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Research paper

Exploring phantom phenomena following brachial plexus block in intact limbs

Emily Pettersen [a,b,*], Giacomo Valle [b], Paolo Sassu [c], Carina Reinholdt [a,d], Max Ortiz-Catalan [e,f]

[a] Center for Advanced Reconstruction of Extremities, Sahlgrenska University Hospital, Mölndal, Sweden
[b] Department of Electrical Engineering, Chalmers University of Technology, Gothenburg, Sweden
[c] IV Clinica Ortoplastica, IRCCS Istituto Ortopedico Rizzoli, Bologna, Italy
[d] Department of Hand Surgery, Institute of Clinical Sciences, Sahlgrenska Academy, University of Gothenburg, Sahlgrenska University Hospital, Sweden
[e] Prometei Pain Rehabilitation Center, Vinnytsia, Ukraine
[f] Center for Complex Endoprosthetics, Osseointegration, and Bionics, Kyiv, Ukraine

A R T I C L E I N F O

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A B S T R A C T

Background and objective: Phantom limb experiences, including phantom limb sensations (PLS) and phantom limb pain (PLP), are common after limb amputation or deafferentation, with PLP significantly impacting quality of life. However, the mechanisms underlying PLP remain unclear, complicating treatment development. Investigating phantom phenomena has been proposed to gain insights into the mechanisms behind the insurgence of PLS and PLP, potentially informing new therapeutic approaches. However, small, heterogeneous samples and a lack of objective pain metrics often limit research on individuals with limb loss.

Here, we investigate whether phantom experiences, similar to those reported after amputation, also occur in individuals with intact limbs following a brachial plexus nerve block, excluding the brain from afferent and efferent signals.

Methods: To investigate the phenomenon, we conducted a multifaceted phenomenological study involving 14 individuals undergoing elective hand or arm surgery under brachial plexus nerve block. Participants were asked to report on the presence of phantom experiences and describe them in terms of vividness, quality, position, telescoping, movements, and pain. Assessments occurred at four-time points: before surgery, during surgery, after surgery, and at home. These findings were then compared to observations in the amputation population.

Results: 93 % of the participants reported PLS 20–40 min following brachial plexus anesthesia. The most frequently reported qualities of PLS were tingling, heaviness, and warmth. Commonly reported experiences after limb loss, such as distorted limb position, telescoping, and execution of phantom limb movements, were also reported by the participants after the deafferentation. Notably, participants experiencing distorted limb positions did not find them painful or uncomfortable. PLP was reported by only one participant.

Conclusions: This study demonstrates that individuals with temporary sensorimotor deafferentation via brachial plexus nerve block experience many phantom phenomena similar to those reported by individuals with limb loss. This suggests that brachial plexus nerve block is a promising model for studying PLP and a potential test bed for its treatment.

1. Background

Individuals who have lost an arm or leg often perceive the missing limb as if it is still present, an occurrence known as the “phantom limb phenomena” (Melzack, 1992). This phenomenon is generally divided into phantom limb sensations (PLS) and phantom limb pain (PLP). PLS includes non-painful somatosensory sensations related to the missing limb, such as touch-like (e.g., tingling), proprioceptive-like (e.g., specific limb positions or movements), or temperature-like sensations. The perception of the phantom limb could be distorted in terms of shapes,

Abbreviations: PLS, Phantom Limb Sensations; PLP, Phantom Limb Pain.

* Corresponding author at: Center for Advanced Reconstruction of Extremities, Sahlgrenska University Hospital, Mölndal, Sweden.
E-mail address: emily-pettersen@outlook.com (E. Pettersen).

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size, or position (e.g., telescoping) (Ramachandran and Hirstein, 1998). Conversely, PLP encompasses uncomfortable or painful sensations referred to the missing limb (Pirowska et al., 2014; Schug et al., 2019). These painful phantom sensations are commonly described as “throbbing”, “piercing”, or “burning” (Ramachandran and Hirstein, 1998; Grüsser et al., 2001). Up to 98 % of people with amputation experience PLS (Giummarra et al., 2007), and 50–80 % report PLP (Diers et al., 2022; Jensen et al., 1985; Richardson et al., 2006; Sherman et al., 1984; Desmond and MacLachlan, 2010; Kooijman et al., 2000). Notably, PLS and PLP have been reported by other individuals with deafferentation, such as those with brachial plexus injuries or spinal cord injuries (Melzack, 1992; Shankar et al., 2015). Additionally, phantom phenomena have also been observed after surgical removal of body parts other than limbs, including the breast (Ramesh and Bhatnagar, 2009), nose (Facial and Phenomenon, 1955), and even internal organs (Dorpat, 1971). Overall, PLS and PLP are prevalent across various patient groups with nerve lesions and, unfortunately, PLP presents significant challenges for those affected (Jensen et al., 1985; Nortvedt and Engelsrud, 2014; Flor, 2002; Trevelyan et al., 2016; Whyte and Niven, 2001).

PLP severely diminishes the quality of life for individuals with amputation (Van der Schans et al., 2003), has high rates of chronicity, and remains difficult to treat (Flor, 2002; Subedi and Grossberg, 2011). Although it is not completely understood why PLP occurs (Collins et al., 2018; Di Pino et al., 2021; Ortiz-Catalan, 2018), factors that may influence the occurrence and extent of PLP include ectopic discharges from neuromas, increased excitability of injured nerves and dorsal root ganglia, and spinal or supraspinal neuroplastic changes (Flor, 2002; Harwood et al., 1992; Vaso et al., 2014; Petersen et al., 2019; Flor et al., 2006). The uncertainty of the mechanisms behind PLP has caused challenges when developing efficient treatments. This has led to numerous treatment proposals, yet no therapy has demonstrated a consistent effect (Urits et al., 2019). Furthermore, existing studies on treatment options for PLP have been criticized for potential biases. These include poor study design, lack of control treatments, unclear definitions of PLP outcomes, heterogeneous study populations, and insufficient sample sizes to achieve statistical significance. Consideration of all possible factors contributing to PLP is paramount for diagnosis and prescription of appropriate treatment (Di Pino et al., 2021; Ortiz-Catalan, 2018; Flor and Andoh, 2017).

By understanding the mechanism behind PLS and PLP, indications for more efficient treatments of the condition could be defined. Studying the perception of the phantom limb may provide key insights into the roles of the peripheral and central nervous systems in PLS and PLP after an injury (Ramachandran and Hirstein, 1998). However, studying the phantom phenomenon within the amputation population is challenging due to its limited prevalence in a single geographical location. For example, the incidence of major limb amputation is relatively low in Sweden, with approximately 1,700 cases annually (Stockholm: Socialstyrelsen. Operationer i sluten vård och specialiserad öppenvård [Internet]., 2024). A solution to this challenge could be to study individuals who receive brachial plexus nerve blocks as part of an elective surgery. Brachial plexus nerve blocks temporarily interrupt nerve signaling to and from the arm, offering a model that mirrors the nerve disconnection occurring in individuals after a lesion (e.g., amputation). Over the past three decades, brachial plexus nerve blocks have become widely used as a form of perioperative anesthesia for upper extremity surgeries (Jones et al., 2020). With approximately 27,000 hand and arm surgeries performed annually in Sweden (Stockholm: Socialstyrelsen. Operationer i sluten vård och specialiserad öppenvård [Internet]., 2024), this patient group is significantly larger than the amputation population. Investigating the phantom phenomenon within this broader, more homogeneous population could enhance our understanding of PLP etiology, potentially allowing these findings to be applied to individuals with amputation or limb deafferentation.

Few clinical studies have previously investigated the phantom limb experience following brachial plexus block. Bromage *et al.*, Gentili *et al.*, Silva *et al.,* and Paqueron *et al.* focused specifically on the perception of phantom limb position or body image (Bromage and Melzack, 1974; Gentili et al., 2002; Silva et al., 2010; Paqueron et al., 2003), without investigating further aspects of PLS. Russell *et al.* presented a single case study on PLS (Russell and Tsao, 2018), while Melzack *et al.* conducted a more comprehensive exploration of PLS after brachial plexus nerve block, however, the detailed methodology was not reported, and an exhaustive characterization of PLS was not conducted for all participants (Melzack and Bromage, 1973). Savarit *et al.* recently studied PLS following nerve block, focusing on PLS frequency, hand-to-face remapping and altered perceptions where PLS descriptors, telescoping, altered phantom position and movements were grouped together during the analyses (Savarit et al., 2025). Furthermore, investigations after peripheral nerve blocks have also been done in amputation population, with focus on PLP (Birbaumer et al., 1997).

This prospective phenomenological study investigated the characteristics of phantom limb phenomena in individuals who underwent a brachial plexus nerve block for elective arm or hand surgery. Fourteen participants completed a study-specific characterization at four different time points, spanning from the preoperative stage to 6 h post-block. In this characterization, participants provided detailed descriptions of their phantom experiences, addressing aspects such as vividness, quality, position, shape, telescoping, movements, and phantom pain. Additionally, close monitoring over time allowed for observing other factors, including the onset time and duration of the phantom limb experience. These parameters were studied since they are frequently reported after limb loss. This allowed us to compare the aspects of the phantom experience collected in this study to previously reported experiences of the amputation population. In conclusion, this study highlights the relevance of studying PLS and PLP in people undergoing brachial plexus nerve blocks as a valuable model for elucidating phantom phenomena. It could potentially accelerate research on the etiology and treatment of phantom limb phenomena after a nervous lesion.

2. Method

2.1. Participants’ demographics

This study received approval from the Swedish Ethics Review Authority (Etikprövningsmyndigheten) under reference number 2020–07035. Data was collected prospectively between August 2022 and February 2023. Written informed consent was obtained from all enrolled participants prior to any study-specific data collection.

The participants were 14 able-bodied individuals who underwent elective surgery on the upper limb. The surgical procedure included an anesthetic nerve block in the brachial plexus region (Table 1). The study population was composed of 9 males, and 5 females aged from 28 to 74 years (56.9 ± 10.9). In twelve participants the location of the surgery was in the wrist and hand regions (ICD-10 ND) and two surgeries targeted peripheral nerves (ICD-10 ACC).

2.2. Data collection

All subjects were placed on a surgical table in a supine position and the brachial plexus was injected with anesthesia with the guidance of ultrasound via an axillary (11 individuals) or supraclavicular (3 individuals) approach. All participants were administered 7–38 ml of 1–1.5 % Carbocain® (active substance: mepivacaine), and one individual was given 10 ml of 0.5 % Narop® (ropivacaine). Additionally, 11 individuals received 9–28 ml of 0.5–1.5 % Chirocaine® (levobupivacaine), and 7 subjects received 0.4 ml of 15 % Catapresan® (clonidine). Regional anesthesia of Ropivacain 5 mg/ml and 7.5 mg/ml were administered to all participants. Furthermore, 4 individuals also received Mepivacain 10 mg/ml and 1 individual Ropivacain 2 mg/ml.

Data was collected by a study-specific questionnaire including questions on PLS, PLP, phantom limb position, and phantom limb

Table 1
Participants' demographics.

Variable	Participants (n_{tot} = 14)
Age, years	
Mean (SD)	56.9 (10.9)
Median	56.5
Sex, n (%)	
Male	9 (64.3)
Female	5 (37.5)
Side of nerve block, n (%)	
Right	6 (42.9)
Left	8 (57.1)
Nerve block procedure, n (%)	
Axillary	11 (78.6)
Supraclavicular	3 (21.4)
Sedation, n (%)	
Yes	11 (78.6)
No	3 (21.4)
Surgery type, n (%)	
Wrists and hands (ICD-10 ND)	12 (85.7)
Peripheral nerves (ICD-10 ACC)	2 (14.3)

movements (Table S1). The PLS section of the questionnaire asked participants about their perception of the anesthetized limb and whether they experienced tactile or proprioceptive sensations in the limb. The vividness of the phantom limb perception was measured by the Numerical Rating Scale (NRS, 0–10; 0 – No perception, 10 – Healthy limb perception). For PLP, participants were asked if they experienced any pain in the phantom limb since the last follow-up. If so, they were further questioned about the intensity of the pain (NRS, 0–10; 0 – No pain, 10 – Worst possible), duration, and location within the phantom limb. The phantom limb position questions explored eventual differences in position between the phantom and the actual hand and arm. The eventual presence of telescoping of the fingers and hand was also evaluated. If a mismatch between the perceived length of the phantom and the actual arm was detected, the participants were asked to report the position of the phantom hand and arm and an estimate of its shortening or lengthening. In addition, participants were asked if they could move the phantom limb. If movements were possible, they were asked to describe which joints they could move and whether they had full range of motion and speed. Lastly, the subjects were asked to report on the qualities of the phantom sensations experienced.

Each enrolled participant completed the questionnaire at four different time points following the nerve block: 1) t_1: between nerve block and surgery (after 26 ± 8 min); 2) t_2: during surgery (after 64 ± 13 min); 3) t_3: immediately (< 20 min) after surgery (after 153 ± 41 min); 4) t_4: at home (after 365 ± 64 min). All parts of the questionnaires were not asked at all 4 different time points, for example, the subjects were not asked to try to move their phantom during the surgery (Table S2). Six participants provided additional information regarding their phantom experience at t_1, where questions regarding that experience were not asked. This unprompted data was collected and is presented in the results alongside the prompted data.

2.3. Data analysis and statistics

Descriptive data analyses included calculating the mean, median, standard deviation, range, and percentages for categorical variables. All data were exported and processed using JASP (JASP Team, 2024, Version 0.19.0 [Computer software]). ANOVA was conducted for comparisons involving multiple groups. Boxplots display a central mark representing the median, with the bottom and top edges of the box indicating the 25th and 75th percentiles, respectively. The whiskers extend to the most extreme data points excluding the outliners. Statistical differences were deemed significant at $p < 0.05$.

3. Results

3.1. Phantom limb sensations and pain

Thirteen of the fourteen subjects (93 %) reported experiencing phantom limb sensations in the anesthetized arm at least once after the nerve block. Only one participant did not report any phantom limb phenomena. For those reporting PLS, the phantom appeared as soon as the anesthesia had reached full effect, approximately 20–40 min after the injection. The average vividness of phantom sensations, measured on an NRS scale of 0–10, was 3.29 ± 2.82. Considering the different time points, the lowest vividness was at t_3 (2.08 ± 2.53) and peaked at t_4 (4.00 ± 3.51) (Fig. 1). ANOVA analysis showed no statistically significant differences ($p > 0.05$) in NRS scores across the time points (t_1-t_4). Pearson correlation coefficients (R) between the vividness and time revealed two distinct patterns among individuals (n = 13). In three individuals, we observed a significant decrease in vividness over time (R = −0.8215, p = 0.0010) while in five we measured a significant increase (R = 0.5120, p = 0.0210) (Fig. S1).

The most frequently reported phantom sensation was "Tingling" (62 %), followed by "Heavy" (54 %), "Warm" (54 %), "Cold" (38 %), "Swollen" (15 %), "Numb" (15 %), "Electrical" (8 %), and "Burning" (8 %) (n = 13) (Fig. 2A). Seven participants reported multiple sensation qualities at each time point (Fig. 2B), and six participants had at least one quality that persisted over time (Fig. 2C). Additionally, some were able to pinpoint specific sensations in distinct areas of the phantom limb. For example, one individual described cold sensations in the phantom fingers with an electrical feeling between the shoulder and elbow, while another noted a warm sensation in the phantom hand with tingling in the fingers, as if deeply asleep, and heaviness in the elbow and distal areas (Fig. 2D). Two individuals (15 %) experienced a temperature mismatch where one perceived the phantom hand as cold while the intact, anesthetized hand was warmer, and the other experienced the reverse, with the phantom feeling warm and the intact hand cold (Fig. 2F). Three participants also reported a quality change over time, e.g., initially experiencing the phantom as tingling at t_2, which then shifted to swollen at t_3 and heavy at t_4 (Fig. 2E).

One subject (7 %) out of fourteen experienced PLP in the thumb, lasting approximately 10 min, with an NRS score of 4 out of 10. The pain was described as a stabbing feeling.

3.2. Phantom limb position

3.2.1. Distorted limb perception

The incidence of distorted limb position, specifically for the phantom hand and arm, varied over time after the nerve block (Fig. 3A). Thirteen participants (93 %) experienced a mismatch between the phantom hand and its actual position in space (i.e., distorted limb perception). In comparison, the incidence of experienced mismatch between the phantom arm and intact arm was slightly lower with ten participants (71 %). Meanwhile, four participants (29 %) did not perceive their phantom hand and arm position during at least one-time point. During surgery (t_2) the individuals did not have any visual feedback on the position of their arm. Notably, all participants had visual feedback after the surgery (t_3) and at home (t_4) and still experienced a mismatch between their phantom and actual arm/hand. None reported the phantom hand or arm to fuse back with the intact arm/hand position with visual feedback at t_3 and t_4. Among those who experienced a hand mismatch, 62 % perceived the phantom hand in a different position than during the nerve block, in contrast, 23 % felt it remained in the same position. Furthermore, 15 % reported a shift over time where they initially felt the

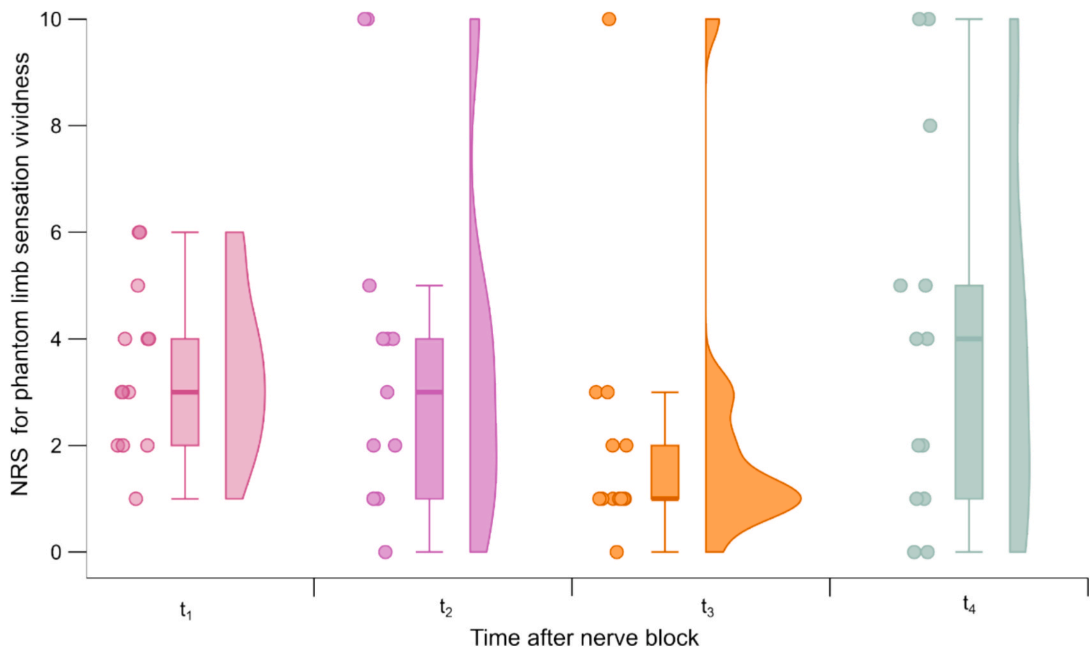

Fig. 1. Raincloud plot of the phantom limb sensation (n = 13). Numerical Rating Score (NRS, 0–10; 0 – No perception, 10 – Healthy limb perception) at t_1 (before surgery), t_2 (during surgery), t_3 (after surgery), and t_4 (at home).

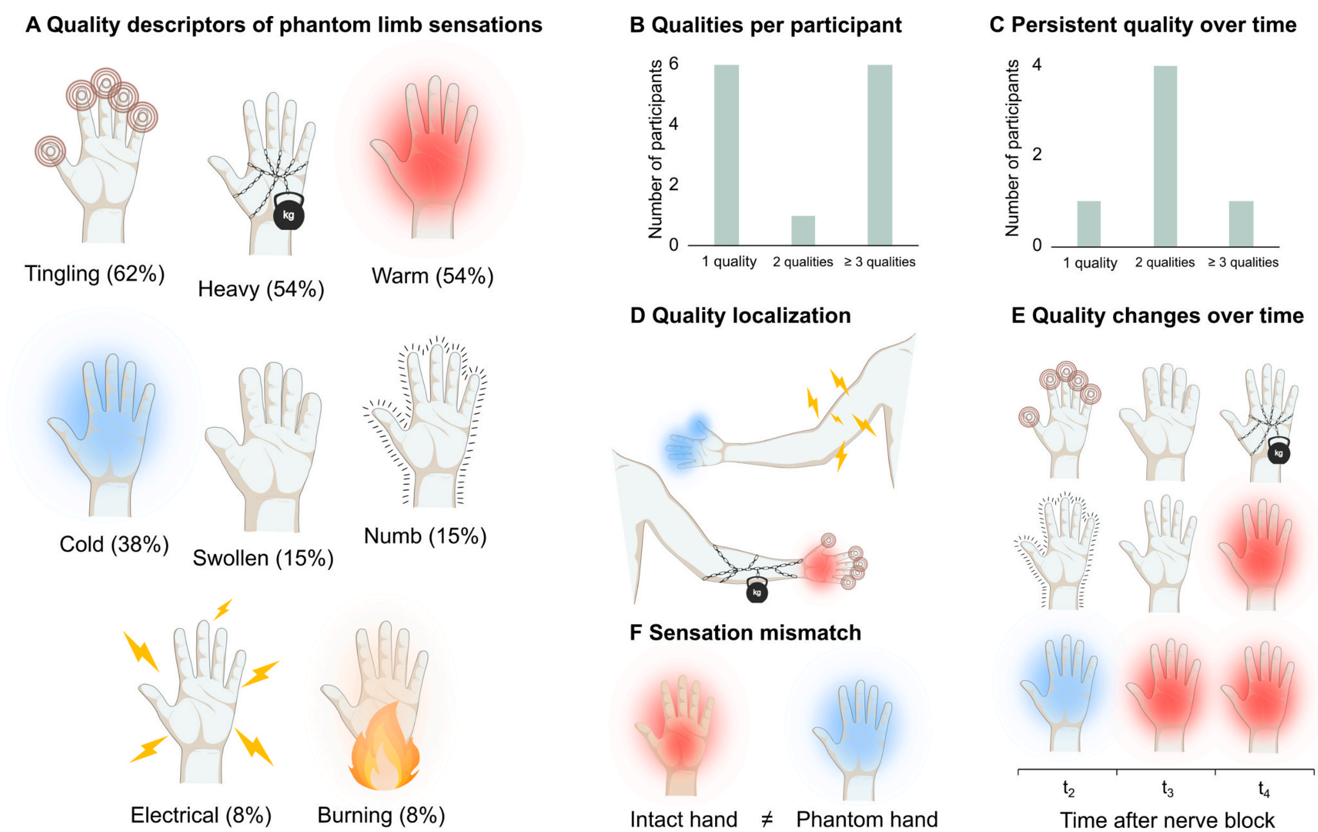

Fig. 2. Graphical representation of the quality and quantity of phantom limb sensations. (A) Phantom sensation qualities reported by participants; (B) The number of different sensation qualities perceived per participant; (C) The number of sensation qualities persisting over time; (D) Localization of various phantom limb sensation qualities; (E) Changes in phantom limb sensation qualities over time (during surgery (t_2), after surgery (t_3), and at home (t_4)); (F) Sensation mismatch between the intact hand and the phantom hand.

phantom hand in the same position as during the block, then perceived a change, and finally experienced it return to the original position. Interestingly, this change emerged during the anesthesia, when all sensory signals from the intact arm were completely blocked.

Regarding the phantom arm, nine participants (64 %) reported perceiving the phantom elbow as flexed at a 90-degree angle, even when

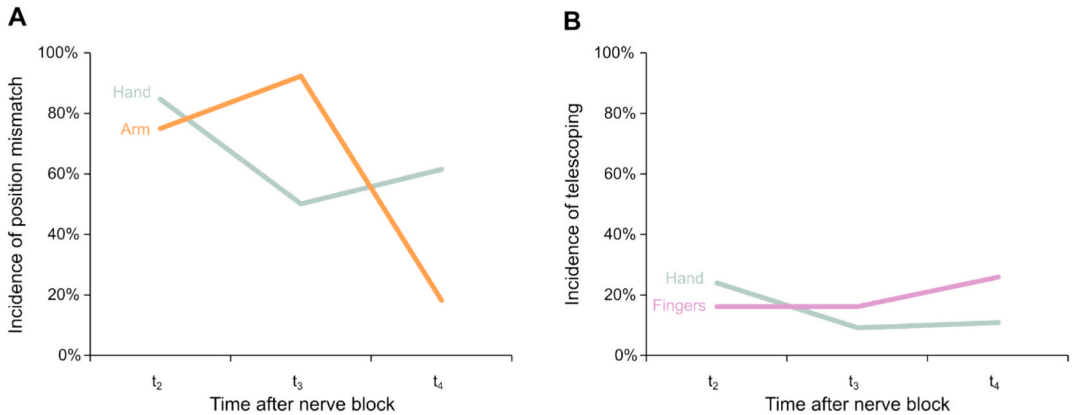

Fig. 3. Incidence of distorted limb perception between the phantom and the intact hand and arm (A), and incidence of telescoping of the phantom hand and fingers (B). t2 – During surgery (64 ± 13 min); t3 – After surgery (153 ± 41 min); t4 – At home (t_4, 365 ± 64 min).

the actual arm was fully extended on the surgical table. Four participants (29 %) also described the phantom arm as positioned above the head, on the chest, or extended beside the body. Among those who experienced a positional mismatch of the arm, 90 % perceived the phantom arm to be in a different position than it was at the time of the nerve block, while 10 % initially perceived it as unchanged during surgery (t_2) but noticed a shift to a different position over time (t_3, t_4). Notably, no subject reported the phantom arm or hand as being in an uncomfortable or painful position.

3.2.2. *Limb telescoping*

Over time (t_2-t_4), the incidence of hand and finger telescoping ranged from 8–23 % and 15–25 %, respectively, both of which were lower than the incidence of limb position mismatch (Fig. 3B). Telescoping of two or more fingers was reported at least once by four participants (29 %) (Fig. 4A), with each describing some or all their fingers as appearing shorter by 1–4 cm (Fig. 4A and B). Two individuals experienced telescoping multiple times where one initially perceived the fingers as shortened (t_2), then later as floating in space, detached from the hand (t_4) (Fig. 4C). Another participant reported progressive shortening, with fingers appearing 1–2 cm shorter at t_2, 3–4 cm shorter at t_3, and, by t_4, only the thumb, ring finger, and pinky appeared shortened by approximately half their length. Additionally, five participants (36 %) perceived telescoping of the phantom hand, i.e., closer or further away from the elbow (Fig. 4D–F). Two of these participants felt the hand as positioned closer to the elbow, by about 5–15 cm (Fig. 4D). In contrast,

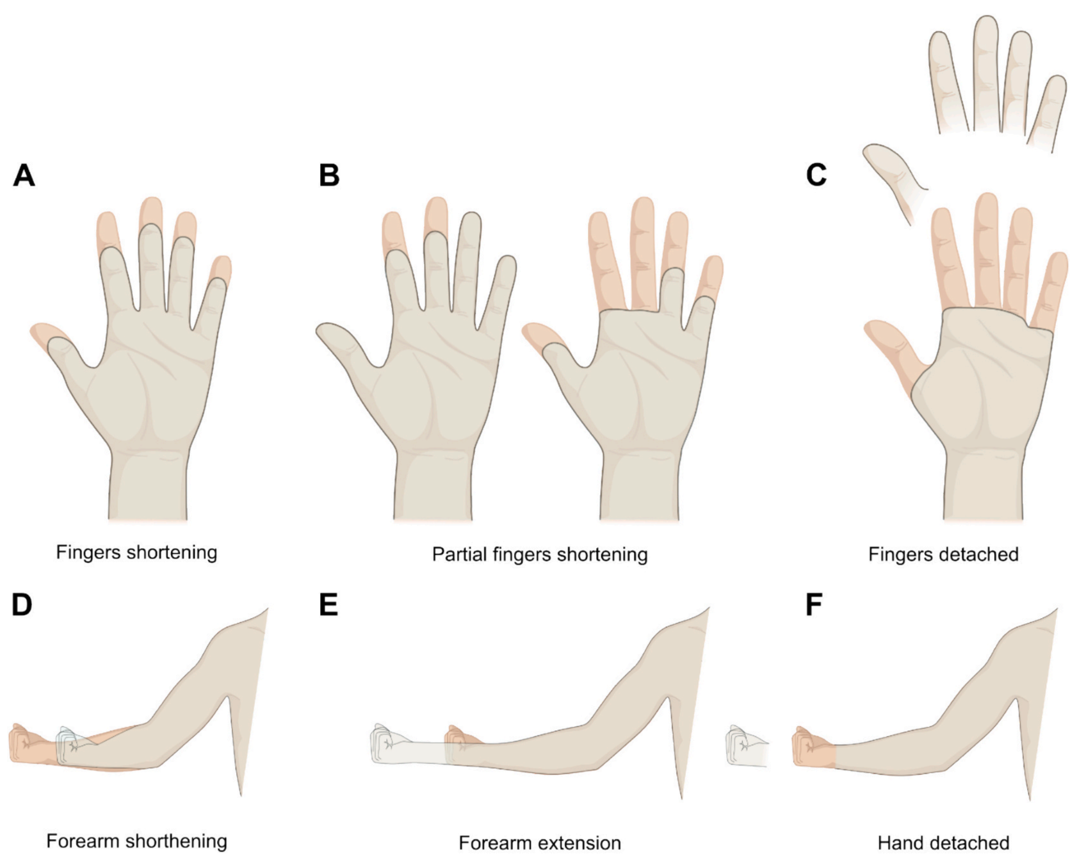

Fig. 4. Body images reported by the participants during a distorted limb perception: telescoping of hand and fingers (A–C) and the forearm (D–F). The grey line represents the body image of the phantom, and the skin color the intact hand and arm.

three participants experienced the hand as further away from the wrist (Fig. 4E), where one perceived it as about 30 cm away, another could not specify the distance, and the third felt the hand floating 5–10 cm away, detached from the wrist (Fig. 4F). Notably, none of the individuals reported the telescoping effect as painful.

3.2.3. Phantom limb movements

When participants were asked to attempt movements of their phantom hand, four main scenarios emerged (Fig. 5). Some participants reported perceiving their phantom limb but lacked any sense of movement or agency (no mobility perception). Others experienced their phantom limb stuck or frozen in a fixed position when trying to move it (frozen limb). Additionally, some participants reported partial movement (partial limb mobility), while one was able to perceive complete movement of the phantom limb (full limb mobility).

At t_3, 79 % of the participants reported the ability to execute movements of the phantom hand, while only 57 % reported similar voluntary movement perceptions at t_4. No mobility perception was slightly lower at t_3 than at t_4 (21 % vs 29 %). Frozen limbs and partial limb mobility were more common at t_3 than at t_4 (43 % vs 29 %, and 36 % vs 21 %, respectively), however, only full mobility of the phantom hand was observed at t_4 (Fig. 5). Participants who could execute phantom movements reported that the phantom hand moved more slowly than their intact hand. Additionally, all participants except one indicated a limited range of motion in the joints they could move, and none reported any involuntary movements.

3.2.4. Phantom experiences in individuals following brachial plexus nerve block and after limb loss

To analyze phantom experiences after temporary deafferentation caused by anesthesia and permanent sensorimotor disconnection caused by an injury, we compared our data and those collected in individuals with amputation. The incidence of PLS in our study (93 %) aligns with previously reported rates after nerve block (mean 82 % ± 18.8 %) (Bromage and Melzack, 1974; Melzack and Bromage, 1973; Savarit et al., 2025), postoperative amputation (0–6 weeks after amputation) (85 % ± 1.5 %) (Shukla et al., 1982; Jensen et al., 1983), and late-stage amputation (> 6 months after amputation) (84 % ± 19.2 %) (Richardson et al., 2006; Jensen et al., 1983; Sin et al., 2013) (Fig. 6A).

Additionally, the incidence of distorted phantom perception in the form of telescoping in our study (38 %) is comparable to rates reported for both early amputation (44 % ± 27.6 %) (Shukla et al., 1982; Jensen et al., 1983) and late amputation (46.13 ± 20.7 %) (Diers et al., 2022; Richardson et al., 2006; Jensen et al., 1983; Sin et al., 2013) (Fig. 6B). However, the large standard deviations observed in the amputation groups indicate considerable variation in the reported incidence of telescoping across different studies.

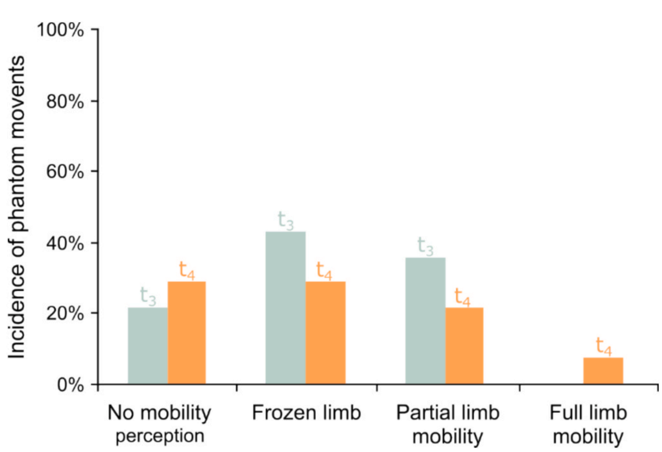

Fig. 5. Incidence of phantom movements at time points t_3 (after surgery) and t_4 (at home) (n = 14).

Moreover, the perception of spontaneous involuntary phantom movements and voluntary execution of phantom movements varied between the groups (Fig. 6C). No participant in our study (0 %) reported experience of involuntary movements of the phantom, the reporting of this experience was limited in literature to a few studies (nerve block (69 %) (Melzack and Bromage, 1973), early amputation (74 %) (Shukla et al., 1982) and late amputation (65.4 %) (Richardson et al., 2006). The lack of reported involuntary movements in our study may be attributed to the questionnaire's focus on questions regarding the voluntary execution of phantom movements. Furthermore, the incidence of the voluntary execution of phantom movements in our study (57 %) is comparable to the reported incidence after nerve block (61 %) (Melzack and Bromage, 1973), but higher compared to early (19 %) (Jensen et al., 1983) and late amputation (27 % ± 27.3 %) (Richardson et al., 2006; Jensen et al., 1983; Sin et al., 2013).

The incidence of PLP in our study (7 %) is considerably lower compared to rates reported in early amputation (78 % ± 12.7 %) (Richardson et al., 2006; Shukla et al., 1982; Jensen et al., 1983) and late amputation (61.7 % ± 22 %) (Diers et al., 2022; Richardson et al., 2006; Sherman et al., 1984; Jensen et al., 1983; Sin et al., 2013) (Fig. 6D). However, our study time was only a few hours, whereas early amputations can cover days up to weeks. Furthermore, the most reported quality descriptors of pain in early amputation studies have been reported to be "Burning", "Electrical", "Knifelike", and "Sticking" (Richardson et al., 2006; Shukla et al., 1982). For late amputation, "Sharp shock or shooting", "Squeezing", "Knifelike", and "Burning" are the most reported qualities (Richardson et al., 2006; Sherman et al., 1984). Notably, the pain descriptor "stabbing," observed in our study, has also been reported in both early and late amputation groups (Richardson et al., 2006; Shukla et al., 1982).

4. Discussion

The underlying causes and mechanisms of phantom limb phenomena following amputation are still unclear. However, it is well-established that many individuals experience their phantom limb as painful, significantly diminishing their quality of life (Diers et al., 2022). Consequently, investigating the mechanisms underlying phantom limb phenomena can provide information for the development of effective treatment strategies for people affected by phantom limb pain, and potentially other neurological diseases and injuries.

Brachial plexus nerve block serves as a routinely used anesthesia during upper limb surgeries, temporarily disrupting both efferent and afferent nerve signaling, resembling the permanent deafferentation following limb amputation and other neurological diseases. In this prospective phenomenological study, individuals with intact limbs reported the emergence of phantom phenomena within 20–40 min following the onset of the anesthetic effect. These findings expand the evidence that phantom phenomena can be induced in individuals through brachial plexus nerve block and that this approach can be exploited to better understand the underlying mechanisms. This is particularly when the participants who undergo limb surgeries are instructed to describe the experiences of the phantom limb, such as sensations, position, movements, and pain (Gentili et al., 2002; Paqueron et al., 2003; Russell and Tsao, 2018; Melzack and Bromage, 1973; Savarit et al., 2025). As shown in Fig. 6A, the incidence of phantom limb presence after temporary deafferentation observed in this study aligns closely with the range of PLS reported by individuals with limb amputation. Additionally, phantom limb distortions, such as telescoping, are also comparable between the temporary deafferentation and amputation groups (Fig. 6B) (Diers et al., 2022; Richardson et al., 2006; Savarit et al., 2025; Shukla et al., 1982; Jensen et al., 1983; Sin et al., 2013). Notably, the amount of distortion caused by the telescoping effect was more pronounced than the body length underestimation typically observed in healthy subjects (Longo and Haggard, 2010).

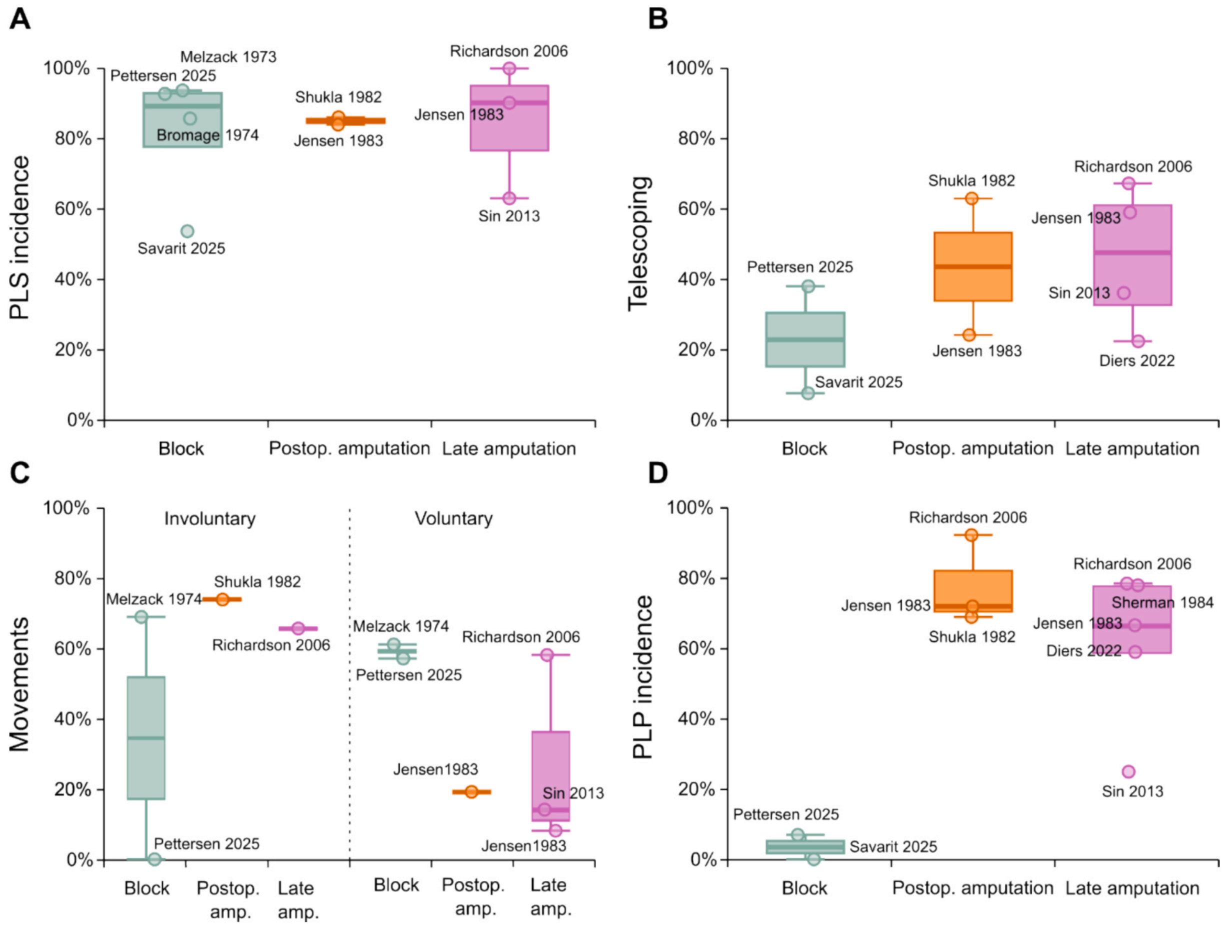

Fig. 6. Boxplots reporting incidence of (A) Phantom limb sensations (PLS); (B) Telescoping; (C) Involuntary and voluntary phantom movements; (D) Phantom limb pain (PLP)) in three groups: 1) Individuals receiving a brachial plexus nerve block (green); 2) Postoperative amputation, 0 days to 6 weeks post-amputation (orange); 3) Late-stage amputation more than 6 months after amputation (purple). (Diers et al., 2022; Richardson et al., 2006; Sherman et al., 1984; Bromage and Melzack, 1974; Melzack and Bromage, 1973; Savarit et al., 2025; Shukla et al., 1982; Jensen et al., 1983; Sin et al., 2013).

Looking at the phantom experience after the temporary block, we found some nuances compared to experiences following limb amputation. Previous studies have documented reports from some individuals with amputations or nerve blocks of the phantom limb "fusing" with a prosthesis or the intact limb when visual feedback is available (Ramachandran and Hirstein, 1998; Bromage and Melzack, 1974). In contrast, in our study, none of the subjects reported experiencing a fusion of the phantom limb with the intact limb at the final follow-ups when visual feedback was accessible. This discrepancy with the amputation population may be attributable to the relatively short duration of anesthesia in our study, which could limit the extent of sensory integration necessary for such fusion phenomena to occur (Droog et al., 2017). The discrepancy with the nerve block population is that their subjects never lost visual feedback for a longer period whereas our participants did not see their arm for the duration of the surgery.

Furthermore, in previous studies, it has been mentioned that "memories" of the limb's position and shape prior to amputation frequently persist within the phantom experience (Katz and Melzack, 1990). This contrasts with the findings in our study and others (Bromage and Melzack, 1974; Gentili et al., 2002), where the majority of participants reported that the position of their phantom hand, and more commonly their phantom arm, differed from its position during the nerve block. This can be explained by the absence of the limb and thereby a lack of visual feedback for individuals with limb loss compared to the group with temporary deafferentation. Additionally, some participants described the phantom limb position as changing over time, which has also been reported by individuals with amputation (Ramachandran and Hirstein, 1998). After the nerve block or amputation, there is no proprioceptive feedback signaling from the arm to the brain, so what is causing the change in the perception of the phantom? The mechanisms driving these changes warrant further investigation. Altogether, the characteristics of PLS such as the distinct sense of position, telescoping, and phantom movements, suggest that the phantom limb resulting from brachial anesthetic block closely resembles those experienced following amputation.

However, when comparing PLP incidence, a clear difference is observed between the brachial plexus nerve block group and both early-stage and long-term amputation groups (Fig. 6D). The key distinction between these two patient groups lies in the state of the peripheral nerves. In amputations, the nerves are severed, whereas in the anesthetized group, the nerve block halts sensory signaling from the arm but leaves the nerves intact. Moreover, severed nerves lead to axonal swelling, regenerative sprouting, and neuroma formation, generating ectopic discharges and abnormal spinal input, contributing to pain (Flor et al., 2006). Consequently, the intact nerves in the anesthetized group may explain the lower PLP incidence, suggesting that preventing peripheral nerve changes could be crucial for mitigating PLP as previously highlighted (Vaso et al., 2014; Souza et al., 2014; Dumanian et al., 2019; Woo et al., 2016; Lee et al., 2025; Pettersen et al., 2024; Pettersen et al., 2024; Cheesborough et al., 2014; Valerio et al., 2019; Santosa et al., 2020). Also, our interpretation is supported by observations from other types of high-level deafferentation caused by injuries in the spinal cord, brachial plexus, or stroke, where the peripheral nerves are partially damaged or totally intact. In these conditions, patients have reported phantom sensations, phantom distortions, and phantom movements, while PLP is less commonly reported (Shankar et al., 2015; Berger and Gerstenbrand, 1981; Antoniello et al., 2010). This suggests that the integrity of peripheral nerves, although damaged, might play a role in the insurgence of PLP.

Notably, participants in this study reported misalignment between their phantom and physical hands, yet these distortions were neither painful nor uncomfortable. Indeed, altered perceptions like telescoping or "floating" sensations occurred without discomfort, suggesting that these factors do not influence PLP (Flor et al., 2006). Furthermore, persistent pain before amputation has been identified as a risk factor for PLP (Limakatso et al., 2020). In future studies, collecting preoperative pain data may be useful to further investigate whether able-bodied subjects who experience persistent hand or arm pain prior to brachial plexus block also have a higher incidence of PLP.

The sensorimotor congruence hypothesis (Harris, 1999) is commonly invoked to justify mirror therapy and the use of virtual reality in treatments of PLP, as it is believed that a visual illusion would solve the discrepancy between motor intention and visual feedback. However, it has been pointed out that somatosensory feedback is clearly more relevant for sensorimotor processing, and that the known inverse correlation between the ability to perform phantom movements and PLP, provides compelling evidence to refute this hypothesis (Ortiz-Catalan, 2018). Our findings provide further evidence to reject this hypothesis, as we did not observe that patients attempting to execute movements resulted in PLP. The only patient who perceived PLP in our study was not attempting to execute movements at the time, in fact, the participant reported lacking the perception of movement.

Phantom limb movements reported following amputation (Richardson et al., 2006; Jensen et al., 1983; Sin et al., 2013), were also observed among participants in our study. These movements were often restricted to a limited range of motion within certain joints and were perceived as slow. Some participants in our study also experienced "frozen limbs" wherein they attempted to move the phantom limb but remained immobilized. Notably, the one participant who experienced PLP did not perceive phantom movements; the phantom limb was neither movable nor frozen. Phantom motor execution has been proposed as a treatment for PLP in which the patient attempts top-down re-engagement of the affected sensorimotor circuitry (Ortiz-Catalan et al., 2016). This approach has been explained by the stochastic entanglement hypothesis for the neurogenesis of PLP, which suggests that training in phantom movements induces progressive neural adaptations, akin to those involved in refining motor skills. These intentional neural changes then separate pathological pain and sensorimotor processing through competitive plasticity, thereby reducing pain (Ortiz-Catalan, 2018). A motivation for this work was to evaluate whether brachial plexus blocks could be used as a model to create phantom hands that could then be trained to move using different tools. Given that both PLP and phantom limb movements were observed in this study population, we suggest further research following brachial plexus nerve block to elucidate potential mechanisms of PLP and treatment optimization.

The limited availability of published literature providing prospective data on the prevalence and incidence of PLS, PLP, and telescoping over the past decade (Stankevicius et al., 2021) significantly restricts the pool of comparable studies, as illustrated in Fig. 6. This scarcity reflects a broader challenge in conducting research within the amputation population and other patient groups with neurological diseases due to the inherent variability in patient characteristics, small sample sizes, and the subjective nature of pain reports. These challenges underscore the need to explore alternative controlled models to gain further insights into the etiology and treatment of PLP.

5. Conclusion

This study shows that people with temporary sensorimotor deafferentation through brachial plexus nerve block experience many of the phantom phenomena reported by people with missing limbs, and therefore, brachial plexus nerve block is a promising model to study PLP and as a potential test bed for its treatment.

Declarations

7. Consent for publication

Not applicable.

Author contributions

MOC conceived the study. EP, PS, and MOC contributed to the study design. EP performed the interviews and collected the data. EP analyzed the data and drafted and revised the manuscript. GV, CR, and MOC discussed the results and edited the manuscript. All authors approved the final version of the manuscript.

CRediT authorship contribution statement

Emily Pettersen: Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Giacomo Valle:** Writing – review & editing. **Paolo Sassu:** Writing – review & editing, Methodology. **Carina Reinholdt:** Writing – review & editing. **Max Ortiz-Catalan:** Writing – review & editing, Supervision, Methodology, Conceptualization.

6. Ethics approval and consent to participate

This study was approved by the Swedish Ethics Review Authority, Etikprövningsmyndigheten, with the reference number 2020–07035. Written informed consent was obtained from all research subjects.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.brainres.2025.149955.

Data availability

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

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