some perceived it immediately post-amputation while others only experienced it months or years later. Two individuals reported recognition of immediate limb shortening. One participant explained that he experienced a shorter phantom limb “right from the beginning” (P003, 52), and another explained she felt it “right away” (P011, 67), suggesting that for some, telescoping occurs immediately after amputation. Others ($n = 3$) first noticed telescoping in the early rehabilitation phase, 4 to 8 months postamputation, often in conjunction with increased proprioceptive demands of prosthetic use. One participant explained “Six months after the amputation was done when I started consistently wearing a prosthetic leg” (P009, 35) was when he noticed shortening of his phantom limb. This participant was the only one to also spontaneously report a concurrent decrease in his PLP intensity when he experienced his phantom limb telescoping. A third cluster of participants did not become aware of telescoping until one to two years after amputation ($n = 4$). Finally, one participant reported only noticing that his limb was telescoped 12 years after amputation while completing the questionnaires pertaining to this research project. He stated: “It was when I was taking the survey. That was one of the questions on there and I thought about it and then it really does seem like it is shorter than it used to be” (P004, 40). The remaining participants ($n = 2$) could not recall when they had first noticed their limb had first felt shorter than its usual length.

3.1.2 *Telescoping in Its Own Way*

Even though each individual experienced telescoping, the way it was perceived varied greatly. Participants described the sensation with reference to personal anatomy, spatial positioning,

235 and metaphors of shrinkage or displacement. Participants explained: “My foot is about six inches
 236 higher than it should be from the ground” (P001, 59), “It feels like my foot is in my upper thigh.”
 237 (P009, 35), and “My forearm I feel like is no longer there. I do feel like my phantom hand would be
 238 very close to where my elbow used to be” (P010, 47). For some, the phantom limb was described as
 239 shorter: “It just seems to be an inch shorter than it used to be” (P005, 67) and “It actually feels like
 240 my hands are really short all of a sudden, [...] it feels like I have little arms” (P012, 38). In some
 241 cases, prosthetic use altered the experience of the phantom limb. As one participant described, his
 242 phantom would sometimes reside in his upper thigh, or change position when using his prosthesis:

243 *Now it's sitting in my prosthetic. So, it's like my phantom is a bit shortened [...] I don't*
 244 *[usually] feel the phantom limb anymore. All I feel is the feeling of the prosthetic. And so, I*
 245 *think that [...] supersedes maybe the phantom sometimes. (P009, 35)*

246 One participant even described the ability to evoke the sensation through thought, stating: “When I
 247 start to think about it, I could make myself feel it” (P009, 35), further emphasizing the flexible nature
 248 of phantom limb telescoping awareness.

249 **3.2 Neither Right nor Wrong, Just Strange**

250 **3.2.1 Perceived Oddity Without Distress**

251 Participants commonly described telescoping as an unusual or surreal sensation. Many ($n =$
 252 10) used language such as “weird,” “odd,” or “interesting” to characterize their impressions. One
 253 participant exclaimed “That’s weird!” (P001, 59), while describing his first reactions to experiencing
 254 telescoping. Another participant described it as a “weirder phantom sensation” (P006, 65). Others
 255 used non-judgmental, humorous framing, without distress, to highlight how telescoping is
 256 perceptually odd, but integrated into their post-amputation experience. For example:

257 *I just assumed it was an oddity in my body or in the way the amputation was done, with the*
 258 *way my body has reacted or the way my brain has, you know, perceived what's happened.*
 259 *Who knows? [...] I just chalked it up to the fact that this is neither a right nor wrong, it is*
 260 *simply a symptom of my circumstances. (P003, 52)*

261 Overall, the telescoping experience was not seen as something to be repaired or feared, but rather as a
 262 natural extension of an altered phantom limb. Participants highlighted that it was not a sensation that
 263 particularly occupied their thoughts. As one participant remarked, the sensation did not elicit any
 264 fearful emotions, “I’d say it was interesting. [...] I mean I wasn't frightened or anything by it, I just
 265 don't know, it's kind of odd” (P004, 40). Another individual expanded on this idea further: “It’s a very
 266 interesting sensation. It’s like if somebody cut your forearm out and re-attached [...] your hand above
 267 [your] elbow. [...] It’s not something that really occupies my thoughts” (P010, 47).

268 **3.2.2 Strange, but Not Insignificant**

269 While most participants framed telescoping as a curious or benign oddity, others ($n = 2$)
 270 viewed it through more cautious or evaluative lenses. They associated telescoping sensations with
 271 uncertainty about prosthetic use, broader post-amputation adaptation outcomes, or the management
 272 of phantom limb pain. These responses still acknowledged the strangeness of telescoping but layered
 273 it with concerns about future impact or overall comfort. One participant shared several of his
 274 concerns about the implications of experiencing telescoping in terms of how it may affect his
 275 function and recovery:

276 *I [...] worry. Just because I'm like 'oh, [what] does that affect going forward?' [...] I don't*
 277 *know if that means my arms getting weaker or if means it's getting stronger. [...] Does that*
 278 *affect if I get prosthetics? Is it always going to have this weird feeling? (P012, 38)*

279 This quote highlights how the sensation itself is not cause for alarm, but its clinical implications are
 280 of concern, particularly for prosthetic use or muscle strength. These reactions still fit within the “odd
 281 but not alarming” framing, but with a more forward-looking concern. This concern also brings to
 282 light the worries of those who experience other non-painful phantom phenomena.

283 3.2.3 Overshadowed By Larger Concerns

284 Other participants ($n = 5$) explained that their focus was more on adjusting to life after having
 285 lost a limb than making sense of individual sensations. They did not deny or dismiss the sensation but
 286 explained how it simply did not register as meaningful compared to the larger psychological and
 287 functional adjustments to limb loss they were experiencing. One participant illustrated this concept
 288 by explaining, “I wasn’t bothered too much by having the feeling up there. It was more so just like,
 289 [...] please make it comfortable.” (P009, 35). Participants minimized the relevance of telescoping,
 290 not because it was not strange, but because PLP was the dominant concern. They prioritized comfort
 291 over clarity of sensation, which again reflects that weirdness alone does not predict distress. In this
 292 context, several participants ($n = 4$) described their awareness of telescoping as minimal or passive,
 293 with the phenomenon often going unnoticed or unexamined. For many, telescoping was not a source
 294 of distress, curiosity, or focus; it simply existed in the background. Participants shared, “I just never,
 295 never thought about it” (P004, 40), “It doesn’t really enter my mind a lot.” (P008, 37), and “I noticed
 296 it, but didn’t pay that much attention to it” (P012, 38). These participants reiterated how their focus
 297 was often placed elsewhere, on potentially more distressing or threatening amputation-related
 298 experiences and sensations.

299 3.3 Carrying the Phantom Alone

300 3.3.1 Isolation and Invalidation

301 Participants ($n = 5$) commonly described a sense that their painful and non-painful phantom
 302 sensations like telescoping were not taken seriously by others, including healthcare providers, peers,
 303 and even themselves. This invalidation often led to a lack of open dialogue, a delay in seeking
 304 support, and feelings of being misunderstood or alone in their experience. A sense of emotional
 305 distance from others was a recurring thread. As one individual put it, “I’ve found other people’s
 306 reaction is, I feel like they try to understand, but they really don’t. Only so far that people can
 307 understand without having experienced it” (P009, 35). This lack of understanding sometimes turned
 308 into outright dismissal. One participant recalled being told by a chiropodist that their phantom
 309 sensations were imagined: “Like, not a real sensation. That [it’s] kind of made-up or invented or
 310 whatever. And I said, ‘I assure you, it’s a very real thing’” (P011, 67). The most acute form of
 311 invalidation came from medical professionals. One participant explained:

312 *It's not recognized as if you were having chronic kidney stones, broken leg, you needed a hip*
 313 *replacement. [...] I had one doctor [who] told me it was all in my head. [In a] very insulting*
 314 *way. I was—believe me—insulted.” (P002, 61).*

315 Others described efforts to normalize or rationalize what was happening by assuming it must be
 316 common, even in the absence of validation. For example, one participant shared, “I did some research
 317 into it, and I just felt that, okay, I guess that’s the normal progression of the injury. It happens to other

318 people, so it must be normal” (P010, 47). This strategy appeared to provide temporary reassurance to
 319 an individual hoping to cope with the sensation alone but often did not resolve the underlying sense
 320 of ambiguity or marginalization.

321 **3.3.2 Who Would Understand?**

322 Despite their vivid and sometimes peculiar experiences associated with telescoping,
 323 participants rarely discussed it with others. Many ($n = 7$) described concerns about believability or
 324 simply not having the right opportunity or language to share their experiences with others. The
 325 sensations were seen as private, strange, or not socially discussable. One participant shared, “I never
 326 really talked about it until you brought it up. [...] I just—I don't know who you sit around and talk
 327 about your phantom limb sensations with. [...] I thought it was a situation unique to me” (P003, 52).
 328 One individual described how their silence was shaped by fear of being disbelieved or judged:

329 *They'll just think I'm crazy. The pain I can explain to them. They seem to grasp that. Though*
 330 *I'd like to dip their feet in boiling water, so they really experience it. But the telescoping I*
 331 *haven't really mentioned to anybody. (P005, 67)*

332 Pain, while also difficult to communicate, felt more “acceptable” than the bizarre and less visible
 333 distortions experienced with a telescoped phantom.

334 Multiple participants ($n = 4$) noted that they had never brought up the experience to anyone,
 335 including medical professionals. Individuals stated: “Have I spoken to anybody? No, not really. [...] My
 336 amputee doctor hasn't really asked me about it” (P008, 37) and “I may have mentioned it to my
 337 team. I can't remember. [...] I never specifically addressed a question to any of my medical team
 338 about it” (P010, 47). These quotes highlight how many individuals never thought to speak to their
 339 medical team about their phantom sensations, nor were they asked about it. Others expressed a
 340 willingness to share but noted they simply did not have the opportunity or had not thought to share
 341 their phantom sensations with others. One participant reflected:

342 *I'm very open with everything. So, I talk to people about stuff. But like I probably—I don't*
 343 *think I ever brought the feeling of [telescoping] up to anybody. [...] Mostly I'll just tell my*
 344 *family about [...] the basics when [...] I was recovering. But other than that, like, unless it*
 345 *hits that moment I [won't]. (P007, 43)*

346 Similarly, some participants ($n = 3$) admitted to a single, brief conversations with their partner. One
 347 individual had described his experience with his wife and stated: “She may be under the impression
 348 that that was just a temporary sensation, ‘cause I only think I discussed it with her once” (P003, 52).
 349 On the other hand, two participants did talk about their telescoping sensations, typically with those
 350 who could personally relate or with whom they had a strong sense of mutual understanding. For
 351 example, “I talked to my wife about it. We're both amputees, so we talk about that stuff all the time”
 352 (P004, 40). In rare cases, participants found partial recognition from others: “There were some people
 353 who got the gist of what I was describing” (P001, 59). Yet, across stories, the sensation was
 354 consistently marked as strange, even when shared with someone they felt comfortable with.

355 **3.3.3 The Weight of Telescoping**

356 Participants ($n = 4$) commonly explained the way phantom sensations, including telescoping,
 357 function as unrelenting reminders of having lost a limb. Participants described how the sensation of
 358 having a shorter limb disrupted moments of peace, reasserted the reality of limb loss, and carried

359 emotional weight that challenged efforts to forget, move on, or feel whole again. One participant
360 described a cyclical tug-of-war between forgetting and being pulled back into awareness:

361 *It takes you away from everything. It's almost like when you can finally check out and not*
362 *really pay attention to it, it brings you back to realizing like 'oh wait, [I] lost some limbs.'*
363 *[...] It's not very easy to forget because [I] obviously look down and see it all the time. [But*
364 *when I] stop paying attention to it, it kind of just brings [me] back in. (P012, 38)*

365 Even moments of stillness, like watching TV, could be interrupted by phantom limb telescoping,
366 serving as an involuntary reminder of having lost a limb. This was echoed powerfully by another
367 participant who named the deep internal loss that underpins such reminders: “In that dark, dark space
368 we all have, we’re not whole anymore. That plays on [my] mental attitude. Any additional [phantom
369 sensations] are just reminders that [I’m] not” (P006, 65). This blunt reflection highlights how
370 phantom sensations, including telescoping, do not merely disrupt comfort; they actively reinforce a
371 perceived lack of wholeness. While the sensations are not interpreted as inherently harmful or
372 painful, they serve as reminders of what their body has had to endure.

373 **3.4 Resilient Adaptation to an Altered Phantom Limb**

374 **3.4.1 Individual Acceptance**

375 Participants ($n = 6$) described how they adapted to the experience of living with phantom limb
376 telescoping. While the sensation was often described as strange, many individuals ultimately
377 integrated telescoping into a new understanding of their bodies, relationships, and everyday lives.
378 This adaptation was neither framed as easy nor complete, but rather as an ongoing process of
379 acceptance, redefinition, and resilience. Multiple individuals ($n = 4$) described a psychological shift
380 toward acceptance of phantom sensations and body changes, often through self-awareness and a
381 focus on regaining function. Phantom sensations became a regular, though strange, part of daily life.
382 One participant explained: “It’s become a regular [...] condition I live with. And I’m probably like,
383 still on the verge of saying, maybe like, comfortable with at this point. But I can proceed with like,
384 my daily activities” (P009, 35). For others, acceptance was rooted in intentional reframing. One
385 participant described a conscious decision not to let the experience of limb loss or phantom
386 sensations like telescoping define him:

387 *“I made a choice some time ago that [...] I wouldn’t be defined by what has happened. And*
388 *then I wouldn’t be defined by this experience. Only that I would let it add to who I am. I*
389 *wouldn’t let it take anything away from who I am. [...] I think maybe I’m a bit stronger as a*
390 *result. Maybe a bit tougher mentally as result. But I don’t feel like it has taken anything away*
391 *from who I am.” (P003, 52)*

392 This was echoed by another participant who stated: “I don’t let it bother me. If that makes sense. If
393 it’s a kind of know something in the back of my mind but it’s not really enough to change anything”
394 (P004, 40). This process of individual acceptance reflects a subtle form of resilience, one that does
395 not require the absence of discomfort, but rather an ability to live alongside it.

396 **3.4.2 Openness to Change**

397 Beyond individual acceptance, multiple participants ($n = 5$) described how they had
398 functionally integrated telescoping into their lives in ways that minimized disruption. Participants
399 described an openness to their altered phantom limb without being defined or overly limited by it.

One participant described how he approached his sensations of telescoping with curiosity rather than fear: “If something happens, I’ll be like, well, it’s pretty neat. I don’t dread it or anything.” (P004, 40). Even those who described the sensations as strange generally did not see them as impairing. As one participant noted, “The telescoping and the shrinking of the limb doesn’t bother me in the least. It’s an odd sensation. It’s not going to change my ability to do anything.” (P009, 35). Moreover, most participants ($n = 8$) explained that painful and non-painful phantom sensations, including telescoping, had minimal effects on their daily life or relationships. One participant reflected, “The phantom sensations? No, not really. [The phantom sensations] don’t really have an impact.” (P008, 37). Others noted that any effects on relationships were temporary or minor. One person explained that close family and friends had no issue with the phantom limb sensations he experienced, “Once they get past the big shocker, right?” (P006, 65), implying that initial surprise of losing a limb had a greater potential impact on relationships than did telescoping.

4 Discussion

The present study aimed to better understand phantom limb telescoping by exploring the phenomenon from the perspective of individuals who experience it. Despite its relevance to post-amputation adjustment, telescoping remains a relatively understudied aspect of phantom limb experience, particularly from a qualitative research lens. While PLP has dominated the literature and clinical focus, other sensations, such as telescoping, have received considerably less attention. The four main themes from our analysis reflect the intricate and multifaceted nature of telescoping, highlighting its complexity as a lived, embodied experience.

The first theme, *A Personal and Evolving Experience*, comprised two subthemes: *Varied Onset of Telescoping Awareness* and *Telescoping in Its Own Way*. Together, these subthemes underscore the individualized and dynamic nature of telescoping, while also revealing shared experiential patterns. For some, telescoping was described as an experience that was not immediately apparent to them, with its onset in time after amputation varying significantly across individuals. This temporal variability suggests that telescoping may be a latent phenomenon that becomes salient only under specific bodily, cognitive, or social conditions, rather than following a uniform postoperative trajectory (2, 6). For instance, one participant only became aware of the shortened length of his phantom limb after completing the pre-interview questionnaire. This highlights how rarely the phenomenon is discussed and how easily it can go unnoticed, especially among those who pay little attention to their phantom limb. These findings align with prior research suggesting that phantom sensations, including telescoping, are shaped by attentional processes, environmental factors, and body schema awareness (20, 21). Accordingly, PLP also increases attention, awareness, and ownership over the phantom limb, and may influence telescoping experience (22). Beyond this, participants' narratives indicated that telescoping is not a singular or static sensation but a complex and evolving experience, influenced by factors such as context, emotional state, prosthesis use, and post-amputation changes.

The second theme, *Neither Right nor Wrong, Just Strange*, encompasses three subthemes: *Perceived Oddity Without Distress*, *Strange, but Not Insignificant*, and *Overshadowed by Larger Concerns*. This theme captures how participants often interpreted telescoping not as a clinical issue requiring a medical or psychopathological explanation, but as an interesting feature of their post-amputation experience. Rather than framing it through a biomedical lens, many integrated telescoping into their broader narrative of bodily change and adaptation, an observation consistent with prior work on how individuals adjust to post-amputation sensations (23). For some, telescoping was experienced with a sense of intrigue or even levity, while for others, limited information and

clinical discussion surrounding the phenomenon gave rise to uncertainty about its implications. This variability suggests that the absence of routine conversations about telescoping in medical settings may contribute to confusion or concern when the sensation is noticed. As such, introducing the phenomenon of telescoping and normalizing it through patient education could reduce unnecessary anxiety and promote acceptance of a broader range of phantom limb experiences (24). Multiple individuals reported giving the sensation little thought, indicating that emotional responses to telescoping are shaped by context and personal meaning-making rather than by the perceptual experience alone. In contrast, sensations that are more intense, painful, or functionally limiting, such as PLP, tend to dominate both participant's attention and interview responses, often overshadowing the recognition or discussion of telescoping. These findings support the view that bodily sensations, particularly those that are perceptually strange, can become neutral or non-disruptive aspects of lived experience when not imbued with negative interpretations, especially in the broader context of post-amputation adjustment.

The third theme, *Carrying the Phantom Alone*, included three subthemes: *Isolation and Invalidation*, *Who Would Understand?* and *The Weight of Telescoping*. Together, these narratives highlight the emotional and interpersonal challenges that often surround the experience of phantom limb telescoping. Participants described navigating a social world in which their telescoping sensations were met with confusion, skepticism, minimization, or outright dismissal, echoing previous research documenting the invalidation of chronic illness and invisible bodily experiences (25-27). Individuals had to negotiate the legitimacy of their experiences in environments that often lack understanding or empathy. Even well-intentioned or supportive relationships did not always translate into genuine understanding. In line with studies on invisible illness and pain disclosure (28), participants often debated when, how, and whether to share their experiences, opting for silence, ambiguity, or guarded disclosure in the face of anticipated disbelief or misunderstanding. These findings reflect the broader sociocultural dynamics of living with a condition that cannot be easily described nor observed from the outside perspective. Ultimately, participants portrayed telescoping as a personal and often private experience, one that is rarely addressed unless explicitly prompted. Its invisibility, both literal and social, compounded feelings of alienation and emotional solitude.

Telescoping also appeared to elicit a psychological toll. For many, telescoping was not just a physical reminder of a lost limb but an emotional flashpoint that reactivated grief, absence of a limb, or the irreversibility of bodily change. This aligns with prior research emphasizing the enduring psychological dimensions of amputation and phantom phenomena, including themes of loss, identity disruption, and ongoing adaptation (29, 30). Even in cases where individuals appeared outwardly well-adjusted or physically functional, the inner experience could be marked by a quiet return to what was missing, kept alive through the persistent phantom sensations of the missing limb.

Within this theme especially, participants sometimes situated telescoping alongside other painful and non-painful phantom sensations when describing its impact. While the literature differentiates these phenomena conceptually and mechanistically, the participants did not always draw such lines when discussing day-to-day functioning, relationships, or emotional well-being. These accounts indicate that mechanistically distinct processes may nonetheless converge on similar psychological and functional consequences in lived experience.

The final theme, *Resilient Adaptation to an Altered Phantom Limb*, consisted of two subthemes: *Individual Acceptance* and *Openness to Change*. Across participant accounts, telescoping was rarely experienced as something to be either wholly embraced or actively resisted; rather, it was gradually folded into the background of everyday life. Participant P003 highlighted how many

individuals' adjustment was neither a celebration nor denial but a kind of neutral perseverance. Acceptance, in this context, did not reflect a resolution of the phenomenon, but instead pointed to a process of adaptive integration, an ongoing recalibration of identity, priorities, and self-concept in light of bodily change. This form of acceptance aligns with theoretical models of post-traumatic growth or survival in the face of chronic conditions, which emphasize psychological flexibility and meaning making over symptom eradication (31, 32). Whether through deliberate reframing or quiet endurance, participants found ways to integrate telescoping into their lives, without allowing them to define their sense of self.

Although some participants chose not to speak openly about their phantom sensations like telescoping with others, their narratives nonetheless reflected a notable degree of emotional resilience and pragmatic adaptation. In contrast to more distressing post-amputation experiences such as PLP, telescoping was often met with a stance of self-curiosity, neutrality, or quiet acceptance. This suggests that not all post-amputation sensations are interpreted as threatening or disruptive. These findings echo previous research emphasizing the variability in how individuals respond to phantom phenomena, and how these responses are shaped by personal meaning-making, contextual support, and broader psychological resources (33, 34). Importantly, the willingness to coexist with change, even in its unfamiliar or shifting forms, may represent a critical dimension of long-term adjustment after limb loss. As such, fostering space for diverse and non-pathologizing interpretations of phantom limb sensations may be a valuable component of post-amputation care and support.

5 Limitations

Several limitations of this study should be acknowledged. First, the sample lacked demographic diversity, as the majority of participants were White men. While saturation was achieved within this sample of 12 individuals, it is possible that certain subtleties were missed, or that additional themes might have been identified with a more diverse sample in terms of ethnicity, gender, and socioeconomic background. As such, the saturation reached in this study reflects the experiences of a specific sociocultural group and may not fully capture the broader spectrum of experiences across a more varied population. Future research should prioritize recruitment strategies that enhance diversity to explore whether the themes identified here hold across different demographic and cultural contexts.

Second, most participants were recruited from a specialized rehabilitation center (St. John's Rehab) and had access to post-amputation health services. This may have influenced both the degree of adaptation and the quality of coping described in the interviews. Individuals without access to such healthcare resources, particularly in under-resourced or rural settings, may report different experiences of phantom sensations, including telescoping. Therefore, the extent to which the findings apply to populations without such access may be limited.

Third, while one participant in the study spontaneously noted a perceived relationship between telescoping and a reduction in the intensity of their PLP, the interview guide did not include direct questions about this potential connection. As a result, systematic data were not collected regarding the interaction between telescoping and PLP across participants. This omission was intentional, as the researchers aimed to avoid leading questions that might influence participant responses or prompt speculative associations. However, the absence of explicit probing limits the extent to which conclusions can be drawn about the relationship between these two phenomena. This remains an important area for future research.

533 Finally, the nature of qualitative inquiry involves retrospective self-reporting that can be
 534 influenced by memory biases, especially when recalling the onset and evolution of a sensation like
 535 telescoping. While participants were reflective and forthcoming, the subjective nature of their
 536 accounts introduces variability in how telescoping is interpreted and described. Despite these
 537 limitations, the study offers valuable insights into an underexplored phenomenon and provides a
 538 foundation for future research to build upon with more diverse samples and complementary
 539 methodologies.

540 **6 Conclusions and Practice Implications**

541 To our knowledge, this study is the first to qualitatively examine the experience of phantom
 542 limb telescoping in individuals with limb loss. Despite its relatively frequent occurrence, telescoping
 543 has received minimal attention in the literature, particularly from approaches that prioritize accounts
 544 of lived experience. The aim of this study was to understand how individuals experience telescoping
 545 and how it influences their daily lives, mental health, and adaptation to limb loss. By centering the
 546 lived experiences of those directly affected, this study contributes novel insights into a phenomenon
 547 that is often overlooked in both research and clinical practice.

548 Integrating qualitative insights of this nature is essential to ensuring that empirical knowledge
 549 remains anchored in the realities of those it directly impacts. The narratives presented in this study
 550 not only deepen our understanding of the perceptual and bodily complexities of limb loss, but also
 551 bring attention to the emotional and psychological dimensions of adapting to altered phantom
 552 sensations. Telescoping was revealed to be more than a neurological event; it is a subjective,
 553 evolving experience that intersects with identity, support, loss, and resilience. For some, it is a neutral
 554 or even curious phenomenon; for others, it carries emotional weight. These findings underscore the
 555 importance of a biopsychosocial framework in understanding phantom limb phenomena, one that
 556 moves beyond pain alone and includes a wider array of sensory and affective experiences.

557 From a clinical perspective, this study highlights important practice considerations for health
 558 care professionals working with individuals with limb loss. First, normalizing telescoping through
 559 early patient education may reduce uncertainty or distress when the phenomenon occurs. Providing
 560 clear, non-pathologizing explanations of telescoping as a common and varied post-amputation
 561 experience can help patients feel validated and better equipped to interpret their sensations. Second,
 562 clinicians should consider integrating open-ended discussions into rehabilitation and follow-up care
 563 to allow patients to share sensory experiences that may otherwise go unreported, such as telescoping.
 564 Doing so may foster trust, reduce feelings of isolation, and help clinicians identify emerging
 565 psychological or emotional concerns linked to the phantom experience.

566 In sum, this study provides early groundwork for understanding telescoping as a meaningful,
 567 multifaceted component of the post-amputation experience. By elevating experiential knowledge, it
 568 paves the way for more nuanced care strategies that acknowledge the full range of phantom limb
 569 phenomena, thereby fostering more empathetic, responsive, and inclusive models of care and
 570 rehabilitation.

571 **7 Conflict of Interest**

572 The authors declare that the research was conducted in the absence of any commercial or financial
 573 relationships that could be construed as a potential conflict of interest.

574 **8 Author Contributions**

575 AA: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project
 576 administration, Visualization, Writing – original draft, Writing – review & editing; HLR: Formal
 577 analysis, Project administration, Writing – review & editing; ND: Formal analysis, Writing – review
 578 & editing; LA: Funding acquisition, Writing – review & editing; ALM: Methodology, Writing –
 579 review & editing; JK: Conceptualization, Funding acquisition, Methodology, Resources, Supervision,
 580 Writing – original draft, Writing – review & editing; SLH: Conceptualization, Methodology,
 581 Resources, Supervision, Writing – review & editing.

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593 **11 Data Availability Statement**

594 Due to the sensitive and identifiable nature of qualitative data, full transcripts cannot be publicly
 595 shared. However, de-identified excerpts or analytic materials supporting the conclusions of this
 596 article will be made available by the authors, without undue reservation.

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608 **Table 1.** The list of interview questions.

No.	QUESTIONS
1.	How would you describe your phantom limb, and any pain associated with it?
	a. When have you experienced it? b. Has it only been in the past or also presently? c. When did it first start? d. Had it ever gone away and then came back? e. How would you describe the type of pain, if any? f. Has the feeling changed over time?
2.	How would you describe your residual limb pain, if any, which is the pain that you feel in the part of your remaining limb after your amputation?
	a. When have you experienced it? b. Has it only been in the past or also presently? c. When did it first start? d. Had it ever gone away and then came back? e. How would you describe the type of pain, if any? f. Has the feeling changed over time?
3.	Have you experienced phantom limb ‘telescoping’?
	a. When did it first happen? b. What were your initial reactions? c. How have others reacted when you have tried to explain it? d. What have been your experiences with it? e. Is it a constant length?
4.	Have you experienced any shrinkage of the phantom limb?
	a. When did it first happen? b. What were your initial reactions? c. What have been your experiences with it? d. Is it a constant size? e. How has it influenced areas of your life negatively or positively?
5.	When thinking about the different types of sensations associated with your amputation (e.g., phantom limb, telescoping, residual limb, etc.), how have any of these affected your day to day life?
	a. Impact on ability to maintain your physical health? b. Impact on your mental wellbeing? c. Impact on your relationships with others?
6.	Is there anything else about your phantom limb that you would like to discuss that we did not touch upon?

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612 **Table 2.** Participant Demographics (*N* = 12)

ID	AGE	SEX	ETHNICITY	HIGHEST DEGREE OF EDUCATION	MARITAL STATUS	LIVING WITH	DATE(S) OF INTERVIEW	INTERVIEW DURATION (MIN : SEC)	# LIMBS AMPUTATED	TIME SINCE AMPUTATION (YEARS)	ETIOLOGY	EXTREMITY/ LEVEL	SIDE	RLP	PLP
001	59	Male	White	Professional	Married	Spouse	15-Jul-2019	57:02	1	6.08	Trauma	LL/BK	R	6	7
002	61	Male	White	College	Divorced	Roommate	13-Nov-2019	27:23	1	7.75	Diabetes	LL/BK	L	7	6
							4-Dec-2019	50:53							
003	52	Male	White	College	Married	Spouse	6-Dec-2019	42:19	1	1.42	Trauma	LL/AK	L	0	1
004	40	Male	White	High School	Married	Spouse	9-Dec-2019	26:23	1	12	Trauma	LL/BK	L	1	1
005	67	Male	White	Bachelor's	Separated	Relatives	17-Feb-2020	53:00	1	1.33	Diabetes	LL/BK	L	3	8
006	65	Male	White	College	Married	Spouse	13-Apr-2022	58:16	1	2.33	Diabetes	LL/BK	R	8	8
007	43	Male	White	Less than High School	Single	Relatives	18-Jul-2023	51:28	1	3.92	Trauma	LL/BK	R	8	8
008	37	Male	East Asian	College	Single	Relatives	21-Jun-2023	39:41	1	5.33	Infection	LL/BK	R	0	0
009	35	Male	White	College	Married	Spouse	15-Sep-2023	39:42	1	4.58	Trauma	LL/AK	R	5	5
010	47	Male	White	Graduate	Married	Spouse	29-Sep-2023	34:23	1	0.92	Trauma	UL/AE	L	7	7
011	67	Female	White	Bachelor's	Widowed	Alone	19-Sept-2023	38:43	1	0.5	Cancer	LL/AK	R	10	8
012	38	Male	South Asian	Bachelor's	In a relationship	Relatives	16-Dec-2024	47:26	4	0.58	Sepsis	UL/BE	R	0	0
												LL/BK	R		
												UL/W	L		
												LL/BK	L		

613 **Note:** RLP; residual limb pain, PLP; phantom limb pain, Min; minutes, Sec; seconds, LL; lower limb, UL; upper limb,
614 BK; below knee, AK; above knee, AE; above elbow, BE; below elbow, W; wrist, R; right, L; left.

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Section 3: Summary of Study 4

Study 4 represents the first qualitative investigation of phantom limb telescoping in individuals with limb loss. By centering the voices of those directly affected, the study provided rich, first-person insights into a phenomenon that, despite its relatively frequent occurrence, has received minimal attention in both research and clinical practice. Semi-structured interviews with 12 participants revealed telescoping to be a dynamic, evolving experience that extends beyond sensory change to encompass emotional, social, and identity-related dimensions. Four overarching themes emerged from the inductive analysis: (1) *A Personal and Evolving Experience*, (2) *Neither Right nor Wrong, Just Strange*, (3) *Carrying the Phantom Alone*, and (4) *Resilient Adaptation to an Altered Phantom Limb*. Collectively, these findings highlight telescoping as a subjective experience shaped by context, coping strategies, and interpersonal factors, rather than solely a neurophysiological or sensory phenomenon.

Importantly, Study 4 demonstrated that telescoping can carry varying emotional weight across individuals. For some participants, it was experienced neutrally or even with curiosity, whereas for others, it elicited uncertainty, distress, or reflection on identity and bodily integrity. These insights underscore the importance of adopting a biopsychosocial framework when understanding phantom limb phenomena, one that situates perceptual changes within broader psychosocial and functional contexts. Clinically, the study highlighted several implications: normalizing telescoping through early education, fostering open-ended discussion during rehabilitation and follow-up, and creating space for patients to articulate sensory experiences that might otherwise go unreported. Such strategies may reduce distress, strengthen rapport, and facilitate more responsive, individualized care.

In sum, Study 4 provided valuable exploratory insights by establishing that telescoping is a meaningful and multifaceted component of the post-amputation experience. The qualitative findings extend prior quantitative work by illuminating how telescoping is interpreted, managed, and integrated into daily life, revealing dimensions that are not readily captured by symptom severity ratings or standardized measures. By demonstrating that telescoping can influence emotional well-being, sense of self, and interpersonal communication in often in subtle and individualized ways, this study underscores the limitations of viewing telescoping solely through a neurophysiological lens. Instead, the findings support the conceptualization of telescoping as an embodied experience shaped by psychological processes, social context, and adaptive meaning-making. Together, these insights provide a critical foundation for future research aimed at clarifying the mechanisms linking telescoping with mental health, as well as for the development of clinical approaches that acknowledge and address the subjective significance of phantom limb experiences.

Chapter 6: General Discussion

Section 1: Overview of Key Findings

The overarching aim of this dissertation was to advance understanding of phantom limb telescoping by examining its characteristics, clinical correlates, and implications for life after limb loss through a sequence of complementary studies. Together, the findings from the narrative review (Study 1), case report (Study 2), quantitative study (Study 3), and qualitative study (Study 4), converge to portray telescoping as a meaningful, multifaceted post-amputation phenomenon.

Study 1

Study 1, a comprehensive review of the existing literature, revealed that research on phantom limb telescoping is limited and methodologically fragmented. The majority of studies relied on small samples or case reports, used inconsistent definitions and measurement approaches, and rarely examined telescoping as a primary phenomenon. Importantly, the review indicated that telescoping occurs in approximately 22% of individuals with limb loss, with higher prevalence observed among those with upper limb loss and trauma-related etiologies. In contrast, telescoping does not appear to be systematically related to basic biological or demographic factors such as age, sex, or time since amputation. The review identified cortical reorganization as a central mechanism implicated in telescoping. Importantly, that telescoping appears to be related to the presence of PLP, while also being associated with enhanced responsiveness to certain PLP interventions. Telescoping was more frequently reported among individuals who do not use a prosthetic limb, and evidence suggested that the experience of telescoping is not always maintained during sleep or dreaming, further underscoring its dynamic and context-dependent

nature. Overall, Study 1 established that telescoping is underexplored despite its relatively frequent occurrence and potential relevance for understanding post-amputation pain.

Study 2

Study 2 extended this work through an in-depth case report examining the co-occurrence of telescoping, PLP, RLP, and psychosocial factors in a single individual with limb loss. The participant described the onset of telescoping approximately one year post-amputation, followed by a notable reduction in PLP intensity and frequency. Although pain remained present, it became more manageable over time. This case illustrated one possible temporal relationship between telescoping and pain reduction while also highlighting ongoing challenges related to catastrophic thinking, low optimism, and mild symptoms of anxiety and depression. Importantly, the case underscored both the potential clinical relevance of telescoping and the limitations of single-case designs, reinforcing the need for broader investigation to determine whether this pattern generalizes to others.

Study 3

Study 3 quantitatively examined demographic, clinical, and psychosocial differences between individuals who endorsed telescoping and those who did not. Nearly half of participants reported telescoping, a higher prevalence than typically reported in large-scale studies, likely reflecting sample characteristics such as traumatic amputation etiology. Telescoping was more commonly reported among younger individuals and those with upper limb amputations, particularly right-sided limb loss. Contrary to past research that suggests that telescoping may be associated with the presence of pain, no between-group differences were found in PLP intensity, RLP intensity, or pain interference. Notably, within the telescoping subgroup, greater degrees of

telescoping were associated with lower PLP intensity, suggesting a more nuanced relationship between perceptual change and pain.

Psychosocial findings in Study 3 further reinforced the complexity of telescoping. Individuals who reported telescoping endorsed higher levels of anxiety and depression, while no differences were observed in optimism or resilience. These results suggest that telescoping is not uniformly associated with either protective or maladaptive psychosocial profiles. Instead, a dual-process interpretation was proposed: the presence of telescoping may be emotionally distressing for some individuals due to uncertainty or heightened attention to bodily sensations, while the extent of telescoping may reflect adaptive perceptual reorganization that co-occurs with lower pain for others. Importantly, these findings challenge the notion that telescoping should be interpreted as a marker of greater post-amputation pain.

Study 4

Building on these quantitative insights, Study 4 qualitatively examined the lived experience of telescoping in a group of individuals with limb loss. This study was the first to prioritize first-person accounts of telescoping and revealed it to be a deeply personal, evolving experience shaped by emotional, social, and contextual factors. Four themes captured participants' experiences: (1) *A Personal and Evolving Experience*, (2) *Neither Right nor Wrong, Just Strange*, (3) *Carrying the Phantom Alone*, and (4) *Resilient Adaptation to an Altered Phantom Limb*. Participants described telescoping as extending beyond sensory change to influence identity, meaning-making, and daily life. These findings emphasized that telescoping is not inherently distressing or benign, but rather varies widely in how it is interpreted and integrated. Clinically, Study 4 highlighted the importance of normalizing telescoping, providing

space for discussion, and acknowledging experiences that are often left unspoken in rehabilitation settings.

Taken together, the findings across Studies 1-4 suggest that phantom limb telescoping is a common yet understudied phenomenon that reflects alterations in body representation shaped by sensory, psychological, and contextual factors. Telescoping does not appear to be a simple indicator of pain severity or dysfunction; rather, it occupies a complex position at the intersection of perception, pain, and adaptation following limb loss. By integrating evidence across methodological approaches, this dissertation highlights the importance of moving beyond pain-centric models to understand the broader lived experience of individuals with limb loss. Collectively, these studies support the need for biopsychosocial frameworks, patient-centered assessment, and continued research using larger, more diverse samples to further clarify the role of telescoping in post-amputation life.

Section 2: Clinical Implications

The findings from Studies 1-4 highlight telescoping as a clinically meaningful and multifaceted post-amputation phenomenon with important implications for assessment, intervention, and long-term care. Across methodologies, telescoping emerged as a dynamic and highly individualized experience, reinforcing the need for personalized, flexible, and biopsychosocial informed approaches when working with individuals with limb loss. From an assessment standpoint, the variability of telescoping across individuals, limb levels, and time underscores the importance of incorporating routine screening for phantom limb characteristics into post-amputation care. Early identification of telescoping, particularly among individuals with upper-limb loss, who may be more likely to experience phantom limb

shortening, may allow clinicians to monitor psychological adjustment, prosthesis use, and the potential development or fluctuation of PLP more closely. Importantly, telescoping is not static; it may change with prosthesis use, rehabilitation progress, or emotional state, highlighting the need for ongoing assessment rather than one-time evaluation.

The findings also suggest that telescoping may have implications for the selection and effectiveness of rehabilitative and pain-focused interventions. Although some studies report that individuals with telescoped phantoms derive greater benefit from PLP treatments, others have observed the opposite pattern. These mixed findings may be attributable to the relatively small sample sizes that characterize much of the existing literature, as well as to differences in the type of intervention examined and the ways in which individuals engage with these treatments. In particular, interventions such as mirror therapy, virtual or augmented reality, and other approaches often rely on congruence between visual feedback and the perceived size or position of the phantom limb. For individuals who experience a telescoped phantom, these interventions may require adaptation to align with the individual's subjective bodily representation. Failure to consider phantom limb length may partly explain the variability in treatment response observed across individuals with PLP. As such, tailoring interventions to the phenomenology of the phantom limb, including its perceived length, may enhance clinical effectiveness.

Study 3 highlights the relevance of psychosocial screening, particularly for anxiety and depression, among individuals who report telescoping. The associations between telescoping and psychological distress suggest that, for some individuals, the experience may be accompanied by heightened bodily monitoring, uncertainty, or difficulty coping. Integrating routine psychosocial assessment into care may help identify individuals who would benefit from targeted psychological interventions. Approaches such as cognitive-behavioral therapy (CBT) or

acceptance and commitment therapy (ACT) may support adaptive coping, reduce distress, and promote psychological adjustment, even when the perceptual experience of telescoping itself cannot be directly modified.

Beyond physical rehabilitation, the qualitative findings of Study 4 emphasize the importance of addressing the emotional and psychological dimensions of telescoping. Study 4 demonstrated that telescoping is not merely a perceptual or neurological phenomenon, but one that can intersect with identity, loss, meaning making, and resilience. For some individuals, telescoping may be experienced as neutral or even intriguing; for others, it may be somewhat worrisome or emotionally charged. Normalizing telescoping through early patient education and providing clear, non-pathologizing explanations may reduce uncertainty and concern, helping individuals contextualize their experiences within the broader spectrum of post-amputation phenomena. Creating space for open-ended discussions about phantom sensations during rehabilitation and follow-up care may also foster trust, reduce feelings of isolation, and encourage disclosure of experiences that might otherwise remain unreported.

Overall, these findings support the conceptualization of phantom limb telescoping as a phenomenon that bridges perceptual, emotional, and social domains. Clinically, this underscores the importance of moving beyond pain-focused models alone and adopting integrated care approaches that recognize the full complexity of post-amputation experience. Continued efforts to link detailed assessment of phantom limb characteristics with tailored rehabilitative and psychological interventions will be essential for translating this growing body of research into meaningful clinical practice.

Section 3: Strengths and Limitations

This dissertation has several notable strengths that enhance its contribution to the understanding of telescoping, while also presenting limitations that should be considered when interpreting the findings. A key strength lies in the use of a multi-method approach across Studies 1-4, incorporating a narrative review, a case report, quantitative analysis and qualitative inquiry. Together, these complementary methodologies allowed for a more comprehensive examination of telescoping, capturing its phenomenology, lived experience, psychosocial correlates, and clinical relevance in ways that would not have been possible through a single methodological lens.

Across studies, particular strengths include the deliberate attention to an underexplored phenomenon, the integration of psychosocial variables alongside sensory and pain-related measures, and the use of validated and standardized instruments where appropriate (Study 2 and 3). The quantitative study benefited from the inclusion of a more precise and nuanced measure of telescoping, addressing a longstanding challenge in the assessment of this phenomenon. Similarly, the qualitative study provided rich, in-depth insights grounded in lived experience, ensuring that empirical findings remained anchored in the realities of individuals with limb loss. Collectively, these approaches support a biopsychosocial conceptualization of telescoping and strengthen the ecological validity of the dissertation as a whole.

Despite these strengths, several limitations should be acknowledged. First, limitations related to study design and sample characteristics were present across multiple studies. The narrative review (Study 1), while comprehensive, was subject to the inherent limitations of narrative synthesis, including potential subjectivity, and reliance on a literature base characterized by small samples, case reports, and variable methodological rigor. Additionally, the

review was restricted to English-language publications, introducing the possibility of language bias. Study 2, as a retrospective single-case report, offered valuable exploratory insights but is limited in its generalizability. Retrospective self-report introduces recall bias, and the absence of standardized neurological or physical examinations constrained the depth of clinical inference. While appropriate for hypothesis generation, conclusions drawn from this study cannot be assumed to reflect broader patterns among individuals with limb loss.

Sample-related limitations were also evident in Studies 3 and 4. The quantitative study (Study 3) included a modest sample size and relied on online recruitment, raising concerns about representativeness, overrepresentation of telescoping, and limited demographic diversity. Across studies, reliance on self-report measures introduces potential recall bias and variability in how telescoping was understood and described by participants. Similarly, the qualitative study (Study 4) achieved thematic saturation within a relatively small and demographically homogeneous sample, primarily composed of White men recruited from a specialized rehabilitation center. Access to comprehensive post-amputation care may have influenced participants' coping, adjustment, and interpretations of telescoping, limiting transferability to individuals in under-resourced or rural settings.

Finally, several methodological constraints limit causal inference. In particular, the cross-sectional design of Study 2 and 3 precludes conclusions about the temporal direction of relationships between telescoping, pain, and psychosocial variables such as anxiety and depression. While associations were identified, it remains unclear whether psychosocial distress contributes to the experience of telescoping, whether telescoping contributes to distress, or whether both are influenced by other underlying factors. Longitudinal and experimental designs will be essential to clarify these relationships.

In sum, while the findings of this dissertation should be interpreted in light of these limitations, the convergence of evidence across diverse methodologies represents a significant strength. By combining breadth and depth, and by explicitly acknowledging methodological constraints, this work provides a robust foundation for future research aimed at refining measurement, improving generalizability, and advancing clinically meaningful interventions for individuals with limb loss.

Section 4: Future Directions

The findings of this dissertation highlight several important avenues for future research aimed at advancing the understanding of phantom limb telescoping and its clinical significance. A primary priority is the development and adoption of standardized methodologies for assessing telescoping. Standardized tools, such as the web-based platform we have developed, available at <https://demo.phantomlimbs.ca/> (Aternali & Katz, 2019a), can improve comparability across studies, enhance reproducibility, and allow researchers to better control for confounding factors such as age, time since amputation, and level of amputation. Consistent measurement approaches will also facilitate the identification of underlying neurophysiological and psychological mechanisms, providing a stronger foundation for both theoretical models and clinical applications.

Longitudinal and prospective studies are needed to clarify the temporal dynamics of telescoping and its relationships with PLP, RLP, prosthesis use, and psychosocial adjustment. Future research should examine whether telescoping precedes, follows, or co-evolves with psychological distress, anxiety, depression, and coping patterns. Such designs would help distinguish adaptive from maladaptive trajectories and identify critical windows for intervention.

Intervention-focused research remains a priority. Emerging technologies, including virtual and augmented reality, offer opportunities to experimentally manipulate phantom limb perception and evaluate effects on pain, embodiment, and emotional well-being. Psychologically informed interventions, such as cognitive-behavioral therapy or mindfulness-based approaches, should be investigated for their potential to reduce distress associated with telescoping, particularly in individuals who exhibit heightened anxiety or depressive symptoms.

Diverse and representative sampling should be prioritized in future studies. Many existing studies overrepresent White participants who have lost their limb due to trauma and who have access to specialized rehabilitation services, limiting generalizability. Including participants of varied gender, ethnicity, socioeconomic status, geographic location, and healthcare access will ensure findings are applicable to the broader population of individuals with limb loss. Further, qualitative research remains essential to capture the lived, subjective experience of telescoping, illuminate emotional and identity-related dimensions, and inform patient-centered interventions.

Finally, neurophysiological and neuroimaging approaches represent promising avenues for elucidating the cortical and sensorimotor mechanisms underlying telescoping. Techniques such as functional MRI, magnetoencephalography, and somatosensory mapping can characterize alterations in cortical representation, sensorimotor integration, and body schema that may contribute to the perceived shortening or displacement of the phantom limb. Importantly, this work can also address whether telescoping reflects adaptive reorganization linked to reduced PLP or, alternatively, a marker of maladaptive neural processes associated with persistent PLP or RLP. By combining rich subjective data with objective measures of brain and body representation, future studies can bridge phenomenology and biology, ultimately improving both scientific understanding and clinical care.

Collectively, these directions underscore the need for theoretically informed, methodologically rigorous, and patient-centered research. By addressing measurement, diversity, intervention, and mechanistic questions, future work can clarify the role of telescoping in post-amputation adaptation and inform more personalized, effective strategies for supporting individuals with limb loss.

Section 5: Conclusions

Phantom limb telescoping represents a complex and multifaceted component of the post-amputation experience, with implications for both clinical care and the scientific understanding of phantom limb phenomena. Across the studies included in this dissertation, telescoping emerged as a dynamic perceptual experience, varying in onset, intensity, and personal significance. The narrative review (Study 1) highlighted that telescoping affects roughly 22% of individuals with limb loss, with higher rates among those with upper limb amputations, particularly following trauma. Importantly, telescoping does not appear to be consistently associated with demographic factors such as age or sex, nor with time since amputation, but instead may reflect underlying cortical reorganization processes. These neural changes may increase vulnerability to PLP while simultaneously enhancing responsiveness to interventions, underscoring the nuanced interplay between neurobiology and clinical outcomes. The review further suggested that telescoping is more common in individuals who do not use prosthetic devices and that it may not be consistently maintained while dreaming, highlighting the fluid and context-dependent nature of this phenomenon.

Building on these broader patterns, the case report (Study 2) offered a detailed, individualized perspective on telescoping, illustrating that the onset of telescoping coincided

with a reduction in PLP intensity for one participant. While limited by its single-case design, this study points to the potential for telescoping to be adaptive, pain alleviating phenomenon. It also emphasizes the need for adequately powered longitudinal research to clarify the temporal and potentially causal relationships between telescoping and PLP. Together with findings from the narrative review, the case report underscores the importance of integrating telescoping assessments into clinical practice and using these insights to guide individualized rehabilitation strategies.

The quantitative study (Study 3) offered further insight into demographic and psychosocial correlates of telescoping. It demonstrated that telescoping was more prevalent among younger individuals with upper limb amputations, particularly below the elbow and on the right side, and was associated with higher levels of anxiety and depression. Notably, percent telescoping was negatively associated with PLP intensity but showed no significant associations with residual limb pain, pain interference, optimism, or resilience. The study reinforces the importance of routine screening for psychological distress and the potential utility of supportive interventions to improve adjustment among individuals experiencing telescoping.

Finally, the qualitative study (Study 4) further deepened understanding by centering the lived experience of individuals with limb loss. Telescoping was shown to extend beyond a mere sensory or neurological phenomenon, encompassing emotional, identity-related, and psychosocial dimensions. Some individuals reported neutral or even curious experiences, while others experienced distress, uncertainty, or heightened vigilance toward bodily sensations. These findings underscore the importance of adopting a biopsychosocial framework in both research and clinical care, moving beyond pain-centric models to acknowledge the broader implications of post-amputation phenomena. Clinically, this highlights the value of patient-centered

approaches that normalize telescoping, provide clear education, and create space for patients to discuss their unique experiences as part of rehabilitation and follow-up care.

Across all four studies, several converging conclusions emerge. First, telescoping is a heterogeneous and context-dependent experience, influenced by neurophysiological, psychological, and behavioral factors. Second, it has meaningful clinical implications, including its potential to inform PLP interventions, guide individualized rehabilitation, and highlight the need for psychosocial support. Third, current evidence suggests that telescoping should be considered within a biopsychosocial framework that integrates sensory, cognitive, and emotional components, rather than as a purely perceptual phenomenon. Finally, this dissertation emphasizes the value of integrating multiple methodologies (e.g., narrative review, quantitative, qualitative, and case-based) to capture both the general patterns and individual nuances of telescoping, thereby advancing both scientific understanding and patient-centered care.

In conclusion, the present work provides a comprehensive foundation for future research and clinical practice. By clarifying the prevalence, characteristics, and psychosocial correlates of telescoping, we are able to contribute to the current body of researching aiming to better understand post-amputation experiences. Future studies that standardize measurement, include longitudinal designs, incorporate diverse samples, and test mechanism-based interventions will be essential to translate these findings into evidence-based care. Ultimately, recognizing the multifaceted nature of telescoping holds the potential to enhance rehabilitation strategies, improve psychological adjustment, and support a more holistic approach to the health and well-being of individuals with limb loss.

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**Appendix: Materials and Measures for the
Post-Amputation Phantom Limb Survey (Study 2-4)**

Section 1: Online Questionnaires

Online Questionnaires on Qualtrics

Page 1



Study ID: Please enter the unique study identifier that was given to you by the research team:

Age: What is your date of birth? (month/year)

Sex:

Male

Female

Other

Prefer not to respond

Education: What is the highest degree or level of school you have completed?
If currently enrolled, highest degree received.

Less than high school degree

High school degree or equivalent (e.g., GED)

Associate's degree or College diploma/certificate

Bachelor's degree

Graduate degree

Professional degree

Ethnicity: How do you self-identify regarding your ethnicity?

Aboriginal

African-Canadian/Caribbean

East Asian (e.g. Hong Kong, China, Vietnam, Korea)

Hispanic/Latino/a

Middle-Eastern or North African (e.g. Iran, Israel, Egypt, Morocco)

South Asian (e.g. India, Pakistan, Sri Lanka)

White

Other

Marital Status: What is your marital status?

Single, never married

In a relationship

Married or domestic partnership

Widowed

Divorced

Separated

Housing: Which of the following are applicable to your living situation?

Living alone

Living with roommate(s)

Living with relative(s)

Living with spouse/significant other

Other

Etiology: What is the cause of your amputation(s)?

Check all that apply

Accident/trauma

Cancer/tumor

Diabetes and/or vascular disease (e.g., infected ulcer, poor circulation)

Burns

Non-diabetic or vascular related infection

Other (please describe)



Page 2



Do you have any ongoing pain problems?

Yes

No



If the participant responds “Yes” to the question above, they will be directed to page 3 of the questionnaires. If they respond “No”, they will be directed to page 7 of the questionnaires.

Page 3

Please identify the area(s) where you experience these ongoing pain problems:

Check all that apply

Head/face

Neck

Back

Front torso

Right upper limb

Right lower limb

Left upper limb

Left lower limb



Page 4

For every area the participant identifies, they will be asked to respond to the following 4 questions. For instance, if the participant selected “Left upper limb” they would be asked the following:



What is the diagnosis or type of pain in your **left upper limb** ? (e.g., residual limb pain, phantom limb pain, arthritis, frozen shoulder)

How intense is the pain in your **left upper limb** on average?
(0 = No pain to 10 = Worst possible pain)

0 1 2 3 4 5 6 7 8 9 10

How long have you had the pain in your **left upper limb** ?

Less than 3 months

3 months - 6 months

6 months - 1 year

More than 1 year

How often do you experience pain in your *left upper limb* ?

Constantly

Daily

Weekly

Monthly



**ID Pain**

Mark 'Yes' to the following items that describe your overall pain experience over the past week and 'No' to the ones that do not.

	Yes	No
Did the pain feel like pins and needles?	☐	☐
Did the pain feel hot/burning?	☐	☐
Did the pain feel numb?	☐	☐
Did the pain feel like electrical shocks?	☐	☐
Is the pain made worst with the touch of clothing or bed sheets?	☐	☐
Is the pain limited to your joints?	☐	☐



**CPAQ-8**

Below you will find a list of statements. Please rate the truth of each statement as it applies to you.

1. I am getting on with the business of living no matter what my level of pain is.

Never true

Very rarely true

Seldom true

Sometimes true

Often true

Almost always true

Always true

2. Although things have changed, I am living a normal life despite my chronic pain.

Never true

Very rarely true

Seldom true

Sometimes true

Often true

Almost always true

Always true

3. I lead a full life even though I have chronic pain.

Never true

Very rarely true

Seldom true

Sometimes true

Often true

Almost always true

Always true

4. Keeping my pain level under control takes first priority whenever I'm doing something.

Never true

Very rarely true

Seldom true

Sometimes true

Often true

Almost always true

Always true

5. Before I can make any serious plans, I have to get some control over my pain.

Never true

Very rarely true

Seldom true

Sometimes true

Often true

Almost always true

Always true

6. When my pain increases, I can still take care of my responsibilities.

Never true

Very rarely true

Seldom true

Sometimes true

Often true

Almost always true

Always true

7. I avoid putting myself in situations where my pain might increase.

Never true

Very rarely true

Seldom true

Sometimes true

Often true

Almost always true

Always true

8. My worries and fears about what pain will do to me are true.

Never true

Very rarely true

Seldom true

Sometimes true

Often true

Almost always true

Always true



**BPI (SF)**

Mark the box below the number that describes how, during the past week, pain has interfered with your:

A. General activity

0 Does not Interfere	1	2	3	4	5	6	7	8	9	10 Completely Interferes
----------------------	---	---	---	---	---	---	---	---	---	--------------------------

B. Mood

0 Does not Interfere	1	2	3	4	5	6	7	8	9	10 Completely Interferes
----------------------	---	---	---	---	---	---	---	---	---	--------------------------

C. Walking ability

0 Does not Interfere	1	2	3	4	5	6	7	8	9	10 Completely Interferes
----------------------	---	---	---	---	---	---	---	---	---	--------------------------

D. Normal Work (includes both work outside the home and housework)

0 Does not Interfere	1	2	3	4	5	6	7	8	9	10 Completely Interferes
----------------------	---	---	---	---	---	---	---	---	---	--------------------------

E. Relations with other people

0 Does not Interfere	1	2	3	4	5	6	7	8	9	10 Completely Interferes
----------------------	---	---	---	---	---	---	---	---	---	--------------------------

F. Sleep

0 Does not Interfere	1	2	3	4	5	6	7	8	9	10 Completely Interferes
----------------------	---	---	---	---	---	---	---	---	---	--------------------------

G. Enjoyment of life

0 Does not Interfere	1	2	3	4	5	6	7	8	9	10 Completely Interferes
----------------------	---	---	---	---	---	---	---	---	---	--------------------------





PCS

Everyone experiences painful situations at some point in their lives. Such experiences may include headaches, tooth pain, joint or muscle pain. People are often exposed to situations that may cause pain such as illness, injury, dental procedures or surgery.

We are interested in the types of thoughts and feelings that you have when you are in pain. Listed below are four statements describing different thoughts and feelings that may be associated with pain. Please indicate the degree to which you have these thoughts and feelings when you are experiencing pain.

When I'm in pain...

	Not at all	To a slight degree	To a moderate degree	To a great degree	All the time
I keep thinking about how badly I want the pain to stop	☐	☐	☐	☐	☐
It's terrible and I think it's never going to get any better.	☐	☐	☐	☐	☐
I become afraid that the pain may get worse.	☐	☐	☐	☐	☐
I anxiously want the pain to go away.	☐	☐	☐	☐	☐





PHQ-4

Over the last week, how often have you been bothered by the following problems?

	Not at all	Several days	More than half the days	Nearly every day
Feeling nervous, anxious or on edge	☐	☐	☐	☐
Not being able to stop or control worrying	☐	☐	☐	☐
Feeling down, depressed or hopeless	☐	☐	☐	☐
Little interest or pleasure in doing things	☐	☐	☐	☐





LOT-R

Please answer the following questions about yourself by indicating the extent of your agreement. Be as honest and accurate as you can throughout. Try not to let your response to one statement influence your responses to other statements.

There are no 'correct' or 'incorrect' answers. Answer according to your own feelings, rather than how you think "most people" would answer.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
In uncertain times, I usually expect the best.	☐	☐	☐	☐	☐
It's easy for me to relax.	☐	☐	☐	☐	☐
If something can go wrong for me, it will.	☐	☐	☐	☐	☐
I'm always optimistic about my future.	☐	☐	☐	☐	☐
I enjoy my friends a lot.	☐	☐	☐	☐	☐

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
It's important for me to keep busy.	☐	☐	☐	☐	☐
I hardly ever expect things to go my way.	☐	☐	☐	☐	☐
I don't get upset too easily.	☐	☐	☐	☐	☐
I rarely count on good things happening to me.	☐	☐	☐	☐	☐
Overall, I expect more good things to happen to me than bad.	☐	☐	☐	☐	☐



**CD-RISC2**

Please indicate how much you agree with the following statements as they apply to you over the last week. If a particular situation has not occurred recently, answer according to how you think you would have felt.

	Not true at all	Rarely true	Sometimes true	Often true	True nearly all the time
I am able to adapt when changes occur.	☐	☐	☐	☐	☐
I tend to bounce back after illness, injury, or other hardships.	☐	☐	☐	☐	☐



Page 12



Please click on the link below to complete the final segment of the questionnaires.

The link will lead you to an online application where you will be required to enter the study identification code the research team has given you. Once entered, you will be permitted to respond to the last set of questions.

<http://phantomlimbs.ca>



Page 13

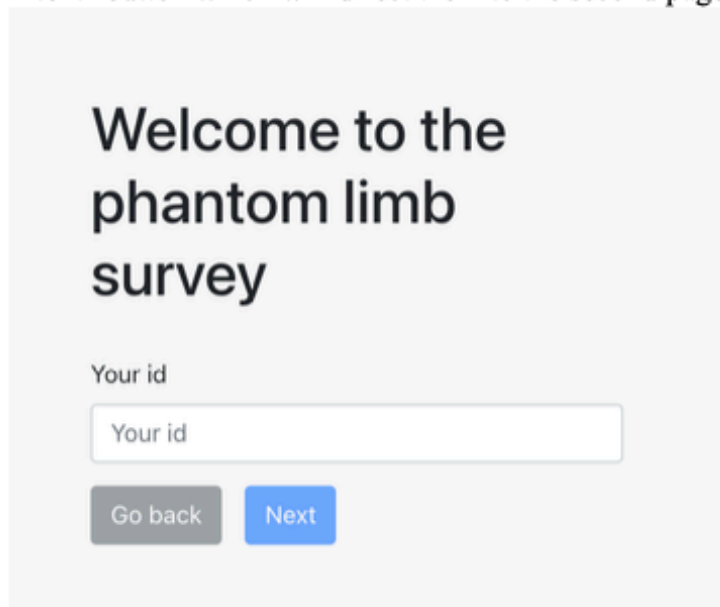


We thank you for your time spent taking this survey.
Your response has been recorded.

Section 2: Telescoping App

The Phantom Limb Survey (Computer Application)

The welcome page of the app asks the participant to enter their ID number and the date of their evaluation, as seen below. Once they have entered the required information, they can press on the “Next” button which will direct them to the second page.

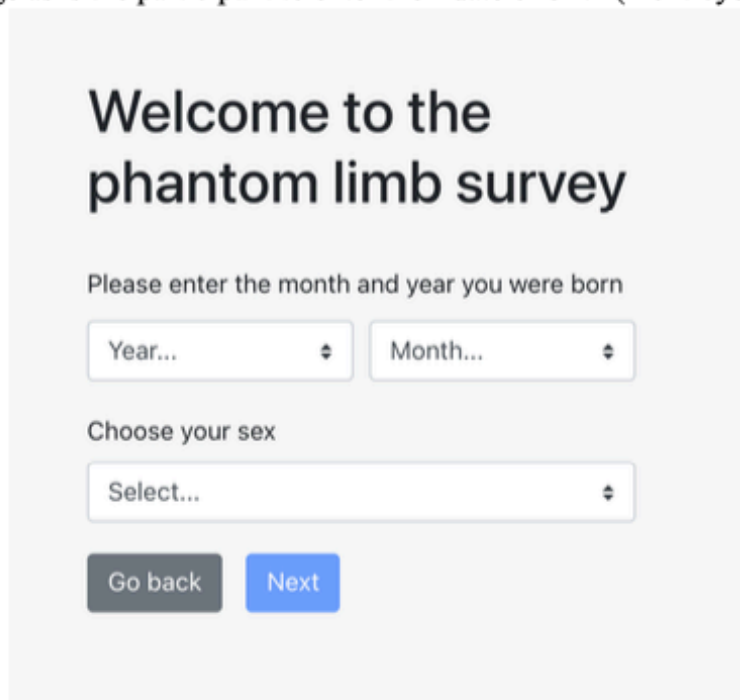


Welcome to the
phantom limb
survey

Your id

Go back Next

The second page asks the participant to enter their date of birth (month/year only) and sex.



Welcome to the
phantom limb survey

Please enter the month and year you were born

Year... Month...

Choose your sex

Select...

Go back Next

Once the participant has completed the first two pages, they are directed to one of four pages which asks if they have had an amputation on the: right upper limb, right lower limb, left upper limb, and/or left lower limb. The four different pages are illustrated below.

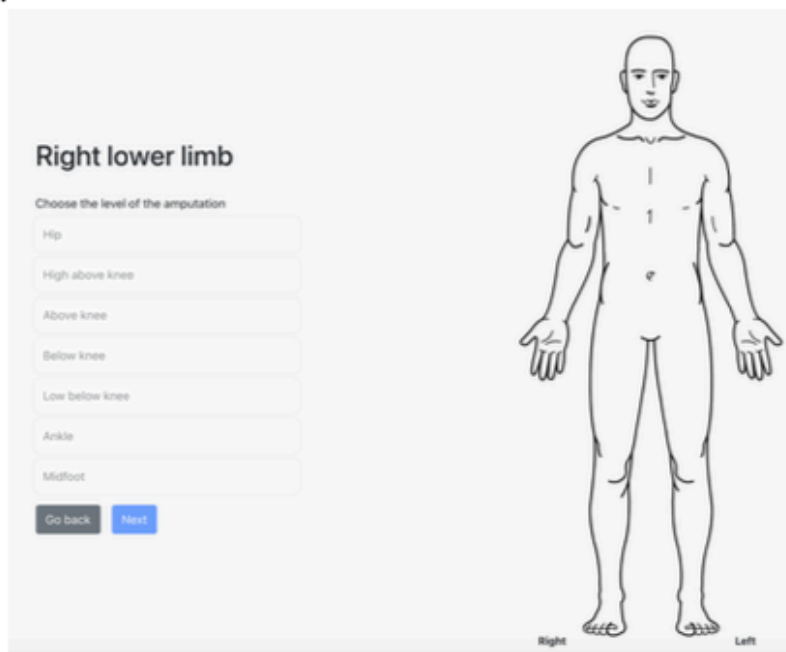
The figure displays four screenshots of a survey interface, each showing a human figure with a red box highlighting a specific limb. The interface includes a title, a question, a 'Yes'/'No' selection, and 'Go back'/'Next' buttons.

- Right upper limb:** The red box highlights the right arm. The question is "Do you have a right upper limb amputation?".
- Right lower limb:** The red box highlights the right leg. The question is "Do you have a right lower limb amputation?".
- Left upper limb:** The red box highlights the left arm. The question is "Do you have a left upper limb amputation?".
- Left lower limb:** The red box highlights the left leg. The question is "Do you have a left lower limb amputation?".

If the participant selects “YES” for a given limb, a question will appear which will ask the participant to enter the date of the amputation. For instance, if the participant identified that they had a right lower limb amputation, they will be asked to enter the date of the amputation, as seen below.

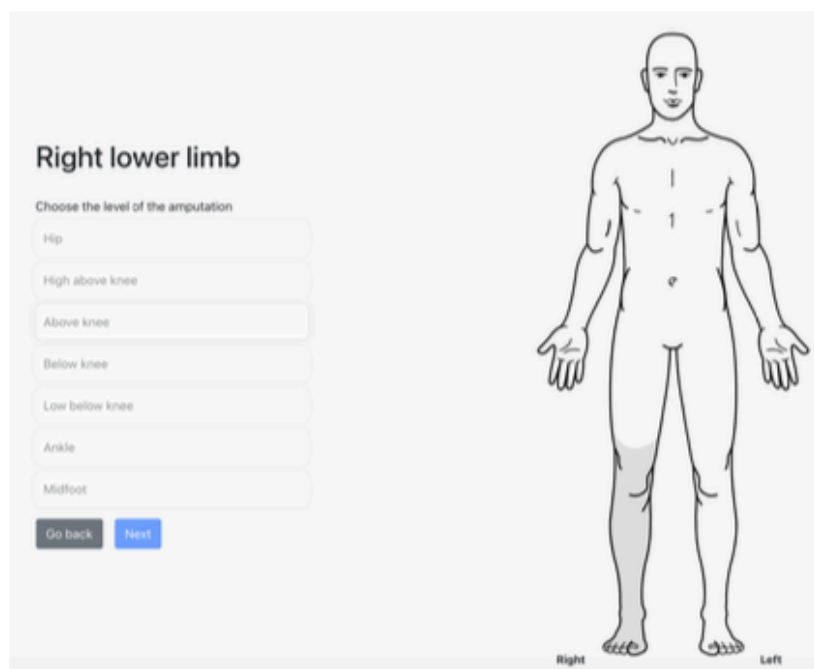
This screenshot shows the follow-up questions for a "Right lower limb" amputation. It includes a "Date of amputation" section with "Year" and "Month" dropdowns, and a "Choose the reason for amputation" section with a "Select..." dropdown. The "Yes" button is highlighted, indicating it has been selected.

Once the participant has entered the date of their amputation, they can click the “Next” button which will direct them to a page that allows them to select the level of amputation on that limb.



The screenshot shows a web interface for selecting the level of amputation for the right lower limb. On the left, under the heading "Right lower limb", is the instruction "Choose the level of the amputation". Below this are eight radio button options: Hip, High above knee, Above knee, Below knee, Low below knee, Ankle, Midfoot, and a "Go back" button. To the right of the options is a blue "Next" button. On the right side of the interface is a line drawing of a human figure. The right leg is shaded from the hip down to the ankle, indicating the selected amputation level. The feet are labeled "Right" and "Left" at the bottom.

The illustration then shades the limb to allow the participant to visually compare where their limb has been amputated, as demonstrated below.



This screenshot is identical to the one above, showing the "Right lower limb" amputation level selection interface. The radio button for "Below knee" is selected, and the right leg of the human figure illustration is shaded from the hip down to the ankle, visually representing the chosen amputation level. The "Go back" and "Next" buttons are present at the bottom of the option list.

Once a level of amputation has been chosen, the participant is asked if they have experienced residual limb pain several times a week or more over the past 3 months. If

they respond “YES”, they are asked to rate their pain from 0 (no pain) to 10 (worst possible pain), as seen below.

Right lower limb

Over the past 3 months, have you had residual limb pain several times a week or more?

☐ Yes ☐ No

[Go back](#) [Next](#)

Right lower limb

Over the past 3 months, have you had residual limb pain several times a week or more?

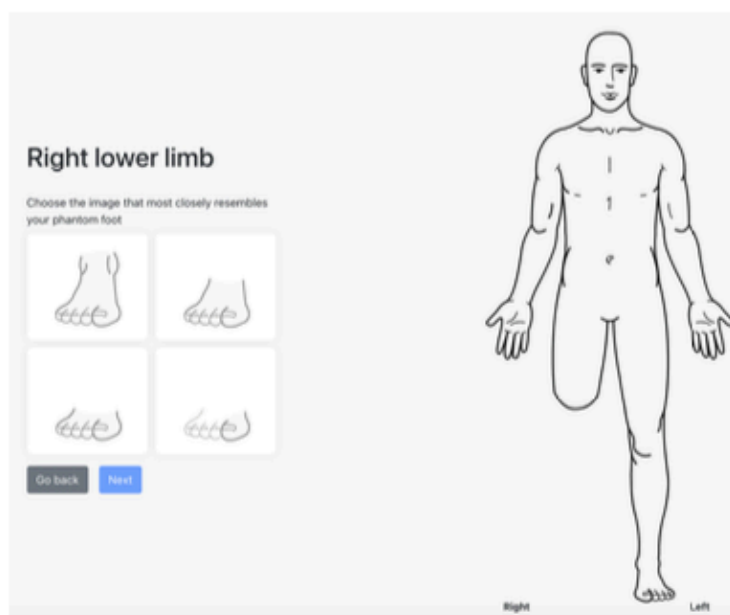
☒ Yes ☐ No

How intense is it on average?
(0 = No pain to 10 = Worst possible pain)

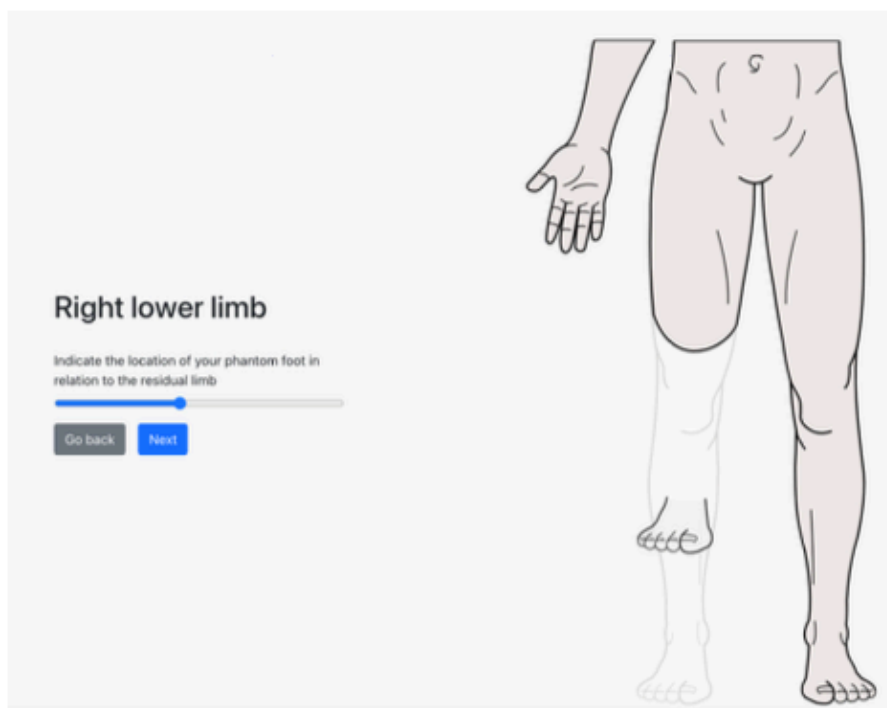
0

[Go back](#) [Next](#)

Participants are then asked to choose a foot (or hand if an upper limb has been identified) which best represents their phantom, as illustrated here.



The participant can then position the foot (or hand) where they usually feel it, in relation to their residual limb, using the slider, as shown here.



Once its position has been chosen, the participant will click on the “Next” button and be asked if they experience phantom limb pain. If they select “YES”, they will be asked to rate their phantom limb pain from 0 (no pain) to 10 (worst possible pain), as shown below.

The image displays two sequential screenshots of a web-based survey form for phantom limb pain assessment, specifically for the right lower limb. Both screenshots feature a line drawing of a human figure with the right lower limb highlighted in pink. The text on the left side of the form is as follows:

Right lower limb

Over the past 3 months, have you had phantom limb pain several times a week or more?

Yes No

Go back Next

The top screenshot shows the initial question with the 'Next' button highlighted in blue. The bottom screenshot shows the 'Yes' button highlighted in blue, indicating a selection. Below the 'Yes' button, the form asks: 'How intense is it on average? (0 = No pain to 10 = Worst possible pain)'. A horizontal slider is visible with a blue dot at the 0 position, and the number '0' is displayed below the slider. The 'Next' button remains highlighted in blue.

Once all questions have been answered, the participant is directed to a page which thanks them for completing the survey.

Section 3: Recruitment Materials

Version October 29, 2021 – APPENDIX A



Post-amputation Phantom Limb Survey

Did you undergo an upper and/or lower limb amputation more than 3 months ago?

Are you interested in sharing how you experience a phantom limb?

If so, we would like you to participate

Researchers from York University and St. John's Rehab are currently looking for individuals to participate in research that examines pain and phantom limbs in people who have undergone limb amputation.

Eligible participants must be fluent in English and have had an upper and/or lower limb amputated more than 3 months ago.

As a participant in this research, you will be asked to respond to online questionnaires and complete an optional interview over the phone or via Zoom. Questions will be related to your phantom limb experience after amputation. They will take a maximum of 40 minutes to complete.

Findings from this research are expected to help contribute to a better understanding of persistent post-amputation pain and how people experience a phantom limb.

If you think you may be interested in participating in this research, please contact us without any obligation.

CONTACT: Andrea Aternali EMAIL: pain@yorku.ca PHONE: (416) 736-2100 ext. 33125

Principal Investigator: Dr. Sander Hitzig, PhD, Sunnybrook Research Institute, St. John's Rehab Research Program

[illegible]

Version October 29, 2021 - APPENDIX A2

Social media flyer (image file)



Post-amputation Phantom Limb Survey

Did you undergo an upper and/or lower limb amputation more than 3 months ago?

Are you interested in sharing how you experience a phantom limb?

If so, we would like you to participate

As a participant in this research, you will be asked to respond to online questionnaires and complete an optional interview over the phone or via Zoom. Questions will be related to your phantom limb experience after amputation. They will take a maximum of 40 minutes to complete.

If you think you may be interested in participating in this research, please contact us without any obligation.

CONTACT: Andrea Aternali **EMAIL:** pain@yorku.ca **PHONE:** (416) 736-2100 ext. 33125

Principal Investigator: Dr. Sander Hitzig, PhD, Sunnybrook Research Institute, St. John's Rehab Research Program

Tweet wording: Do you have phantom limb pain due to limb loss? We would like to learn more, please see the embedded flyer.

Section 4: Consent Forms

Survey consent form



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ONLINE INFORMED CONSENT TO PARTICIPATE IN A RESEARCH STUDY

Full Study Title: Post-amputation Phantom Limb Survey

Principal Investigator: Sander L. Hitzig, PhD, St. John's Rehab, Sunnybrook Health Sciences Centre, 416-226-6780 ext. 7177

Funder: Not applicable

INFORMED CONSENT

You are being asked to consider participating in a research study. A research study is a way of gathering information on a treatment, procedure or medical device or to answer a question about something that is not well understood.

This form explains the purpose of this research study, provides information about the study procedures, possible risks and benefits, and the rights of participants.

Please read this form carefully and ask any questions you may have. You may have a copy of this form sent to you electronically and all information concerning the study explained to you. You may take as much time as you wish to decide whether or not to participate. Please ask the study staff or one of the investigator(s) to clarify anything you do not understand or would like to know more about. Make sure all your questions are answered to your satisfaction before deciding whether to participate in this research study.

Participating in this study is your choice (voluntary). You have the right to choose not to participate, or to stop participating in this study at any time.

INTRODUCTION

You are being asked to consider participating in this study because you have had an upper and/or lower limb amputated more than 3 months ago.

More than 50% of people who have undergone limb amputation report significant levels of residual (lasting) limb pain and/or phantom limb pain even years after amputation. There is a lack of effective treatments in treating post-amputation pain. The development of interventions for reducing phantom limb and residual limb pain requires more knowledge on what factors influences recovery (e.g., age, sex, type of amputation, coping styles, etc.). To better understand how people are experiencing pain after amputation, we would like to have individuals who have had a limb amputated at least over 3 months ago to complete a series of questionnaires so that they can share their insights about their phantom limb(s) and how much pain (if any) they are experiencing. We hope that this research will be beneficial by helping to better explain how people are describing and coping with their pain, which could be used to develop effective interventions that reduce post-amputation pain.

WHY IS THIS STUDY BEING DONE?

This study is a collaboration between St. John's Rehab Research Program and the Psychology department at York University. The purpose of this study is to better understand the factors that contribute to the development of post-amputation pain. We will be exploring how age, sex, time since the amputation, qualities of the phantom limb (e.g., how it is experienced), and psychological features (e.g., coping styles) contribute to level of post-amputation pain.

WHAT WILL HAPPEN DURING THIS STUDY?

To participate in this online study, you will have been sent an email with instructions about this online document which provides you with information on how to give consent and complete the questionnaires.

After reading this online informed consent document, you can click on the buttons below indicating if you would like to participate in the study or not. If you click on the 'I NEITHER AGREE NOR CONSENT', then you will not take part in the study and we thank you for your time and consideration.

If you click on the 'I AGREE AND CONSENT' button below, you will be taken to an online site where you can respond to the questions to complete the study. There will be instructions provided throughout the process of completing the questionnaires. The questionnaires will ask you about your background (date of birth, sex, etc.), amputation(s) (date of amputation, location of amputation, etc.), if you have pain and the level of pain intensity you typically experience, and the way you cope with life and with your pain. The surveys will take approximately 45 minutes of your time to complete.

If you are unsure of how you would like to proceed or would like more information, please send an email to Ms. Andrea Aternali, study coordinator, at: pain@yorku.ca or by phone at: (416) 736-2100 ext. 33125. The study coordinator will then follow-up with you to provide you with more information about the study.

HOW MANY PEOPLE WILL TAKE PART IN THIS STUDY?

It is anticipated that 500 people will participate in this study from around the world. The entire study is expected to take about one year to complete and the results should be known in 2 years.

ELIGIBILITY TO PARTICIPATE

To participate in this study, you must be:

- An adult (18 years or older);
- Fluent in English;
- Have had an upper and/or lower limb amputated more than 3 months ago.

If you are younger than 18 years of age, have not undergone an amputation at least 3 months ago, cannot read or understand English, or if you have a cognitive issue (e.g., dementia, psychotic

disorder, etc.) that would impair your ability to participate in this study, you are not eligible to participate.

WHAT ARE THE RESPONSIBILITIES OF STUDY PARTICIPANTS?

If you decide to participate in this study:

- 1) the study procedures will be explained to you so that you understand what is involved in participating
- 2) you will be asked to give your informed consent to participate
- 3) you will fill out questionnaires online, which take approximately 45 minutes to complete. The questionnaires deal with:
 - a. Age, sex, and limb, side, and date of amputation(s)
 - b. Intensity of any residual and/or phantom limb pain, pain quality, and how you feel about any pain you have
 - c. the qualities of any phantom limb sensations you may feel
 - d. your mood and other aspects of how you have been feeling over the past week

WHAT ARE THE RISKS OR HARMS OF PARTICIPATING IN THIS STUDY?

There are no medical risks to you from participating in this study, but you may feel uncomfortable answering questions related to your experiences living with your amputated limb. You may refuse to answer questions or stop your participation at any time if you experience any discomfort. You will be told about any new information that might reasonably affect your willingness to continue to participate in this study as soon as the information becomes available to the study staff.

WHAT ARE THE BENEFITS OF PARTICIPATING IN THIS STUDY?

In terms of benefits, the findings from this work are anticipated to provide a better understanding of how people with amputations experience and cope with their pain, which might contribute to the development of interventions for reducing phantom and residual limb pain.

CAN PARTICIPATION IN THIS STUDY END EARLY?

The investigators may decide to remove you from this study without your consent for any of the following reasons:

- You are unable or unwilling to follow the study procedures.

If you are removed from this study, the research staff will discuss the reasons with you. You can also choose to end your participation at any time without having to provide a reason. If you choose to withdraw, your choice will not have any effect on your current or future medical treatment or healthcare at Sunnybrook Health Sciences Centre, including St. John's Rehab.



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WHAT ARE THE COSTS OF PARTICIPATING IN THIS STUDY?

Participation in this study will not involve any additional costs to you.

ARE STUDY PARTICIPANTS PAID TO PARTICIPATE IN THIS STUDY?

If you agree to participate in this study, you will be provided an electronic gift card to Starbucks to the amount of \$25 CAD. The gift card information will be sent to you via email once you have agreed to participate in the study by selecting the "Agree and Consent" box at the end of this consent form. Compensation will still be provided in the event you choose to withdraw without completing all study components.

HOW WILL MY INFORMATION BE KEPT CONFIDENTIAL?

You have the right to have any information about you and your health that is collected, used or disclosed for this study to be handled in a confidential manner.

If you decide to participate in this study, the investigator(s) and study staff collect only the information they need for this study. Personal information is information about you that could identify you because it includes information such as your;

- name,
- address,
- telephone number,
- date of birth, or
- current condition (e.g. amputation)

You have the right to access, review and request changes to your personal health information.

The following people may come to the hospital to look at your personal information to check that the information collected for the study is correct and to make sure the study followed the required laws and guidelines:

- Representatives of the Sunnybrook Research Institute, Sunnybrook Health Sciences Centre or the Sunnybrook Research Ethics Board, because they oversee the ethical conduct of research studies at Sunnybrook.

Access to your personal health information will take place under the supervision of the Principal Investigator.

Please note that this study is a collaboration between St. John's Rehab Research Program and York University, which has implications on how the study data will be managed. "Study data" is information about you that is collected for the study, but that does not directly identify you.

Your responses to the online questionnaires is being collected by a system called *Qualtrics*, which is a secure data platform. This data will be de-identified (only using an ID number to refer to it, only asking for month and year of birth, etc.). All de-identified study data will be stored in an encrypted password-protected folder on York University computers accessible only to the research team. Data with personal information (e.g., name and phone number) will be stored in

an encrypted password-protected folder separate from the de-identified data and accessible only to the research team. All participants who consent to participate will be given a unique identifier to maintain their anonymity in the study. Any study data about you that is sent outside of your rehabilitation hospital will have a code and will not contain your name or address, or any information that directly identified you. Study data that is sent outside of the hospital will be used for the research purposes explained in this consent form.

The investigator(s), study staff and the other people listed above will keep the information they see or receive about you confidential, to the extent permitted by applicable laws. Even though the risk of identifying you from the study data is very small, it can never be completely eliminated.

The Principal Investigator will keep any personal information about you in a secure and confidential location for 10 years and then destroy it according to Sunnybrook policy.

When the results of this study are published, your identity will not be disclosed.

You have the right to be informed of the results of this study once the entire study is complete. If you would like to be informed of the results of this study, please contact Sander L. Hitzig at 416-226-6780 ext. 7177 or by email at sander.hitzig@sunnybrook.ca.

INTERVIEW PARTICIPATION

We are also asking people if they would be interested in undergoing an additional and optional interview about your phantom limb. Based on responses to the online questionnaires and surveys, we may invite you to share your insights about living with an amputation and to provide some details about your phantom limb and/or pain to gain a more in-depth understanding of your experience. Interview questions deal with:

- a. the qualities of any phantom limb sensations you may feel
- b. how phantom limb sensations first manifested, your initial reactions, your experiences with it, and how it has influenced your wellbeing.

The interview will take approximately 60 minutes at most to complete and will be audio recorded. It can be done over the phone or via secure videoconferencing (Zoom). A separate informed consent process will be required for this part of the study. You will receive a \$25 CAD electronic gift card to Starbucks if you choose to complete the optional interview and you meet inclusion criteria, which is determined by your questionnaire and survey responses. If you agree to learning more about this interview, the study coordinator will follow-up with you about this part of the study.

If you do not consent to this interview you may indicate as such at the end of this page.

PARTICIPATION TO FUTURE STUDIES



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You have the option to include your name in a database that will be used to contact participants for future research studies. If you agree, your contact information, age, sex, and a brief description of your condition (if applicable) will be entered and stored in our laboratory. Please note that this disclosure is entirely voluntary, and declining to do so will not cause any consequences. You may at any time ask for your name and contact information to be removed from this database. If you do not consent to this process you may indicate as such at the end of this page.

ARE THERE ANY CONFLICTS OF INTEREST/RELATIONSHIPS?

There are no conflicts of interest to declare related to this study.

WHAT ARE THE RIGHTS OF PARTICIPANTS IN A RESEARCH STUDY?

You have the right to receive all information that could help you make a decision about participating in this study. You also have the right to ask questions about this study and your rights as a research participant, and to have them answered to your satisfaction, before you make any decision. You also have the right to ask questions and to receive answers throughout this study.

If you have any questions about this study you may contact the person in charge of this study, Sander L. Hitzig, St. John's Rehab, Sunnybrook Health Sciences Centre, 416-226-6780 ext. 7177.

If you have questions about your rights as a research participant or any ethical issues related to this study that you wish to discuss with someone not directly involved with the study, you may call the **Chair of the Sunnybrook Research Ethics Board at (416) 480-6100 ext. 88144.**

DOCUMENTATION OF INFORMED CONSENT

Full Study Title: Post-amputation Phantom Limb Survey

By checking the "AGREE AND CONSENT" box below, I confirm that:

- This research study has been fully explained to me and all of my questions answered to my satisfaction
- I understand the requirements of participating in this research study
- I have been informed of the risks and benefits, if any, of participating in this research study
- I have been informed of any alternatives to participating in this research study
- I have been informed of the rights of research participants
- I have read each page of this form
- I authorize access to my personal information, and research study data as explained in this form

I AGREE AND CONSENT

I NEITHER AGREE NOR CONSENT

INTERVIEW PARTICIPATION

I am INTERESTED in completing the optional interview for the purposes of this research project.

I am NOT INTERESTED in completing the optional interview for the purposes of this research project.

PARTICIPATION TO FUTURE STUDIES

I AGREE AND CONSENT to have my contact information used by the principal investigator in order to be contacted about other research projects.

I NEITHER AGREE NOR CONSENT to have my contact information used by the principal investigator in order to be contacted about other research projects.

Interview consent form



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INFORMED CONSENT TO PARTICIPATE IN A RESEARCH STUDY

Full Study Title: Post-amputation Phantom Limb Survey

Principal Investigator: Sander L. Hitzig, PhD, St. John's Rehab, Sunnybrook Health Sciences Centre, 416-226-6780 ext. 7177

Funder: Dr. Joel Katz's Canada Research Chair

INFORMED CONSENT

You are being asked to consider participating in a research study. A research study is a way of gathering information on a treatment, procedure or medical device or to answer a question about something that is not well understood.

This form explains the purpose of this research study, provides information about the study procedures, possible risks and benefits, and the rights of participants.

Please read this form carefully and ask any questions you may have. You may have this form and all information concerning the study explained to you. You may take as much time as you wish to decide whether or not to participate. Please ask the study staff or one of the investigator(s) to clarify anything you do not understand or would like to know more about. Make sure all your questions are answered to your satisfaction before deciding whether to participate in this research study.

Participating in this study is your choice (voluntary). You have the right to choose not to participate, or to stop participating in this study at any time.

INTRODUCTION

More than 50% of people who have undergone limb amputation report significant levels of residual (lasting) limb pain and/or phantom limb pain even years after amputation. Phantom limb pain is defined by pain that feels like it is coming from a body part that is no longer there. There is a lack of effective treatments in treating post-amputation pain. The development of interventions for reducing phantom limb and residual limb pain requires more knowledge on what factors influences recovery (e.g., age, sex, type of amputation, coping styles, etc.). To better understand how people are experiencing pain after amputation, we would like to have individuals who have had a limb amputated at least over 3 months ago to complete a series of questionnaires so that they can share their insights about their phantom limb(s) and how much pain (if any) they are experiencing. We hope that this research will be beneficial by helping to better describe how people are describing and coping with their pain, which could be used to develop effective interventions that reduce post-amputation pain.

WHY IS THIS STUDY BEING DONE?

This study is a collaboration between St. John's Rehab Research Program and the Psychology department at York University. The purpose of this study is to better understand the factors that contribute to the development of post-amputation pain. We will be exploring how age, sex, time since the amputation, qualities of the phantom limb (e.g., how it is experienced), and psychological features (e.g., coping styles) contribute to level of post-amputation pain.

WHAT WILL HAPPEN DURING THIS STUDY?

You are being asked to participate in this interview study because you completed a series of online questionnaires about your amputation and phantom limb pain. To gain a more in-depth understanding about these issues, we would like you to share your insights about living with an amputation and to provide some details about your phantom limb and/or pain. For instance, you will be asked if you have ever experienced 'telescoping' of the phantom limb. Phantom limb 'telescoping' is described as the feeling of your phantom limb gradually shortening over time. You may choose to do this interview either in person at St. John's Rehab or over the phone. The length of this study for participants is approximately 30 minutes. The interviews will be audio recorded and will be used to create an anonymized, printed transcript that will be analyzed by the investigators. Anonymized means that it will not contain any identifying information about you.

If you prefer to participate in person, a time will be scheduled for you to sign the consent form and complete the interview at St. John's Rehab. If your preference is to participate over the phone, you will be sent an envelope containing a consent form and stamped return envelope. Once the research team has received the signed consent form, a time will be scheduled to complete the interview.

HOW MANY PEOPLE WILL TAKE PART IN THIS STUDY?

It is anticipated that up to 200 people will participate in this study from various rehabilitation centres throughout the Greater Toronto Area. The entire study is expected to take about one year to complete and the results should be known in 2 years.

To participate in this study, you must be:

- An adult (18 years or older);
- Fluent in English;
- Have had an upper and/or lower limb amputated more than 3 months ago;

If you are younger than 18 years of age, have not undergone an amputation at least 3 months ago, cannot read or understand English, or if you have a cognitive issue (e.g., dementia, psychotic disorder, etc.) that would impair your ability to participate in this study, you are not eligible to participate.

WHAT ARE THE RESPONSIBILITIES OF STUDY PARTICIPANTS?

If you decide to participate in the interview segment of this study:

- 1) the study procedures will be explained to you so that you understand what is involved in participating
- 2) you will be asked to give your informed consent to participate
- 3) you will be interviewed, which take approximately 30 minutes to complete, either at St. John's Rehab or by phone. The interview will be audio recorded. The interview questions deal with:
 - a. the qualities of any phantom limb sensations you may feel
 - b. how phantom limb sensations first manifested, your initial reactions, your experiences with it, and how it has influenced your wellbeing

WHAT ARE THE RISKS OR HARMS OF PARTICIPATING IN THIS STUDY?

There are no medical risks to you from participating in this study, but you may feel uncomfortable answering questions related to your experiences living with your amputated limb. You may refuse to answer questions or stop your participation at any time if you experience any discomfort.

WHAT ARE THE BENEFITS OF PARTICIPATING IN THIS STUDY?

You will not benefit directly from participating in this study. The findings from this work are anticipated to provide a better understanding of how people with amputation experience and cope with their pain, which might contribute to the development of interventions for reducing phantom and residual limb pain.

CAN PARTICIPATION IN THIS STUDY END EARLY?

The investigators may decide to remove you from this study without your consent for any of the following reasons:

- You are unable or unwilling to follow the study procedures.

If you are removed from this study, the research staff will discuss the reasons with you. You can also choose to end your participation at any time without having to provide a reason. If you choose to withdraw, your choice will not have any effect on your current or future medical treatment or health care.

WHAT ARE THE COSTS OF PARTICIPATING IN THIS STUDY?

Participation in this study will not involve any additional costs to you.

ARE STUDY PARTICIPANTS PAID TO PARTICIPATE IN THIS STUDY?

You will not be paid to participate in this study.

HOW WILL MY INFORMATION BE KEPT CONFIDENTIAL?



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You have the right to have any information about you and your health that is collected, used or disclosed for this study to be handled in a confidential manner.

If you decide to participate in this study, the investigator(s) and study staff collect only the information they need for this study. Personal information is information about you that could identify you because it includes information such as your;

- name,
- address,
- telephone number,
- age, or
- current condition (e.g. amputation)

You have the right to access, review and request changes to your personal health information.

The following people may come to the hospital to look at your personal information to check that the information collected for the study is correct and to make sure the study followed the required laws and guidelines:

- Representatives of the Sunnybrook Research Institute, Sunnybrook Health Sciences Centre or the Sunnybrook Research Ethics Board, because they oversee the ethical conduct of research studies at Sunnybrook.

Access to your personal health information will take place under the supervision of the Principal Investigator.

“Study data” is information about you that is collected for the study, but that does not directly identify you. All de-identified study data will be stored in an encrypted password-protected folder on York University computers accessible only to the research team. Data with personal information (e.g., signed informed consent sheets, recording of interviews) will be locked in a locked filing cabinet at St. John’s Rehab and data will be stored on the research network server at the hospital. These are all secure venues that are accessible only to the research team. Interview recordings will be deleted once they have been transcribed and de-identified via a unique numeric identifier. All participants who consent to participate will be given a unique identifier to maintain their anonymity in the study. Any study data about you that is sent outside of your rehabilitation hospital will have a code and will not contain your name or address, or any information that directly identified you. Study data that is sent outside of the hospital will be used for the research purposes explained in this consent form.

The investigator(s), study staff and the other people listed above will keep the information they see or receive about you confidential, to the extent permitted by applicable laws. Even though the risk of identifying you from the study data is very small, it can never be completely eliminated.



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The Principal Investigator will keep any personal information about you in a secure and confidential location for 10 years and then destroy it according to Sunnybrook policy.

When the results of this study are published, your identity will not be disclosed.

You have the right to be informed of the results of this study once the entire study is complete. If you would like to be informed of the results of this study, please contact Sander L. Hitzig at 416-226-6780 ext. 7177 or by email at sander.hitzig@sunnybrook.ca.

ARE THERE ANY CONFLICTS OF INTEREST/RELATIONSHIPS?

There are no conflicts of interest to declare related to this study.

WHAT ARE THE RIGHTS OF PARTICIPANTS IN A RESEARCH STUDY?

You have the right to receive all information that could help you make a decision about participating in this study. You also have the right to ask questions about this study and your rights as a research participant, and to have them answered to your satisfaction, before you make any decision. You also have the right to ask questions and to receive answers throughout this study.

If you have any questions about this study you may contact the person in charge of this study, Sander L. Hitzig, St. John's Rehab, Sunnybrook Health Sciences Centre, 416-226-6780 ext. 7177.

If you have questions about your rights as a research participant or any ethical issues related to this study that you wish to discuss with someone not directly involved with the study, you may call the **Chair of the Sunnybrook Research Ethics Board at (416) 480-6100 ext. 88144.**

By signing this consent form, you do not give up any of your legal rights.



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DOCUMENTATION OF INFORMED CONSENT

You will be given a copy of this informed consent form after it has been signed and dated by you and the study staff.

Full Study Title: Post-amputation Phantom and Residual Limb Pain

Name of Participant _____

Participant

By signing this form, I confirm that:

- This research study has been fully explained to me and all of my questions answered to my satisfaction
- I understand the requirements of participating in this research study
- I have been informed of the risks and benefits, if any, of participating in this research study
- I have been informed of any alternatives to participating in this research study
- I have been informed of the rights of research participants
- I have read each page of this form
- I authorize access to my personal information, and research study data as explained in this form

_____ Name of participant (Print)	_____ Signature	_____ Date
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Person obtaining consent

By signing this form, I confirm that:

- This study and its purpose has been explained to the participant named above
- All questions asked by the participant have been answered
- I will give a copy of this signed and dated document to the participant

_____ Name of person obtaining consent (Print)	_____ Signature	_____ Date
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Interview consent form (virtual interviews)

Version March 7, 2023 – Appendix G

Script for Obtaining Verbal Consent to Optional Interview

Thank you for considering to participate in our research study. The online consent form you completed prior to this optional interview provided information about the study, possible risks and benefits, and the rights of participants. I'm going to go over this information once again. If you have any questions, please feel free to interrupt me and ask. You may take as much time as you wish to decide whether or not to participate. Participating in this study is completely voluntary. You have the right to choose not to participate, or to stop participating in this study at any time.

You are being asked to participate in this interview study because you completed a series of online questionnaires about your amputation and phantom limb pain. To gain a more in-depth understanding about these issues, we would like you to share your insights about living with an amputation and to provide some details about your phantom limb and/or pain. The duration of this study for participants will be no longer than 60 minutes.

There are no medical risks to you from participating in this study, but you may feel uncomfortable answering questions related to your experiences living with an amputation. You may refuse to answer questions or stop participating at any time.

In terms of benefits, the findings from this work are anticipated to provide a better understanding of how people experience and cope with their pain after an amputation, which might contribute to the development of interventions for reducing phantom and residual limb pain.

Participation in this study will not involve any additional costs to you. If you agree to participate in this study, you will receive a \$25 CAD electronic gift card to Starbucks to compensate you for your time. The gift card information will be sent to you via email once you have agreed to participate in the study by saying "I agree to participate in this study" at the end of this consent process. Compensation will still be provided in the event you choose to withdraw without completing the entire interview.

The interview will be recorded. Interview recordings will be deleted once they have been transcribed and de-identified via a unique numeric identifier.

The Principal Investigator will keep any personal information about you in a secure and confidential location for 10 years and then destroy it according to Sunnybrook policy.

You have the right to receive all information that could help you make a decision about participating in this study. You also have the right to ask questions about this study and your rights as a research participant, and to have them answered to your satisfaction, before you make any decision. You also have the right to ask questions and to receive answers throughout this study.

If you have any questions about this study you may contact the person in charge of this study, Sander L. Hitzig, St. John's Rehab, Sunnybrook Health Sciences Centre, 416-226-6780

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ext. 7177. If you have questions about your rights as a research participant or any ethical issues related to this study that you wish to discuss with someone not directly involved with the study, you may call the Chair of the Sunnybrook Research Ethics Board at (416) 480-6100 ext. 88144.

By saying “I agree to participate in this study”

You confirm that:

- This research study has been fully explained to you and all of your questions answered to your satisfaction
- You understand the requirements of participating in this research study
- You have been informed of the risks and benefits, if any, of participating in this research study
- You have been informed of any alternatives to participating in this research study
- You have been informed of the rights of research participants
- You authorize access to my personal information, and research study data

Section 5. Research Ethics Board Approvals

Research ethics board approval from Sunnybrook Health Sciences Centre



To: Dr. Sander Hitzig
From: Dr. Brian Murray
Date: 07/Mar/2025
Subject: Post-Amputation Phantom Limb Survey
Submission: Continuing Review

Project Identification Number: 3071

The Research Ethics Board is in receipt of your Continuing Review submission form pertaining to the above referenced study. REB members involved in the research study or who have declared a conflict do not participate in the review, discussion or decision.

A delegated review has been conducted and the study has been approved until **March 14, 2026**.

This study may continue at Sunnybrook Health Sciences Centre.

During the course of the research, any significant deviations from the approved protocol and/ or any unanticipated developments must be brought to the attention of the Research Ethics Board.

Please also note that it is the responsibility of the Principal Investigator to ensure that the study protocol and consent form(s) conform to current research guidelines and regulations. If updates to the protocol and/or consent form(s) are needed, please submit an amendment to the REB.

Thank you for keeping the Board informed.

A handwritten signature in black ink, appearing to read "B. Murray".

Brian J. Murray, MD FRCPC FAAN D, ABSM
 Chair, Research Ethics Board

The Research Ethics Board of Sunnybrook Health Sciences Centre Operates in Compliance with the Tri-Council Policy Statement 2nd edition, ICH GCP Guidelines, Part C Division 5 of the Food and Drug Regulations, Part C Division 3 of the Food and Drug Regulations, Part 4 of the Natural Health Products Regulations, Part 3 of the Medical Devices Regulations, and the Provisions of PHIPA 2004 and its applicable regulations. The Sunnybrook Research Ethics Board is registered with the U.S. Department of Health and Human Services (DHHS) Office for Human Research Protection (OHRP). All Health Canada regulated trials at Sunnybrook are conducted by a Qualified Investigator.

Fully affiliated with the University of Toronto

Approval from York University Office of Research Ethics



OFFICE OF RESEARCH ETHICS (ORE)

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ore@yorku.ca
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Certificate #:	e2019-138
Initial Approval:	04/22/19-04/22/20
Amendments:	05/15/19, 07/17/19, 03/15/21, 12/06/21 03/21/22, 03/24/23
Renewals:	01/13/21 - 03/14/21 03/14/21 - 03/14/22 03/21/22-03/21/23 03/24/23-03/24/24 02/22/24-02/22/25 03/14/25-03/14/26
Current Approval Period:	03/14/25-03/14/26

ETHICS RENEWAL

To: Professor Joel Katz
Department of Psychology
Faculty of Health
jkatze@yorku.ca

From: Alison M. Collins-Mrakas, Director, Research Ethics
(on behalf of Gillian Parekh, Chair, Human Participants Review Committee)

Date: Friday, March 14, 2025

Title: Post-amputation Phantom Limb Survey

Risk Level: ☒ Minimal Risk ☐ More than Minimal Risk

Level of Review: ☒ Delegated Review ☐ Full Committee Review

I am writing to inform you that this research project, "Post-amputation Phantom Limb Survey" has received ethics review and renewal by the Human Participants Review Sub-Committee, York University's Ethics Review Board and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines.

Note that renewal is granted for one year. Ongoing research – research that extends beyond one year – must be renewed prior to the expiry date.

Any changes to the approved protocol must be reviewed and approved through the amendment process by submission of an amendment application to the HPRC prior to its implementation.

Any adverse or unanticipated events in the research should be reported to the Office of Research ethics (ore@yorku.ca) as soon as possible.

For further information on researcher responsibilities as it pertains to this approved research ethics protocol, please refer to the attached document, "RESEARCH ETHICS: PROCEDURES to ENSURE ONGOING COMPLIANCE".

Should you have any questions, please feel free to contact me at: ore@yorku.ca

Yours sincerely,

Alison M. Collins-Mrakas M.Sc., LL.M.
Director, Office of Research Ethics